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PROSPECTIVES FOR EXPLOITING THE GEOTHERMAL RESOURCES OF IKARIA, GREECE

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ABSTRACT

Ikaria is a small Greek island in the NE Aegean sea. Low-temperature hot springs 35-50°C are spread all over the island and especially on the eastern part near the capital Agios Kirikos. At present the springs are used only for medical purposes. According to the LINDAL diagram there is a great variety of possible geothermal applications in Ikaria, but the limited extent of this report restricts us to only two, swimming pool design and district heating simulation. The swimming pool which has been selected for Ikaria is 25×13 m^2 in size, has a volume of 455 m^3 and a surface area of 325 m^2. The design water temperature is 30°C and the turnover period is 4 hours. The total heat demands of the hot saline water, using a titanium plate heat exchanger, is about 628 kW. The amount of geothermal water needed is about 8 kg/s (or 691 m^3/day). The NovaSim District Heating Simulator was used for obtaining the most important information for a hypothetical space heating system in Ikaria. The results of this simulation indicate that the amount of geothermal water needed for heating 1000 buildings in Ikaria during the maximum heat demand season is 38 l/s (or 3283 m^3/day). Regarding energy needs, the hot springs of the island are able to cover the heat demands of any low enthalpy geothermal application. But feasibility does not depend only on the availability of the energy resource but also on economic factors and market needs.

1. INTRODUCTION

The aim of this report is to demonstrate geothermal applications, other than spas, which could be run in Ikaria, Greece, using only the potential of its hot springs.

1.1 Geological characteristics of Ikaria

Ikaria is a small island in the Northeast Aegean Sea in Greece which covers an area of 270 km^2. The island of wonder-working waters and unequalled beauty has a population of about 7500 inhabitants.

Together with the islands of Fourni, which have about 1400 inhabitants, it forms the county of Ikaria which belongs to the prefecture of Samos. The southern part of the island is steep, whereas the northern part is flat and wooded with ample ground water. The southern part is separated from the northern part by a narrow mountain range, Mount Atheras, whose highest peak is 1040 m high.

Ikaria belongs to crystalic regional field. There is a discrimination at the western porphyritic zone and the eastern metamorphic zone (Figure 1). The tectonic contact is near Messarias syncline. This syncline has N-S strike. At this contact the porphyritic granite of Raches thrusts over the eastern metamorphic anticline.

Generally, the hot springs of Ikaria come through a fracture zone near sea level at the south coast of the island along a great tectonic grabben of E-W direction. The temperature of these hot springs varies from 35 to 58°C. This water comes in contact with pegmatic protuberances of the granodiorite and that causes the radioactivity of the springs. Also dykes of granodiorite appear in the gneiss system which dominates the eastern part of the island. The variation in radiation values are either due to direct or indirect contact with pegmatitic protuberances, or mixture with sea water.

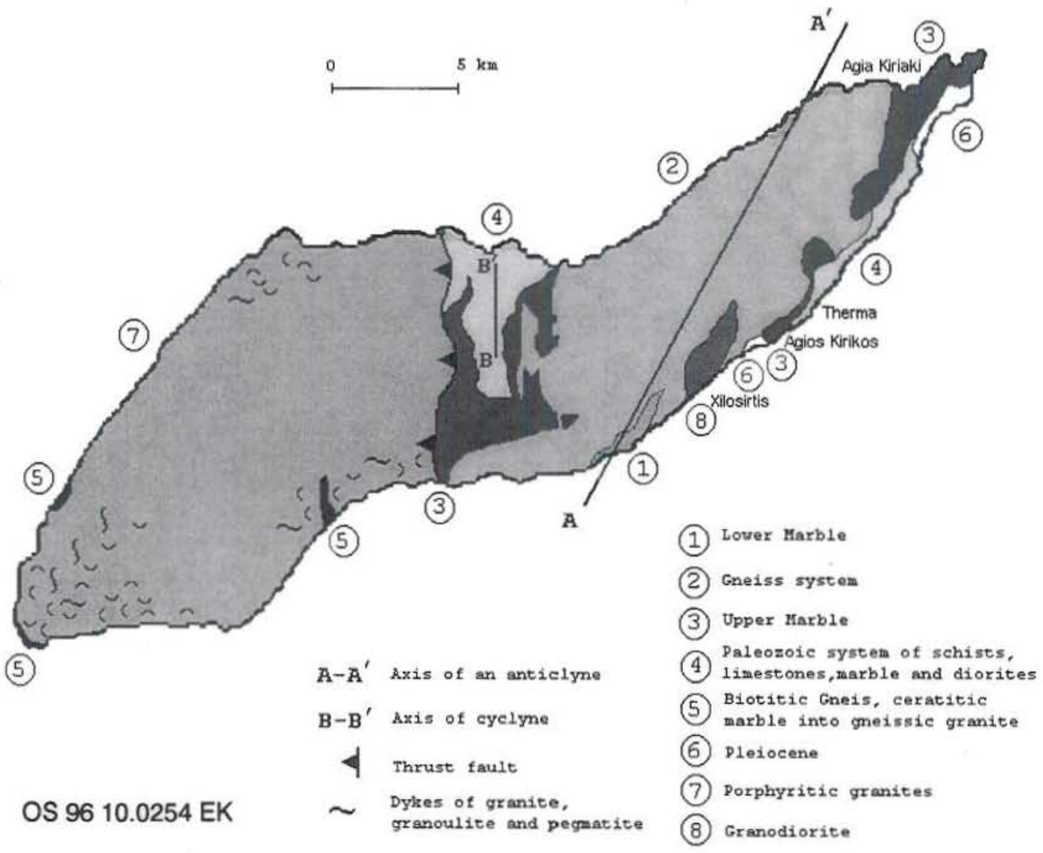

FIGURE 1: Geological map of Ikaria

1.2 Present geothermal situation

Low temperature springs 35-59°C are spread all over the island, but are especially dense in the eastern part of the island near the capital Agios Kirikos (Figure 1). Some of the springs are among the most radioactive springs in Greece and are used only for medicinal purposes. Table 1 shows the most important hot springs of the island and their physical characteristics. Table 2 shows the chemical analysis of four of the hot springs (Makri et al., 1965).

TABLE 1: Physical characteristics of the most important hot springs in Ikaria

Area	Spring	Temperature (°C)	Flow rate (m^3/day)	Radioactivity (Mache)	Present use
Agios Kirikos	Asklipios	40-47	1200	396.6	Bathing
Therma	Apollonas	47.8	1200	521.4	Bathing
	Kratsa	54	500	217.25	Bathing
	Palia Therma	40	-	32.58	Unused
	Pamfili	55	1200	82.55	Bathing
	Spileo	54	-	6.5	Bathing
Xilosirtis	Lefkada	58-59.2	10000*	Low	Unused
	Athanato Nero	21.5	600	6.5	Potable
Perdiki	Agia Kiriaki	37	-	52.14	Unused
	Agia Kiriaki	35	-	28.4	Unused
	Armirida	35	-	8.69	Unused

* Accurate flow measurement of this spring is technically difficult because the water wells up directly from the sea, but according to older studies the flow rate has been estimated at about 10000 m^3/day.

TABLE 2: Chemical analysis of four hot springs

	Lefkada	Apollonas	Spileo	Asklipios
Gases (ppm)				
CO_2	38	29	39.5	21.2
O_2	7.5	20.1	15.2	60.5
Tot. solid residue at 105°C	42243.6	29711.6	41972.4	32227.6
Cations (ppm)				
K^+	322.5	287.5	302.1	292.5
Na^+	13187.9	8606.4	11299.6	10021.8
Li^+	3.8	3.5	4.1	0.8
Ca^{++}	1378.2	989.7	1433.6	1239.2
Mg^{++}	907.8	644.9	873.3	683.2
Fe^{++}	20.5	9.1	20.1	9
Al^{+++}	0.4	0.11	0.33	0.18
Anions (ppm)				
Cl^-	23403.6	15602.4	20566.8	18439.2
Br^-	45	10.5	40.1	8.0
F^-	6.9	4.2	5.6	4.95
I^-	0.39	0.19	0.36	0.07
$SO_4^=$	3016.7	2010.2	2932.8	2086.2
$HPO_4^=$	0.95	0.49	0.62	0.47
HCO_3^-	116.1	155.7	133.4	149.5
NO_3^-	0.3	0.1	0.15	0.1

Some 20,000 tourists, mostly health spa visitors, visit the island every year. The fact that a large proportion of the island's income stems from tourism and tourist-related activities indicates the importance of the springs for the local economy. But at present the bathing facilities are somewhat primitive and insufficient attention is given to engineering details such as piping, flow and temperature control, efficiency and stability of utilization, etc.

1.3 Geothermal development in Ikaria

The geothermal development of the island can be divided into two parts, improvement of the existing bathing installations and equipment, and use of unexploited water for purposes other than bathing. The first would lengthen the tourist season on the island by attracting senior citizens while the second, which is no less important, would significantly reduce dependence on oil and coal by utilizing a great amount of the unused geothermal energy. Of course commercial and market data must be collected for the estimation of the most profitable applications. Possible geothermal applications, according to the LINDAL diagram (Figure 2) are: space heating, animal husbandry, greenhouses with combined space and hotbed heating, mushroom growing, soil warming, swimming pools, biodegradation, fermentation, fish hatcheries, fish farming (Dickson and Fanelli, 1995).

°C	
80	Space heating Greenhouses by space heating
70	Refrigeration (lower temperature limit)
60	Animal husbandry Greenhouses with combined space and hotbed heating
50	Mushroom growing Balneological baths
40	Soil warming
30	Swimming pools, biodegradation, fermentation, Warm water for year-round mining in cold climates De-icing
20	Fish hatcheries, fish farming OS 96 10.0255 EK

FIGURE 2: The LINDAL diagram

Only a few studies concerning the utilization of geothermal resources in Ikaria have been carried out. That means that there are insufficient data about the area and further geothermal investigation is needed. Geothermal resource assessment must be carried out in order to ensure that the geothermal reservoir potential is sufficient to cover the needs. Furthermore, more extensive hydrological and geochemical studies would give a complete figure of the geothermal field and possible applications.

2. HOT WATER TRANSMISSION

2.1 Transmission

One of the tasks people face in geothermal utilization is the transportation of geothermal fluid from the source to the user. Of course the water transportation is carried out by pipes, but special care must be taken in the selection of the pipe material, because the chemical species present in geothermal fluids are the primary factors that result in corrosion and scaling when these fluids are used as heat sources. The most important parameters for the selection of a suitable type of piping are:

- The chemical resistance of the pipe; the piping material has to be resistant to corrosion and scaling;
- The temperature of transferred water;
- Initial and maintenance cost;
- The pipe size; the diameter must not be too small as that can cause large drops in pressure, and it should not be too big as that increases the cost. A rule of thumb says that the pipe diameter should be chosen so that the pressure drop is of the order of 0.5-1.0 bar/km.

Dissolved oxygen in water can cause corrosion of metallic pipes, even though the concentration is low. Corrosion can damage the pipelines and increase maintenance cost. The deposition of minerals as a result of super-saturation or the accumulation of corrosive products can cause scaling in the systems which transfer geothermal water. Both of these types of scaling reduce the efficiency of the system by increasing resistance to heat transfer and fluid flow.

Tables 1 and 2 show physical and chemical characteristics for the most important hot springs in Ikaria. The water of most of the springs is thermal saline water which contains a great amount of dissolved O_2 and solid residues. For instance, in the hot spring Lefkada the water contains 7.5 ppm O_2, 23,000 ppm Cl^-, and 42,000 ppm of TDS (total dissolved solids). The combination of chloride and oxygen causes corrosion to any metallic pipe. On the other hand, the high concentration of Mg^+ increases the possibilities for scaling in typical metallic pipes.

Consequently, the use of plastic pipes is necessary. The most commonly used materials are Polyvinyl Chloride (PVC), Chlorinated Polyvinyl Chloride (CPVC), Polybutylene (PB), Polyethylene (PE), fibreglass which is commonly referred to as Reinforced Thermosetting Resin Pipe (RTRP), or Fiberglas-Reinforced Plastic (FRP). The selection of one of these pipe types is not only compulsory but also advantageous for low temperature geothermal water because plastic pipes have excellent chemical resistance, a wide range of thermal expansion and temperature limitations (Table 3), low initial cost and easy pipe laying. Figure 3 shows the material costs for bare 6 in pipes (Rafferty, 1991). Obviously the plastic pipes provide the most economical solution for transmission pipeline systems. The only disadvantages are the ingression of oxygen by diffusion and the high heat loss.

TABLE 3: Maximum service temperature for plastic pipes

Plastic pipe	**Maximum service temperature (°C)**
PVC	60
CPVC	100
PB	82
PE	65
RTRP	150

Polyethylene transmission pipelines seem to be the most suitable choice for the hot springs of Ikaria. Because of the chemical nature of polyethylene piping the most positive method for joining is thermal fusion. Two methods are available, socket fusion and butt fusion. The fusion joining procedure requires the use of a special tool. Basically, the two lines to be joined are aligned in the tool, heated and brought together under light pressure to form the joint. Because of the big thermal expansion of polyethylene, the piping must be anchored only at sufficient intervals to limit lateral movement to the extent of available space.

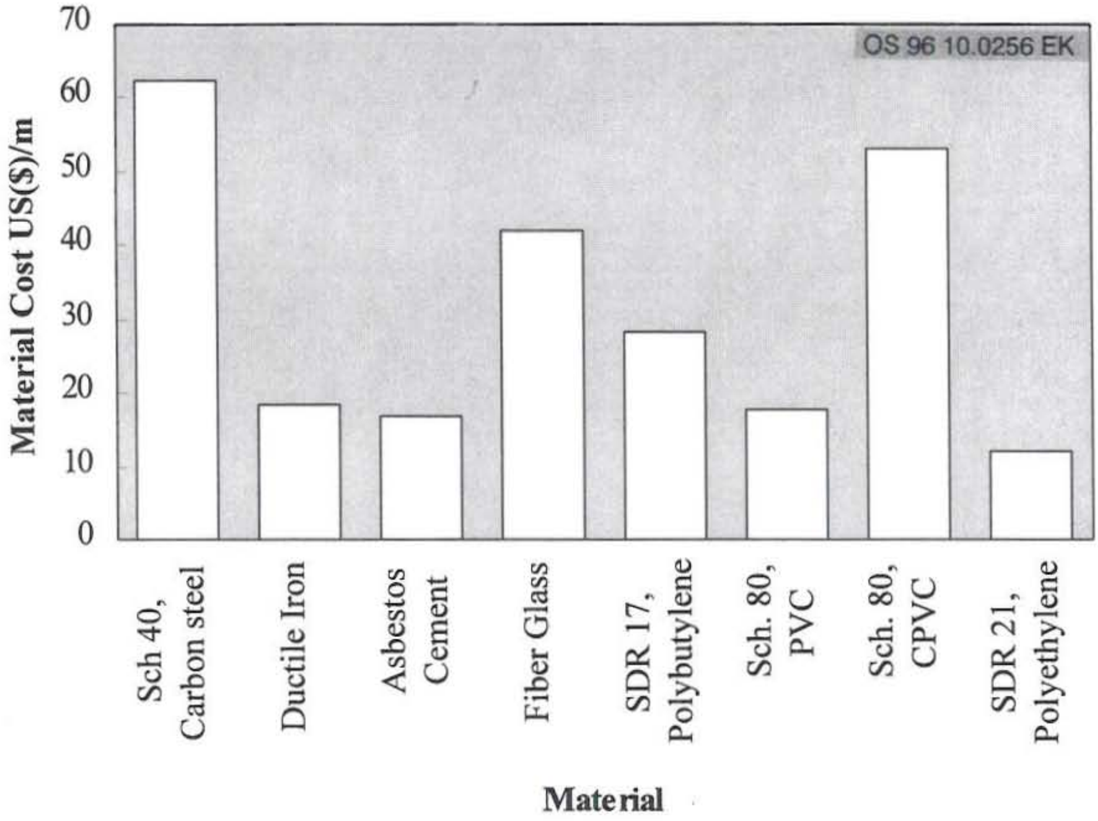

FIGURE 3: Material cost for bare 6 pipe

2.2 Insulation

Most long transmission lines carrying warm geothermal fluid require some form of insulation. Piping insulation is used primarily to conserve heat and provide protection for the piping. The decision to insulate should be based on economics, the necessity to preserve the temperature of a low temperature geothermal water, or both.

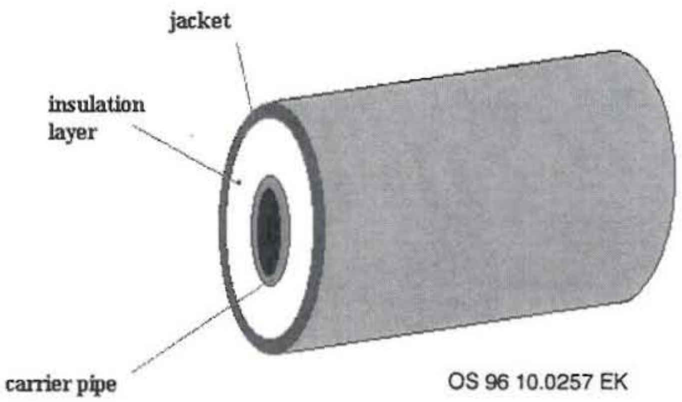

FIGURE 4: Pre-insulated transmission pipeline

The insulation can be provided by selected backfill methods, field applied insulation or more commonly, a pre-insulated piping system. As shown in Figure 4, the pre-insulated system consists of a carrier pipe, through which the fluid is transported, an insulation layer, and a jacket material.

There is a wide variety of combinations available in terms of jacket and carrier pipe material. The only common factor among most products is the use of polyurethane for the insulation layer. Most systems employ a 25-50 mm insulation layer and fittings are left uninsulated. Thermal conductivity of the polyurethane varies but a mean value of 0.026 W/m °C at 65°C is generally specified. For FRP, PB, PE, and PVC a variety of jacket materials are available. These include polyethylene, PVC, and fibreglass. But the most common material is PVC. Most jacket systems employ a rubber end seal to protect the insulation from exposure to moisture.

In Iceland, geothermal fluids are being transported by pre-insulated pipes for many kilometres without considerable heat losses. The following example demonstrates the heat losses for three different pipe types: 1) a polyethylene bare pipe, 2) a polyethylene pre-insulated pipe with PVC jacket and a polyurethane insulation layer and 3) a polyethylene pre-insulated buried pipe at 855 mm depth, with PVC jacket, polyurethane insulation layer and a 150 mm sand layer cover. The size, the thermal conductivities and the conditions are shown in Figure 5.

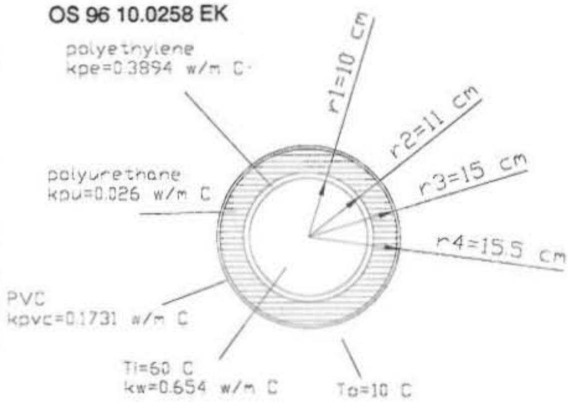

FIGURE 5: Polyethylene pre-insulated pipe with PVC jacket and polyurethane insulation layer

From experience we know that the convection heat resistance inside the pipe is so small that it can be ignored. The thermal conduction resistances of the layers of the pipe have been calculated by the formula:

$$R = \frac{\ln\frac{r_o}{r_i}}{2\pi k} \tag{1}$$

where

- r_o = Outside radius of the layer [m];
- r_i = Inside radius of the layer [m];
- k = Thermal conductivity of the layer [W/m °C].

The thermal convection resistance of atmospheric air has been calculated by the formula:

$$R_{air} = \frac{1}{h_o 2\pi r_o} \tag{2}$$

where

- h_o = Convective heat transfer coefficient for free convection in air (Holman,1989) [W/m² °C];
- r_o = Outside radius of the outside layer [m].

Considering the C_p value constant for temperature range 10-60°C, the temperature versus the length of the pipe is given by:

$$T = T_o + (T_i - T_o) e^{-\frac{UL}{mC_p}} \tag{3}$$

where

T_o	= Air temperature [°C];
T_i	= Water inlet temperature [°C];
U	= Heat loss per unit length ($1/R_{tot}$) [W/m°C];
L	= Length of the pipe [m];
Q	= Flow rate [kg/s];
C_p	= Heat capacity of water (4179) [J/kg°C].

Figure 6 presents the temperature drop for the pipe types mentioned previously, versus the pipe length. It is obvious that the most important factors which influence heat loss in a pipeline are the insulation and the flow rate.

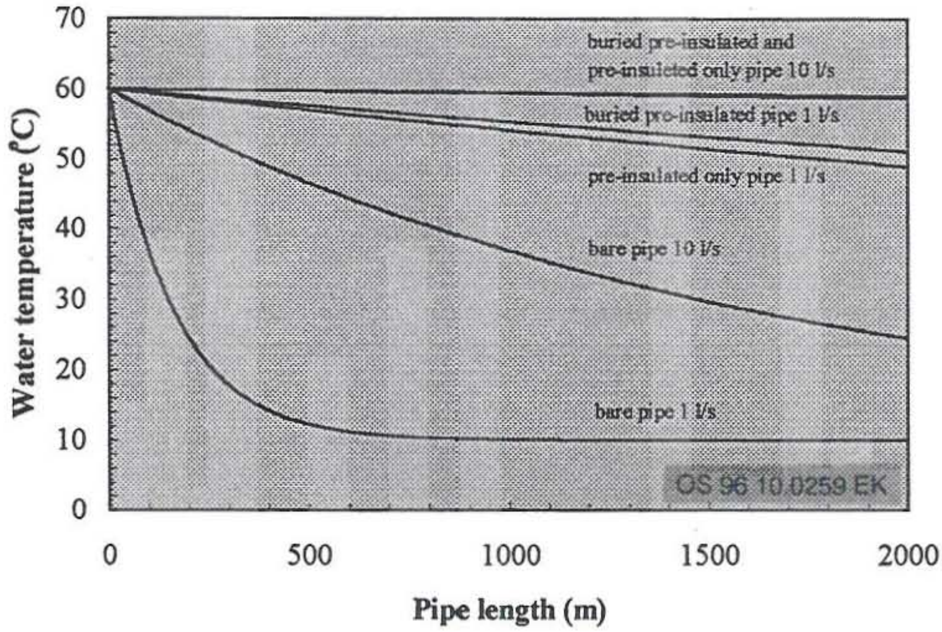

FIGURE 6: Heat losses from pipelines for outside temperature 10°C

3. SWIMMING POOL

3.1 Swimming pools in Iceland

One of the oldest and most popular uses of geothermal water in Iceland is for swimming. There are 120 public swimming pools heated by geothermal energy with a combined surface of 25,000 m^2. Most of them are outdoors and are used year round. They are both for recreational and athletic use. The largest swimming pool, Laugardalslaug, is placed in Reykjavik. It has 1500 m^2 surface area and five hot tubs with a water temperature ranging from 35 to 42°C. The total geothermal energy used in swimming pools in Iceland is estimated to be 1000 TJ per year.

3.2 Swimming pool in Ikaria

From ancient times sea swimming has been one of the most favourite leisure practices for Mediterranean people. The duration of the swimming period is restricted to summertime, because of the low ambient temperature and rough water in other seasons. I believe that the existence of a swimming pool in Ikaria not only would increase the swimming and tourist season but also would upgrade the tourist image of the island, and create a new athletic status. This chapter will deal with the main technical aspects of an outdoor swimming pool in Ikaria. It is impossible to give detailed requirements for all components, but a few general comments will be made on the more fundamental ones.

3.3 The operating principle of the swimming pool

Figure 7 shows a schematic diagram of a modern geothermal swimming pool, which uses a plate heat exchanger for transferring heat from the geothermal water to the swimming pool. The saline geothermal water flows from the hot spring at 59°C and enters the heat exchanger (HX). In the heat exchanger, the geothermal water provides the treated water with a sufficient amount of energy to recover heat losses in the swimming pool. The cooled geothermal brine could be used in one or more small hot ponds for medicinal or recreational purposes.

The circulation of the pool water is carried out by four self-priming pumps (P). A pump filter (PF) is installed before the water enters the circulating pump in order to remove the large impurities. The treated water is piped from the swimming pool through the strainers and to the pressure sand filters (SF) for filtration. After this stage, fresh cold water is added to the circulated water, which enters the pool, after having been heated in the heat exchanger. Simultaneously, an amount of pool water is discharged through drainage.

The pool water temperature is regulated automatically by a control temperature unit (CTU). A temperature sensor (S1) is situated in the pool water and checks the temperature. When the temperature decreases or increases over the setting point (30°C), the sensor informs the control temperature unit which commands the electromagnetic valve (V1) to supply the heat exchanger with more or less hot water.

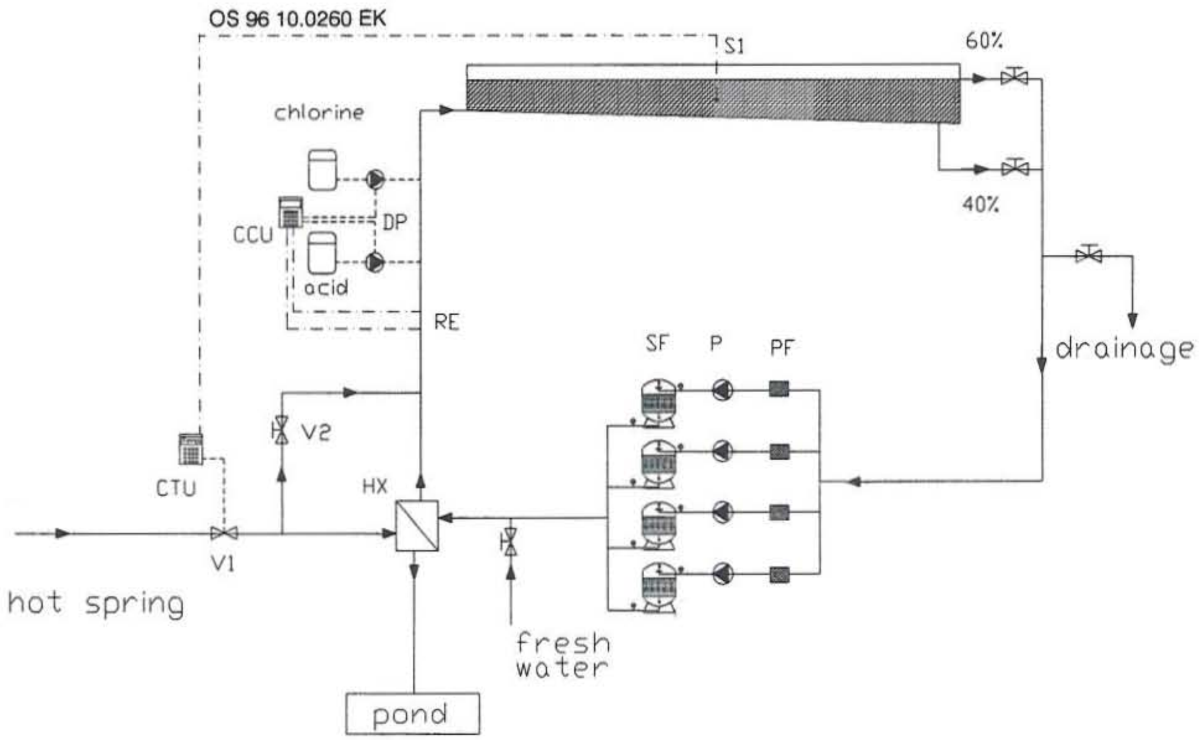

FIGURE 7: Schematic diagram of a modern swimming pool

The introduction of chemicals (chlorine & acid) into the pool is accomplished with the help of a control chemical unit (CCU) which is connected with two reading electrodes (RE) and two chemical dosing pumps (DP). The reading electrodes, which are located just before the injection point, measure the pH and redox (or free chlorine) values. The computer processes the signal from the reading electrodes and regulates the injection of the chemical dosing pumps.

After repairs the swimming pool needs to be refilled with warm water. The valve (V2) supplies hot water directly from the spring to the pool, saving time and wasted fresh water.

3.4 Size of the swimming pool

The size of the swimming pool is the primary designing parameter, because the size indicates how many and which groups of people are going to be served. In Ikaria we can divide the swimmers into three categories: children and adults (who cannot swim or are learning to swim), public (tourists and residents who swim for their recreation), and athletes.

According to international regulations, three lengths fulfil the standards for swimming competitions: 25, 33.3 and 50 m. It is assumed that the shortest one (25 m) is sufficient for a place like Ikaria. In swimming pools with 25 m length and at least 11 m width, it is possible to carry out swimming events of 400 m distances (or less) and identify records. It needs 6 lanes with 2 m width and 0.5 m extra width for each bank, in order to reduce the effects of waves on the swimmers closest to the banks. Consequently the pool must be 25x13 m. Also, according to international standards the depth of the pool should be 1 m in the shallower end and 1.8 m in the deeper end (Figure 8). However, most of the time the swimming pool is used by public and children. A good idea to ensure safe bathing for children or people who cannot swim, is the division of the pool crosswise. Hence the public could be in the deeper and children in the shallower side of the pool. Table 4 shows the dimensions of the pool.

TABLE 4: Dimensions of a suggested pool for Ikaria

Length	25 m
Width	13 m
Depth in the shallower end	1 m
Depth in the deeper end	1.8 m
Surface area	325 m^2
Volume of water	455 m^3

Halldórsson (1975) has stated that in pools deeper than 1.35 m, each swimmer should have 4.5 m^2 surface area for his comfort and safety. This means that the 325 m^2 swimming pool area could satisfy 72 persons at the same time. Of course the number of guests in the pool any one time is decided by the capacity of the cleansing equipment. Half the number mentioned before, i.e. 36, seems to be a reasonable number of guests for such a place as Ikaria.

3.5 Circulation system for the swimming pool

Maintenance of the water in the pool at the required standard of purity and temperature is of the utmost importance. So, special attention should be paid to the provision of inlets and outlets to ensure, as far as this is practicable, that:

- There are no ′dead′ pockets of water;
- The surface water (which is known to contain the greatest amount of contamination) is drawn off quickly and efficiently;
- The temperature is homogeneously distributed.

There are many different designs for water circulation, inlets and outlets, suggested by water treatment plant manufacturers, tile manufacturers and consulting engineers. But we will follow the Icelandic engineer's suggestions who have long experience in geothermal swimming pool design.

3.5.1 Inflow pipe

The inflow pipes are put under the pool bottom and the hot water is distributed by 15 distribution spouts, as shown in Figure 8. Due to a good circulation and blending of the water, this new system is adopted by many constructors. It is also more expensive than older techniques, requiring extra work for proper installation as access to the pipes is limited. The wide pipes must be put in before cementing while special preparation is needed around the distributors so they can be connected and packed later. The pipe material must be chemical and heat resistant as the chloride water which will be transferred, is very corrosive and hotter than the water in the pool. Recommended material for the pipes is polypropane (PP) or polyethylene (PE) as they have good heat resistant properties (Svavarsson, 1990).

3.5.2 Outflow pipe

The recommended method for withdrawal of the water from the pool is by means of drainage pipes in the overflow channel. The channel should extend the full perimeter of the pool. This system provides

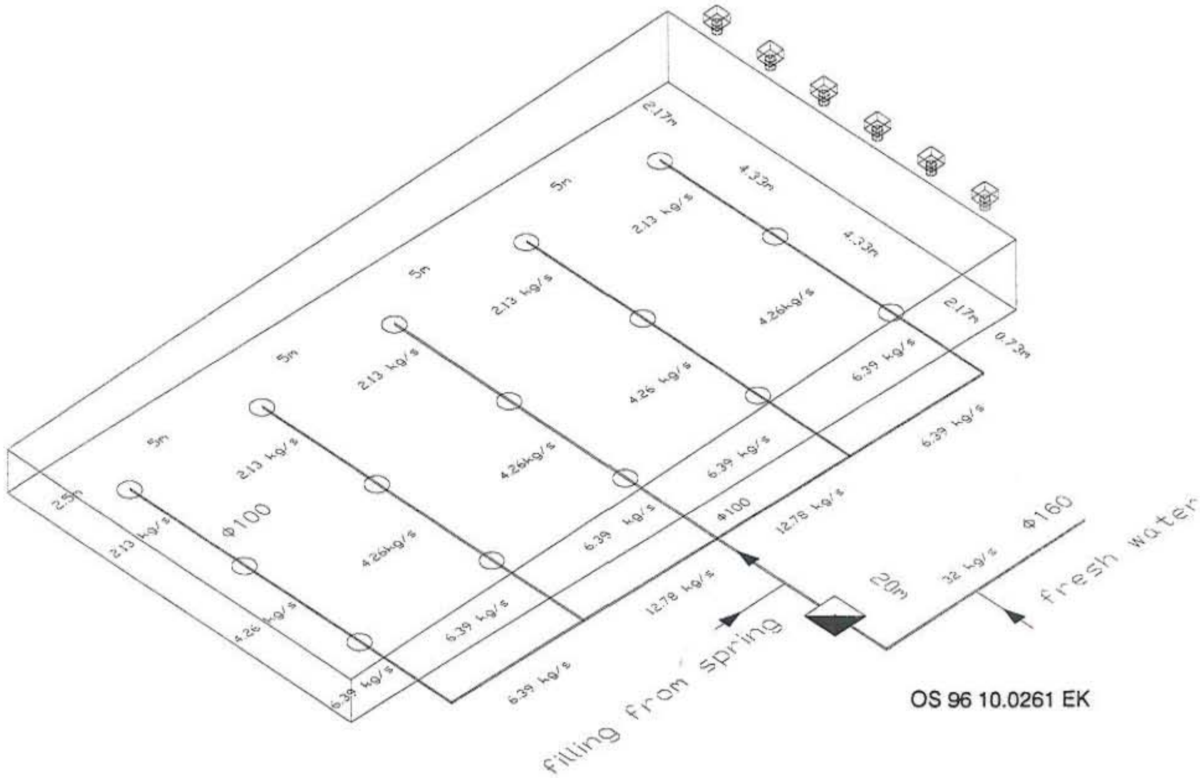

FIGURE 8: Isometric drawing of the swimming pool and the inflow pipes with the distribution spouts

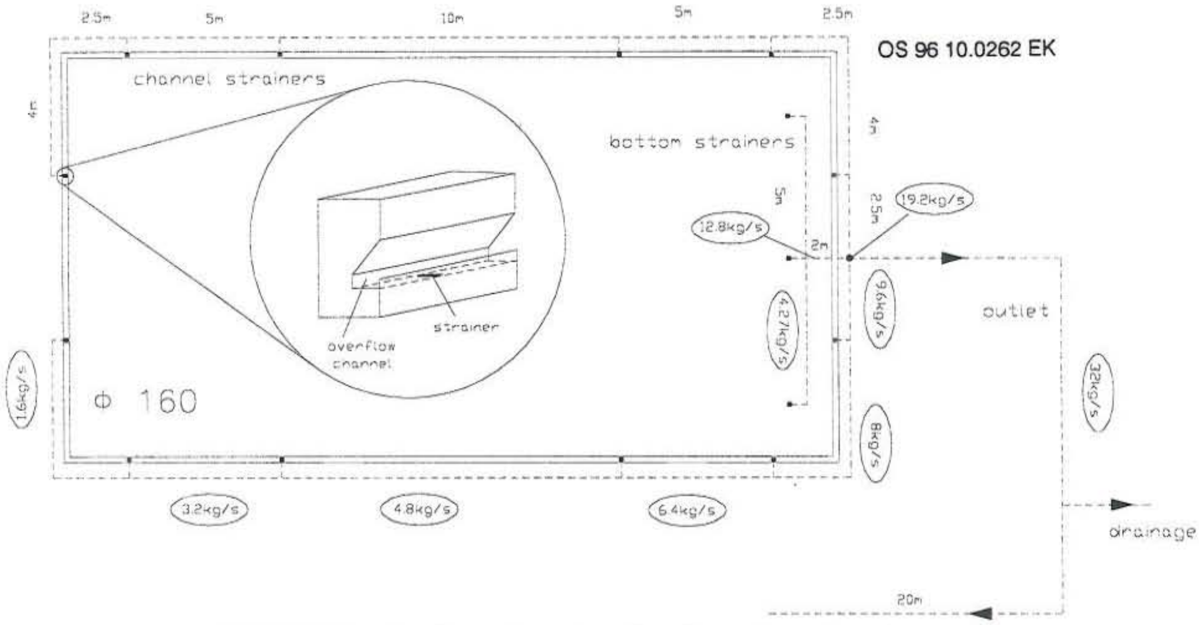

FIGURE 9: Configuration of outflow from the swimming pool

a very even draw-off and is very successful as the greatest part of contamination (hair, leaves, body fat) floats on top of the water. With overflow channels, outlet pipes fitted with an anti-vortex device and put in the deeper end are recommended. The floor outlets supply the circulation pumps with water (avoiding operation in vacuum) in case the water level is lower than overflow channel level. They should be able to handle about 40% of the outflow water. Plastic materials are usually used for the drainage pipes. Figure 9 shows the outflow configuration.

3.5.3 Strainers

The strainers (Figure 9) usually consist of a cast-iron box with an inner basket of perforated heavy-gauge copper. This basket is removable for cleaning and can be replaced by a spare one. It is required to intercept leaves and coarse suspended matter which could reduce the efficiency of the pump filters.

3.6 Renewal of water

According to international regulations, fresh water must be added continuously to the swimming pool. The quantity of water depends on the attendance at the pool. The German regulations state that 30 litres of fresh water should be added for each guest every day. Earlier we considered that there are 36 persons in the pool at any one time. If each of them stays about 1 hour and the swimming pool operates for 10 hours, the total amount of fresh water which must be added to the pool is $30 \times 360/10 = 1080$ l/h (or 0.3 kg/s).

3.7 Water treatment

3.7.1 Turnover period

This is one of the most important factors in the operation of a swimming pool. The turnover period is the time it takes to circulate all the water in the pool from the outlets, through the treatment plant and back to the pool inlets.

The number of guests which can be in the pool simultaneously dictates the turnover period and the capacity of the cleansing equipment. As we have already mentioned a number of 36 persons is considered to be a reasonable number of guests during the high peak hour. Opinions about the turnover period vary. For instance, Halldórsson (1975) suggests 2 m^3/h recycling water per bather, which means a turnover period of 6 hours. Perkins (1988) suggests 2-3 hours while new requirements demand 4 hours. Following these new requirements, we decide to recycle the water every 4 hours. As the volume of the pool is 455 m^3, we have to provide 455/4=114 m^3/h (or 32 kg/s) treated water for the pool.

3.7.2 Main filter

Modern swimming pools only use pressure sand filters of cylindrical steel, painted steel or glass-reinforced plastic (grp) tanks, using grained sand as the filter medium. These are generally classified as standard, medium and high rate filters. The water is pumped at a certain speed through the sand and the impurities remain in the sand. The lower the speed is, the better quality of rinsing is obtained. When the sand has absorbed a lot of impurities, the measurable pressure drop between outlet and inlet increases. So, when the pressure drop has reached a certain value, the filter is cleaned by sending pool water in the opposite direction. A method which could increase cleansing efficiency is suppling the water with alum, before it enters the filter. It causes impurities and bacteria to form clots and stay behind in the sand. We selected a sand filter, manufactured by the Astral company, model 865 (1995). This type of filter was specially chosen because it is totally anticorrosive and resistant to salt water. It is manufactured with fibreglass and polyester resin and provided with a battery of 4 PVC valves for filtering and backwashing operations and their supports. Further technical information is in Table 5.

TABLE 5: Technical characteristics for Astral sand filter (865)

Astral sand filter (865)	
Capacity	30 m^3/h
The filtration speed	20 m^3/m^2 h
Height of equipment	1.755 m
Tank diameter	1.4 m
The filter surface area	1.54 m^2
Volume	2035 l
Working pressure	2.5 kg/cm^2
Max. temperature	50°C
Net weight	140 kg
Sand	1900 kg
Sand+Gravel	1400+500 kg
Total service weight	3650 kg

According to Table 5 we need 114/30 ~ 4 filters of this type. The pumping capacity is 114/4=28.5 m^3/h while the filtration speed 28.5/1.54=18.5 m^3/m^2 h. From the head loss diagram for the filters provided by the manufacturer (Figure 10), we can calculate the pressure loss due to the filter. It is about 12,000 Pa (1.2 m).

3.7.3 Pump filters

Pump filters remove large objects from the pool water before it enters the pumps. They protect the pump wheels from damage and assist the main filtration. These filters are a part of the pump and are put in accessible places, because they need to be opened and cleaned frequently.

TABLE 6: Pressure drop in swimming pool circulation system

Flow rate (kg/s)	Object	Number of pieces	Diameter (mm)	Length (m)	Equiv. length (m)	Nomogr. (Pa/m)	Press. drop (Pa)
PRESSURE LOSSES IN THE SYSTEM, FROM FILTERS TO POOL							
2.13	pipe	1	100	4.33	-	9	39.0
4.26	pipe	1	100	4.33	-	30	129.9
6.39	pipe	1	100	3	-	70	210.0
6.39	pipe	1	100	5	-	70	350.0
12.78	pipe	1	100	5	-	260	1300.0
32	pipe	1	160	20	-	130	2600.0
6.39	standard elbow	1	100	-	3.048	70	213.4
12.78	standard tee	1	100	-	6.096	260	1585.0
32	cross	1	160	-	12.192	130	1585.0
32	standard elbow	1	160	-	5.1816	130	673.6
32	standard tee	2	160	-	10.668	130	2773.7
32	heat exchanger	1	-	-	-	-	25000.0
PRESSURE LOSSES IN THE SYSTEM, FROM POOL TO FILTERS							
1.6	pipe	1	160	4	-	neglected	-
1.6	pipe	1	160	2.5	-	neglected	-
3.2	pipe	1	160	5	-	2	10.0
4.8	pipe	1	160	10	-	4.5	45.0
6.4	pipe	1	160	5	-	7.5	37.5
8	pipe	1	160	2.5	-	11	27.5
8	pipe	1	160	4	-	11	44.0
9.6	pipe	1	160	2.5	-	16	40.0
4.27	pipe	1	160	5	-	4	20.0
12.8	pipe	1	160	2	-	30	60.0
19.2	pipe vert	1	160	1.8	-	60	108.0
32	pipe	1	160	20	-	130	2600.0
1.6	standard elbow	1	160	-	5.1816	neglected	-
8	standard elbow	1	160	-	5.1816	11	57.0
19.2	standard tee	1	160	-	10.668	60	640.1
19.2	gate valve 1/2 closed	1	160	-	30.48	60	1828.8
12.8	standard tee	1	160	-	10.668	30	320.0
12.8	gate valve 1/2 closed	1	160	-	30.48	30	914.4
32	cross	1	160	-	12.192	130	1585.0
32	standard elbow	2	160	-	5.1816	130	1347.2
32	standard tee	1	160	-	10.668	130	1386.8
PRESSURE LOSSES IN THE SYSTEM, DUE TO THE FILTRATION							
32	standard elbow	2	160	-	5.1816	130	1347.2
32	standard tee	4	160	-	10.668	130	5547.4
32	sand, filter & battery	4 parallel	-	-	-	-	12000.0
TOTAL PRESSURE DROP IN THE SYSTEM =							**66425**

3.7.4 Pumps

The pump types used for the circulation of swimming pool water vary according to the designer's choices. It is obviously an advantage to have the pump and motor in duplicate in spite of the higher expense. For a selection of the pump size it is necessary to identify the total pressure drop in the system and total flow rate of water.

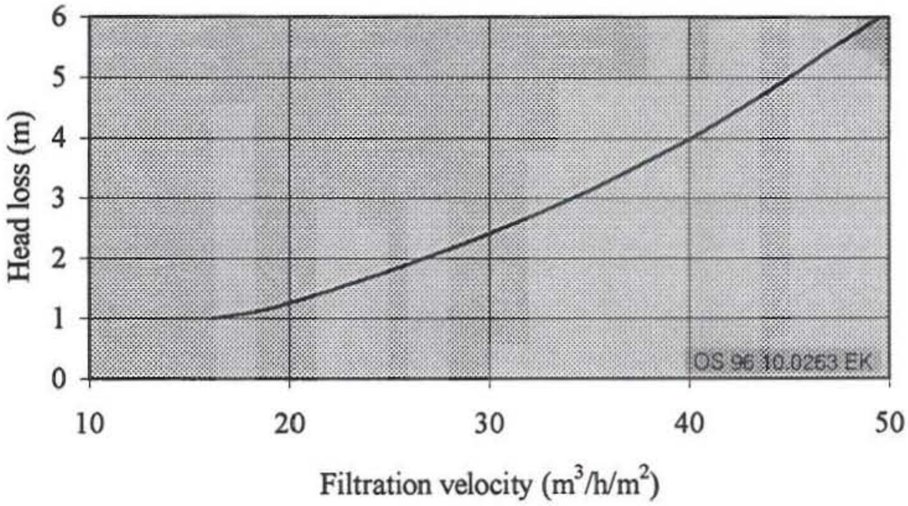

FIGURE 10: Head loss diagram for filters with sand and valve battery

The total flow rate of water has already been calculated in Chapter 3.7.1 as 114 m^3/h (or 32 kg/s). The total pressure drop which the pumps have to recover are calculated in Table 6. The determination of pressure losses at plastic pipes has been carried out with nomogram provided by Grundfos company (1995) and the equivalent length for valves and fittings with nomogram provided by Davis (1952). The pressure drop in the heat exchanger is calculated by the CAS-200 software program of Alfa-Laval (See Chapter 3.11.2). Pressure losses due to the inlet of fresh water and outlet of drainage water flow because of the small flow rate values at these parts has not been taken into account. The total number of pumps will be 4 (one pump for each filter) and they will be connected in parallel. This means that each pump must recover pressure equal to the total pressure drop (66425 Pa) and supply water flow rate equal to the one forth of total flowrate of water 28.5m^3/h (or 8 kg/s).

The type of pump we chose (Astral model 09.57.58) is the pump which is recommended by the manufacturer of the sand filter. The impeller and diffuser of the pump are made from bronze and are suitable for sea water. The shaft is made of AISI-316 stainless steel. Its design allows complete removal of moving parts without the need to remove the pump body from the system. Further technical information is given in Table 7.

TABLE 7: Technical characteristics for Astral Self-primming pump (1236)

Astral Self-primming pump (1236)	
Power	2 HP (1.47 kW)
Flow rate	28 m^3/h
Voltage	220 V ~1 220/380 V ~3
r.p.m	3000
Connections	2'' (50 DN)
Length	595 mm
Height	269
Max. ambient operating temperature	40°C

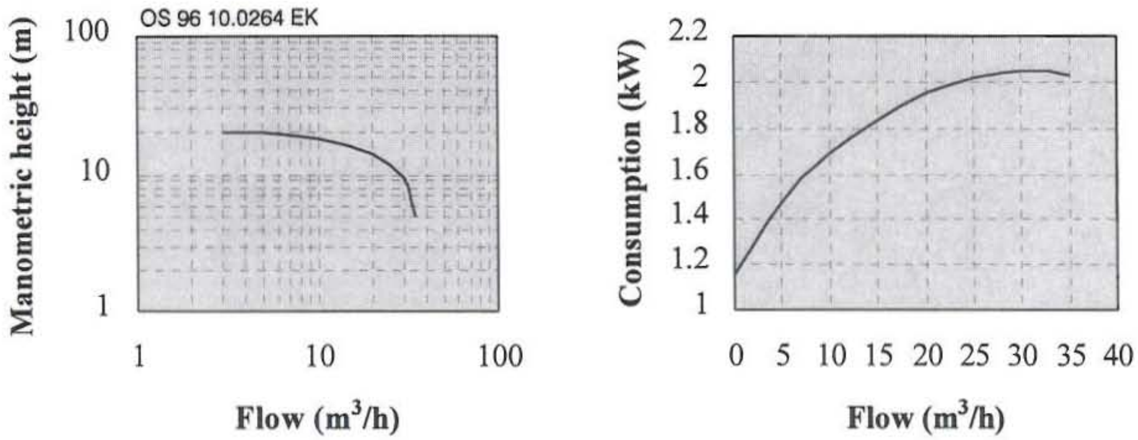

FIGURE 11: Performance curve and consumption curve for the self-priming Astral pump

Figure 11 shows the performance and consumption curves for the self-priming pump selected. From the consumption curve one finds that the electrical consumption of the pump is about 2 kW.

3.8 Disinfection of water

The destruction of harmful bacteria in the water as it passes through the treatment plant is not enough. Sterilising (disinfecting) agents must be injected into the water so that their potency remains active in the pool itself. In this way continuous destruction of pathogens, brought in by the bathers, is assured and the health of the pool users safeguarded. The addition of some agents in the water are also required for controlling the pH within the range 7.2-7.8. The most efficient and widespread disinfecting agent is chloride. Chloride reacts to water and forms hypochlorous acid and hydrochloric acid.

$$Cl_2 + H_2O \rightarrow HOCl + HCl \qquad (4)$$

The hydrochloric acid will be neutralised by any alkalis present in the water, while the hypochlorous acid will react with organic and nitrogenous compounds. The quantity of the chemical components is regulated by an electronic control unit (Figure 7). When the pH or Redox reading electrodes detect that chemical additives are needed the dosing pumps are activated until the reading reaches the pre-set value.

Equipment from the Astral company (1995) was selected. Electronic control unit VIGILANT-3 model 5467, which comprises pH and redox regulator proportional dosing with alarm and diagnosis leds; membrane dosing pumps, pH regulators; one head model 1299 and RX regulators; one head model 1301 with maximum flow rate at 10 kg/cm^2 or 5 l/h; reading electrodes, pH electrodes model 1303 and RX electrodes model 1304; polyethylene tank 200 l capacity, model 1315; and electrode carrier model 1304.

3.9 Conditions

3.9.1 Water temperature

The water temperature in swimming pools varies from country to country. In most European countries the water temperature for open-air swimming pools is between 20-27°C. In Iceland the water is kept at

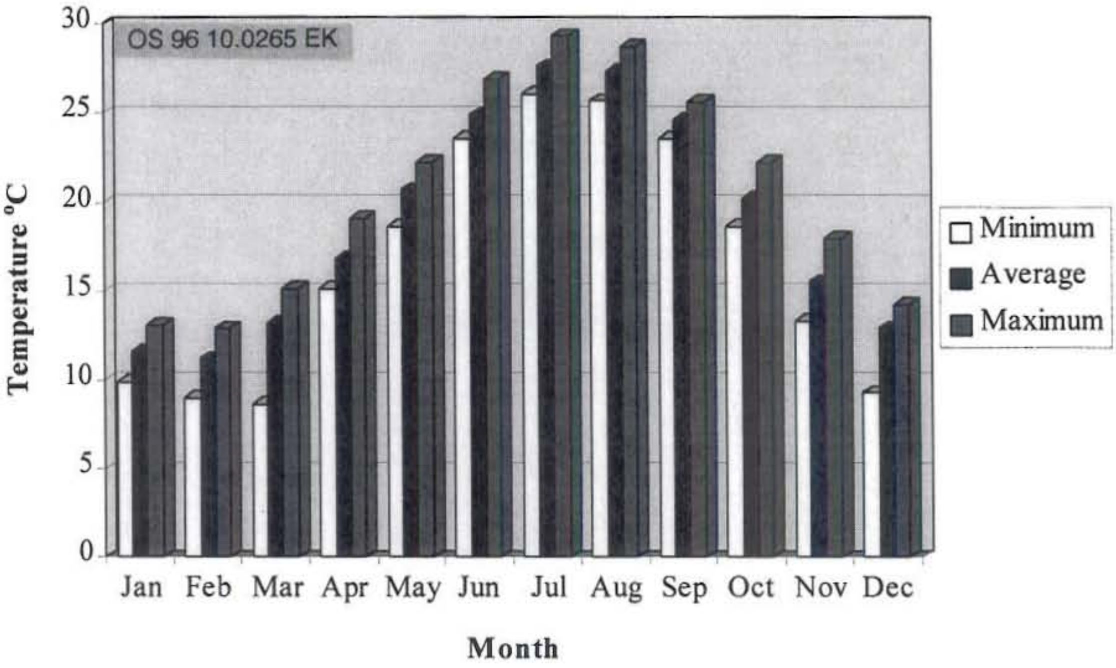

FIGURE 12: Monthly average temperature in Ikaria in period 1980-1991

30°C and provides extremely comfortable conditions for the swimmers. So, in order to satisfy the most demanding bathers we will keep the water temperature at T_w=30°C.

3.9.2 Outdoor conditions

Figures 12, 13 and 14 present weather data for Ikaria, as they have been measured by the meteorological station placed in Agios Kirikos, (Papadakis 1993 and Papadakis 1995).

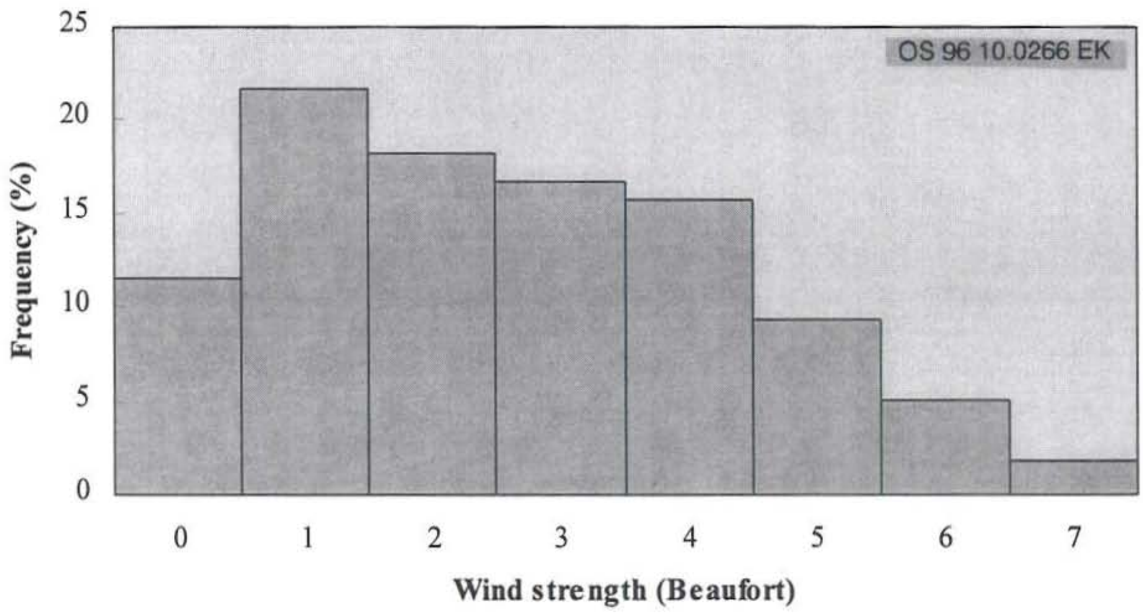

FIGURE 13: Wind strength contribution in Ikaria during a year

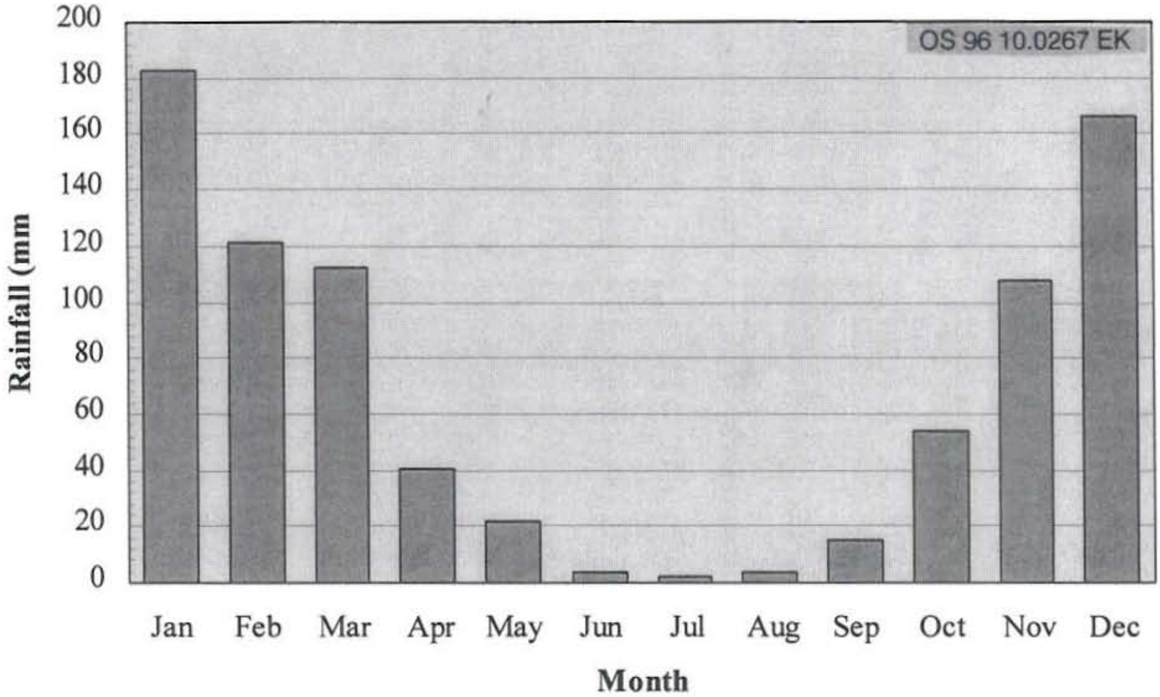

FIGURE 14: Monthly average rainfall in Ikaria

The design criteria used are not based on the worst possible weather conditions in Ikaria, not only because they exist only a few days per year but also because this would dramatically increase equipment cost. The minimum average temperature T_a = 8.7°C (March) has been chosen as outside design temperature. The wind strength is assumed to be about 5 Beaufort (v_2 = 9 m/s). The partial pressure of steam in air (8.7 °C) is e_a = 12 mbar and the partial pressure of steam at the pool surface (30°C) is e_w = 42.43 mbar (Berry et al., 1945).

3.10 Heat demands

The energy which is needed for heating the pool water is the sum of the following terms:

- Heat losses due to convection;
- Heat losses due to evaporation;
- Heat losses due to radiation;
- Heat losses due to conduction;
- Heat losses due to rain;
- Energy needed for fresh water heating.

3.10.1 Convection

The Newton law of cooling is used

$$Q_c = h_c(T_w - T_a) \tag{5}$$

where

Q_c	= Heat losses due to cooling [W/m²];
h_c	= K+ 1.88v_2 [W/m² °C];
K	= 4.1868[0.93+0.04(T_w-T_a)] [W/m² °C];
T_w	= Water temperature [°C];
T_a	= Air temperature [°C];
v_2	= Wind speed [m/s].

The chart in Figure 15 shows the calculations of heat losses due to convection for three different wind strengths 1, 5 and 7 Beaufort. So, for the design conditions (8.7°C, 5 Beaufort or 9 m/s) we find that the heat losses due to convection are 520 W/m².

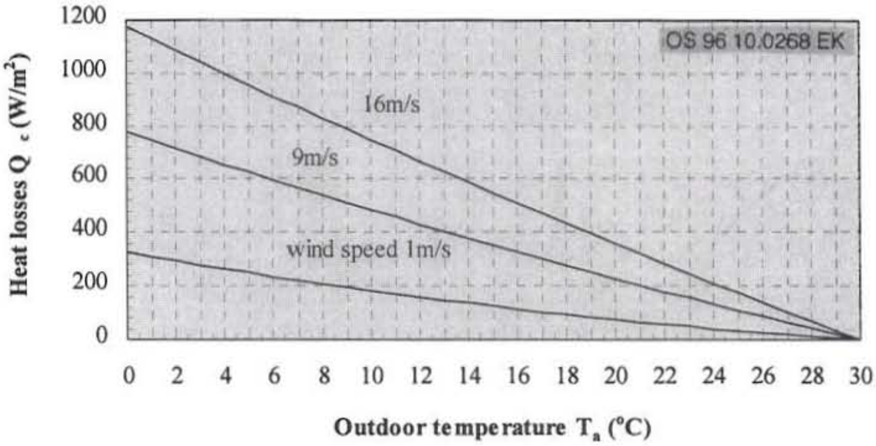

FIGURE 15: Calculations on heat losses due to convection

3.10.2 Evaporation

From the surface of the swimming pool, an amount of water is evaporated absorbing heat from the warm water. The heat loss can be calculated by using the Rinsha-Doncenko's formula

$$Q_e = (1.56K + 2.93v_2)\ (e_w - e_a) \tag{6}$$

where

Q_e	= Heat loss due to evaporation [W/m²];
K	= 4.1868[0.93+0.04(T_w-T_a)] [W/m² °C];
T_w	= Water temperature [°C];
T_a	= Air temperature [°C];
v_2	= Wind speed [m/s];
e_w	= Partial pressure of steam at surface [mbar];
e_a	= Partial pressure of steam in air [mbar].

The chart in Figure 16 shows the calculations of heat losses due to evaporation for three different wind strengths 1, 5 and 7 Beaufort. For the design conditions (8.7°C, 5 Beaufort or 9 m/s) we find that heat losses due to evaporation are 1195 W/m².

3.10.3 Radiation

Due to evaporative losses near the pool surface, the air tends to contain a large quantity of water vapour. In this case, the pond surface radiates thermal energy to the water vapour in the air, which is assumed to have the same temperature as the air. The equation which describes this process is as follows:

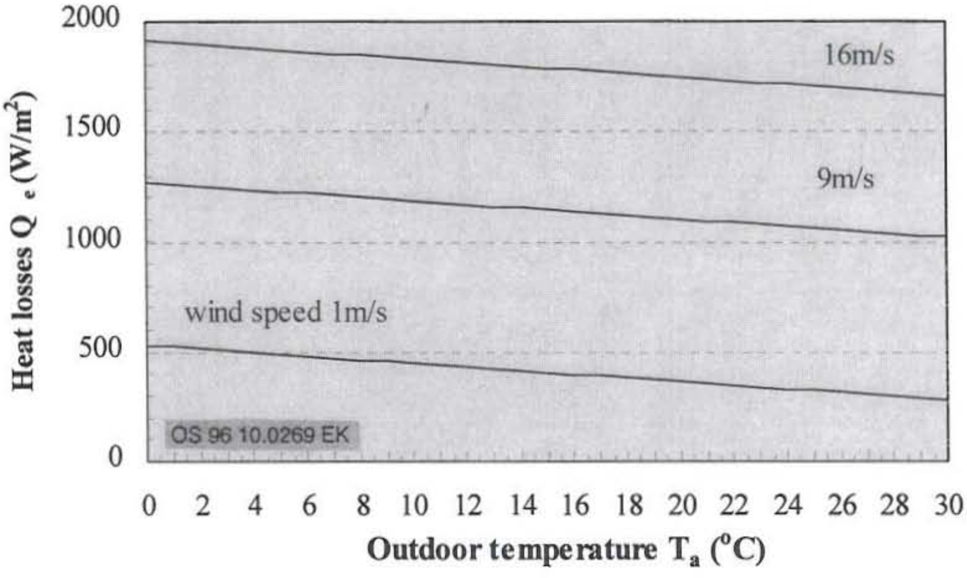

FIGURE 16: Heat losses from a swimming pool due to evaporation

$$Q_R = 0.51x10^{-8}[(492+1.8T_w)^4-(492+1.8T_a)^4] \qquad (7)$$

where

Q_R = Heat loss due to radiation [W/m²];
T_a = Air temperature [°C];
T_w = Water temperature [°C].

The chart in Figure 17 shows the calculations of heat losses due to radiation. From it, we find that the heat losses are 114.5 W/m².

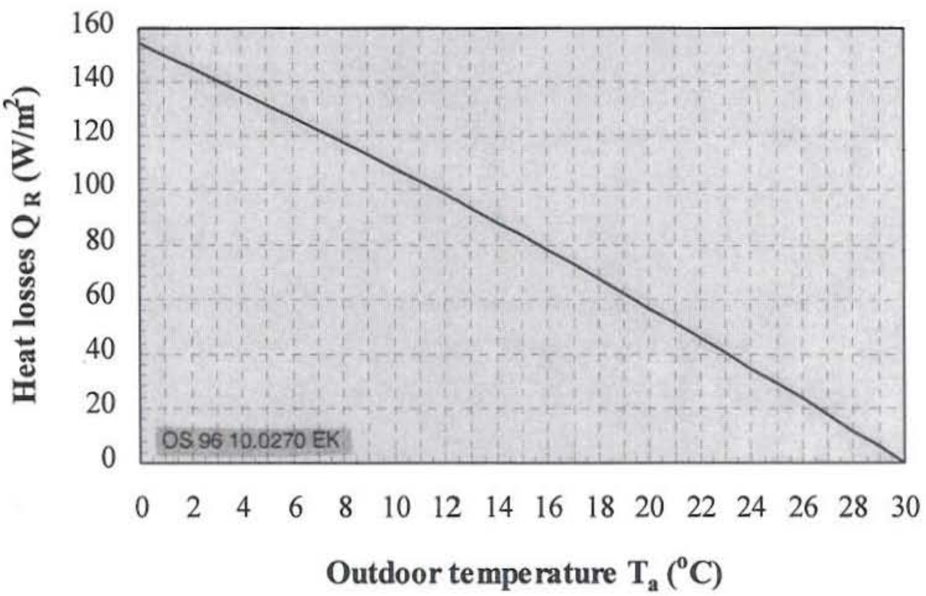

FIGURE 17: Heat losses from a swimming pool due to radiation

3.10.4 Conduction

It is assumed that the pool walls are made of 18 cm concrete (k_l = 1.82 W/m °C) and that they are insulated with 6 cm rock-wool (k_2 = 0.0415 W/m °C) (Baumeister et al. (1978). If we assume that the temperature difference between the inside pool wall and the ground is about ΔT=20°C, we can calculate the conductive heat losses, Q_{cd} (W/m²),

$$Q_{cd} = \frac{\Delta T}{\frac{l_1}{k_1} + \frac{l_2}{k_2}} \tag{8}$$

where

ΔT	= temperature difference between the inside pool wall and the ground [°C];
l_1	= thickness of concrete [m];
l_2	= thickness of rock wool [m];
k_1	= thermal conduction of concrete [W/m °C];
k_2	= thermal conduction of rock wool [W/m °C].

Calculations show that conductive heat losses are 13 W/m² of wall surface area.

3.10.5 Rain

The average rainfall in March (Figure 14) is 112.3 mm. This means that approximately 4.3 x 10^{-5} mm (or 4.3 x 10^{-5} kg/m²) rain water falls per second. It is assumed that the temperature of the rain water is equal to the temperature of the air T_r=T_a. The formula which gives the losses due to rain is:

$$Q_{rain} = m\,c_p(T_w - T_r) \tag{9}$$

where

Q_{rain}	= Loss due to rain [W/m²];
m	= Rainfall [kg/s m²];
T_r	= Rain water temperature [°C];
T_w	= Water temperature in the pool [°C];
c_p	= Specific heat of water at constant pressure = 4200 [J/kg°C].

So, the heat losses due to rain are 3.8 W/m².

3.10.6 Fresh water

As we stated before, the swimming pool must be supplied with m_f = 0.3 kg/s fresh water. If we accept that the fresh water temperature is equal to the outdoor temperature T_f = 8.7°C, we are able to calculate the energy required for the heating of this amount of water, Q_f [W/m²]:

$$Q_f = m_f c_p(T_w - T_f) \tag{10}$$

where

m	= Fresh water supply [kg/s];
T_f	= Fresh water temperature [°C];
T_w	= Water temperature [°C];
c_p	= Specific heat of water at constant pressure = 4200 [J/kg °C].

After calculations we conclude that 26838 W is required for heating the fresh water.

3.10.7 Total heat demands

Table 8 contains the summary results from heat demand calculations:

TABLE 8: Summary results from heat demand calculations

	Heat demands [W/m²]	Surface [m²]	Heat losses [W]	Percentage [%]
Convection	520	325	169000	27
Evaporation	1195	325	388375	62
Radiation	115	325	37212	6
Conduction	13	431.4	5608	0.8
Rain	3.8	325	1235	0.2
Fresh water	-	-	26838	4
Total	1933	325	**628268**	100

3.11 Heat recovery

3.11.1 Direct supply

The energy recovery due to the total heat demands can be provided by means of supplying the pool with water from a hot spring. If we select the spring Lefkada which has hot water at 59°C, we can estimate the flow rate, m_h needed.

$$m_h = \frac{Q_t}{c_p(T_h - T_w)} \qquad (11)$$

where

m_h	= Estimated flow rate [kg/s];
Q_t	= Total heat losses [W];
T_h	= Spring water temperature [°C];
T_w	= Pool water temperature [°C];
c_p	= Specific heat of water at constant pressure = 4200 [J/kg °C].

After calculations we find m_h = 5.2 kg/s (or 446 m³/day). The problem which comes up, with the direct supply of 5.2 kg/s hot water, is that the same amount of water has to be discharged from the pool. This means that a lot of treatment chemicals are wasted and, consequently, operation costs rise and probably to a level which makes the running of the pool prohibitive. In order to decrease the amount of wasted chemicals we can use a heat exchanger.

3.11.2 Heat exchanger

The heat transfer technique suggested has been adopted from the most modern pools and is based on the use of heat exchangers. A suitable heat exchanger for operating with water containing many dissolved solids (sea water) is the plate-type heat exchanger, made of stainless metal, like titanium. In spite of the high cost, the advantages of this type of heat exchanger are considerable. It is not affected by corrosion and furthermore the plates can be easily dismantled and cleaned of depositions.

The selection of a heat exchanger which would fulfil the demands of the swimming pool presented here was carried out by using the software program CAS-200, provided by the company Alfa Laval (1996). Figure 18 shows the screen of the CAS-200 with technical information about the suitable heat exchanger. The geothermal water flow rate has been calculated to be about 8 kg/s.

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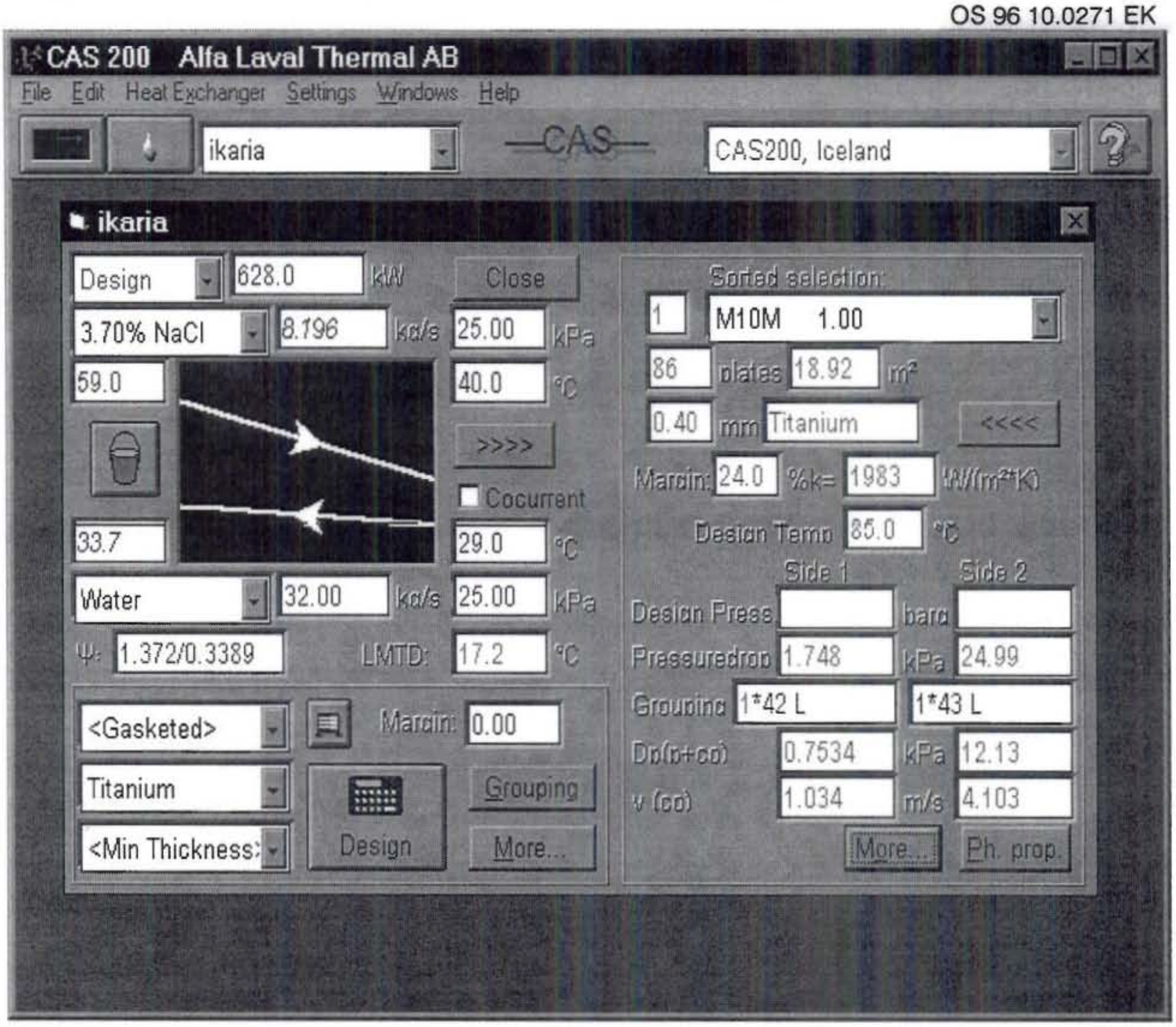

FIGURE 18: The screen of the CAS-200

3.12 Equipment cost

The objective of this report is not to carry out a detailed economic study for a complete swimming pool. But a demonstrating cost analysis of the main operation parts of the simple swimming pool described in this chapter (Figure 7) is presented in Table 9. The prices for Astral products were taken from the brochures provided by the company for 1995, and do not include taxes. The price for control temperature unit was estimated and the price for the plate heat exchanger was provided by the Alfa Laval company.

TABLE 9: Cost analysis of the main operational parts of the swimming pool

Equipment	Model	Number	Price per unit (US $)	Total price (US $)
Sand filter	Astral (865)	4	5,004	20,016
Self-priming pump with pre-filter	Astral (1236)	4	2,505	10,020
Chemical control unit	Astral vigilant-3 (5467)	1	6,370	6,370
Membrane dosing pump	Astral pH Regulators, 1 head (1299)	1	1,278	1,278
Membrane dosing pump	Astral RX regulators, 1 head (1301)	1	1,278	1,278
Reading electrode	Astral pH electrodes (1303)	1	310	310
Reading electrode	Astral RX electrodes (1304)	1	322	322
Polyethylene tank	Astral (1315)	2	297	594
Control temperature unit with motor valve	-	1	3,000	3,000
Heat exchanger	Alfa Laval M10M 1.00	1	8,788	8,788
				51,976

4. SPACE HEATING

4.1 Space heating in Iceland

The main use of geothermal energy in Iceland is for space heating. Today about 85% of the space heating is by geothermal energy, the rest is by electricity (12%) and oil (3%). The benefits of geothermal heating are of great importance to the country as about 100 million US$ in imported oil is saved annually. The total geothermal energy used for space heating in Iceland is about 16,300 TJ per year. There are now 27 municipally owned geothermal district heating services in Iceland. The biggest one is Reykjavik Municipal District Heating which serves about 150,000 people. Also many district heating systems have been built in rural areas with low population densities. These single pipe systems typically serve ten to twenty farms that can be one to three kilometres apart. These systems serve about 4,000 inhabitants and the total pipe length is about 900 km, or 225 m per person, compared to 12 m in towns. (Ragnarsson, 1995).

4.2 Space heating system

Space heating by means of geothermal energy is one of the most successful present-day applications of this valuable resource. Over twenty countries have now put geothermal energy to use for this purpose. There are many different types of space heating systems. The choice of which of them is suitable for heating an area depends on many factors like geothermal water quality, temperature, flow rate, investment cost, etc. An example of a space heating system is shown in Figure 19. It consists of three heat production units

a. Heat exchanger; b. Heat pump; c. Boiler.

Units a and b are the base load stations while unit c is the peak load unit (Piatti et al., 1992). The heat

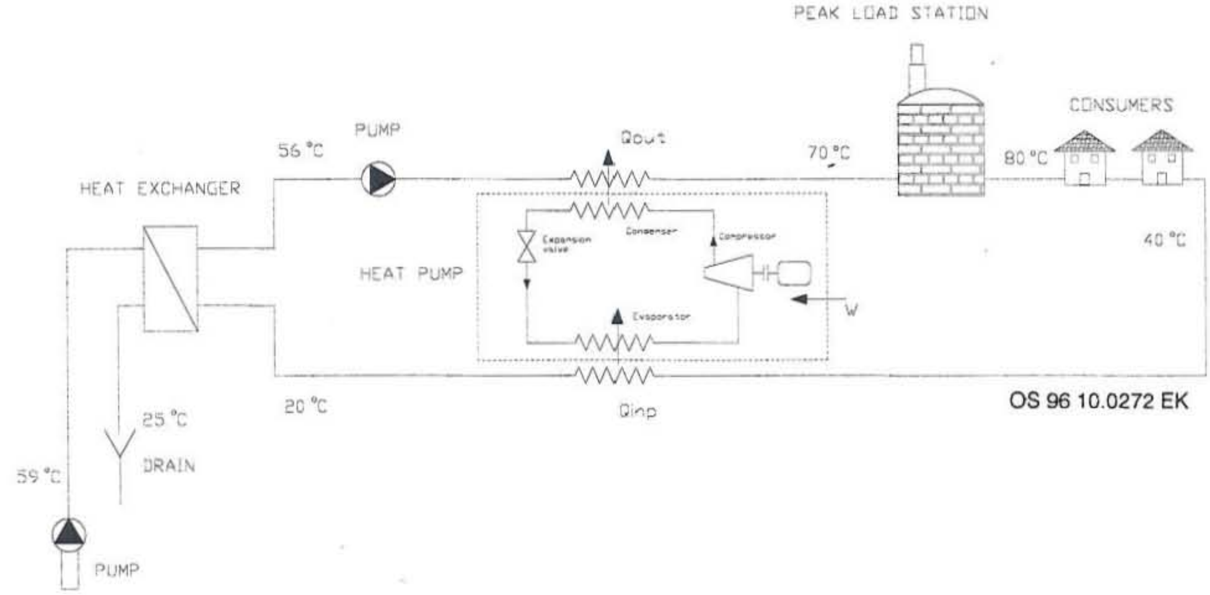

FIGURE 19: Space heating system

exchanger of the specific space heating layout presented here utilizes geothermal water from 59 to 25°C, while the temperature of the return water in the closed loop must be boosted from 20 to 56°C. The big temperature differences at both sides of the heat exchanger dictate the use of a large and probably non-economical heat exchanger. So, in order to use a smaller heat exchanger the geothermal water is cooled to 43°C instead of 25°C and sent directly to the evaporator. At the same time the return water, which is cooled down to 40°C instead of 20°C, is driven directly to the heat exchanger.

Geothermal fields with temperatures over 60°C can be utilized directly or by means of heat exchangers for space heating. But at some places there are geothermal fields where the fluid temperature is lower than 60°C and considered too low for space heating. In these cases the supply water temperature is usually raised in a boosting station with, for example, a heat pump unit.

Low-temperature geothermal water in the range 50-60°C, can be used for heating purposes without boosting. But it requires a fairly large heat-transfer area in order to supply a sufficient amount of heat to the building. This means that the radiators need extended dimensions and occupy considerable space in the building. So, the feasibility of such a low-temperature district heating system depends mainly on economic and aesthetic factors rather than technical ones.

4.3 Heat exchanger

If the geothermal water is relatively pure and free of oxygen it can be used directly, both for radiators and tap water. On the other hand, if the geothermal water is rich in minerals or contains constituents harmful to the system, the use of heat exchangers and double-pipe distribution is necessary. A closed-loop system employing heat exchangers is the most common type of geothermal district heating system everywhere except in Iceland, where the geothermal water is generally potable.

4.4 Heat pump

The heat pump is a machine which is capable of absorbing heat from a low-temperature fluid and rejecting it in a higher one. This process needs external energy input. This operation may seem paradoxical but the heat provided by modern heat pumps is about three times greater than the electrical energy consumed by the machine.

The vapour-compression cycle, which is the most common principle for a heat pump, is shown schematically in Figure 19. The low-pressure, low-temperature refrigerant is boiled in the evaporator by extracting heat Q_{inp} from the low-temperature water and emerges in the form of a dry saturated vapour. From here, it is compressed adiabatically to a high-temperature, high-pressure superheated vapour by the compressor which uses electrical or fuel power W. From there, the superheated vapour enters the condenser where it first of all loses the sensible heat associated with the superheating above the boiling point at the pressure of interest, and then condenses to saturated liquid, giving the Q_{out} to the water in the heating system. Then, the high-temperature, high-pressure liquid is expanded through an expansion valve to much lower pressure and temperature of the evaporator. The energy balance of the pump gives

$$Q_{out} = Q_{inp} + W \tag{12}$$

The coefficient of performance for heating is given by

$$COP_h = \frac{Q_{out}}{W} \tag{13}$$

If we assume that the thermodynamic cycle is an ideal cycle, the *COP* of the system is given by the reversed Carnot cycle as

$$COP_h = \frac{Q_{out}}{W} = \frac{T_{out}}{T_{out} - T_{inp}} \tag{14}$$

Consider the use of a heat pump which extracts heat from the atmosphere at 5°C and delivers it to a house at 20°C. The theoretical *COP* is 19.5, which is highly attractive since this implies that 19.5 kW of heat can be supplied to heat a house for the expenditure of only 1 kW compressor power (McMullan and Morgan, 1981). Of course this never can be achieved because the real thermodynamic cycle is irreversible. Common values for COP_h lie between 2 and 4.

The decision to install a heat pump or a peak load boiler and the choice of their capacities should be based on an economic optimization. Generally, the heat pump installation is characterized by high investment cost and low operating cost.

4.5 Boilers

Peak load oil or electrical boilers are absolutely necessary when the energy demand in the district heating network is so high that it cannot be obtained by means of base load unit only. Otherwise, the decision to install peak load boilers and the choice of the thermal power of these units depend on an economic optimization. The boiler installation is characterized by low investment cost and high operating cost.

4.6 Geothermal district heating simulation for Ikaria

The NovaSim District Heating Simulator is a powerful tool made in ACSL (Advanced Continuous Simulation Language) which gives valuable insight into the geothermal district heating system and the main factors that affect the operation of the system. This simulator was used in order to obtain the most important points of a hypothetical space heating system in Ikaria.

Using this simulator, the heat loss of one typical house, the necessary amount of water, the necessary power capacity and the total energy consumption of peak heating station were calculated. The simulator is based on the theory which Karlsson (1982) stated for geothermal district heating. The simulator processes weather data, civil construction characteristics, design system data and carries out dynamic calculations for one year.

TABLE 10: The values of the most important simulation factors for Ikaria

Supply temperature	56°C
Return temperature	40°C
Room temperature	20°C
Standard deviation (RMS value) of temperature noise sequence	1°C
Lowest monthly average temperature	11.2°C
Annual average temperature	18.9°C
Amplitude of monthly average temperature curve	16.4°C
Space volume per square metre of floor	2.564 m^3
Flat total area	109.6 m^2
Total area of exterior walls including windows	127.3 m^2
Relative area of windows (percentage of exterior walls)	0.2794
Relative area of inner floor section (percentage of exterior walls)	0.6619
Relative area of outer floor section (percentage of exterior walls)	0.2704
k-value of exterior walls	1 W/m^2 °C
k-value of windows	5.5 W/m^2 °C
k-value of ceiling	0.3 W/m^2 °C
k-value of outer section of the floor	0.3 W/m^2 °C
k-value of inner section of the floor	0.3 W/m^2 °C
Heat capacity of hot mass excluding exterior walls per m^2 of floor area	397.3 kJ/°C
Heat capacity of exterior walls per m^2 of floor area	500 kJ/°C
Radiator power per m^2 of exterior walls	22 W
Maximum radiator flow (in l/min. per m^2 of floor area)	0.05

Selecting the hot spring Lefkada (saline water 59°C), the use of heat exchanger is unavoidable because of the corrosive nature of the water. For the simulation we assumed that the supply temperature in the closed loop system is 3 degrees less (56°C) than the temperature of the hot spring. The values of the most important factors which are used for the simulation are presented in Table 10.

After the simulation process we can make the following comments:

- Figure 20 shows the heat demand of one house in Ikaria during the year. The maximum heat demand is about 2.2 kW during the coldest period of the year while the house does not need heating during the greatest part of the year (April-October). The yearly energy supplied from the geothermal field to one house is 4,270 kWh. According to the simulation results the peak

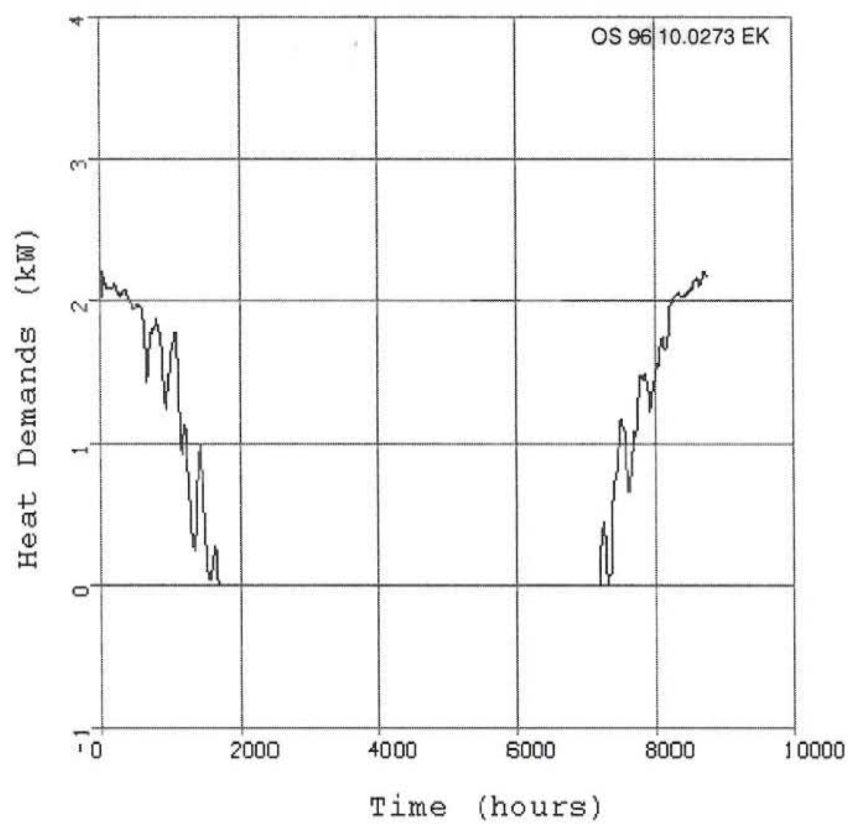

FIGURE 20: The heat demand of a house in Ikaria during the year.

heating station will never be used to cover extra power needs because the geothermal water temperature and flow rate are sufficient.

- Figure 21 shows the outdoor temperature during the year and the consumption of hot water. Of course the greatest water consumption is observed during the cold spell (winter) and gradually reduced to zero. The maximum water consumption is calculated at about 0.038 l/s per house and the yearly total water consumption is 262 m^3.
- Figure 22 shows the radiator supply and return water temperature.

All the dynamic calculations are carried out only for the closed loop itself. So, in order to confirm the sufficiency of the hot spring water (open loop) we assume that the temperature of the discharged water in the open loop is 43°C. Then, the temperature drop in the closed loop system is equal to the temperature drop in the open loop and consequently the flow rates at both sides are equal, according to the following energy equation:

$$Q = c_p m_{open} \Delta T_{open} = c_p m_{closed} \Delta T_{closed} \tag{15}$$

where

ΔT_{open} = 59-43 = 16°C
ΔT_{closed} = 56-40 = 16°C
c_p = Specific heat of water
m = Flow rate
Q = Heat demand

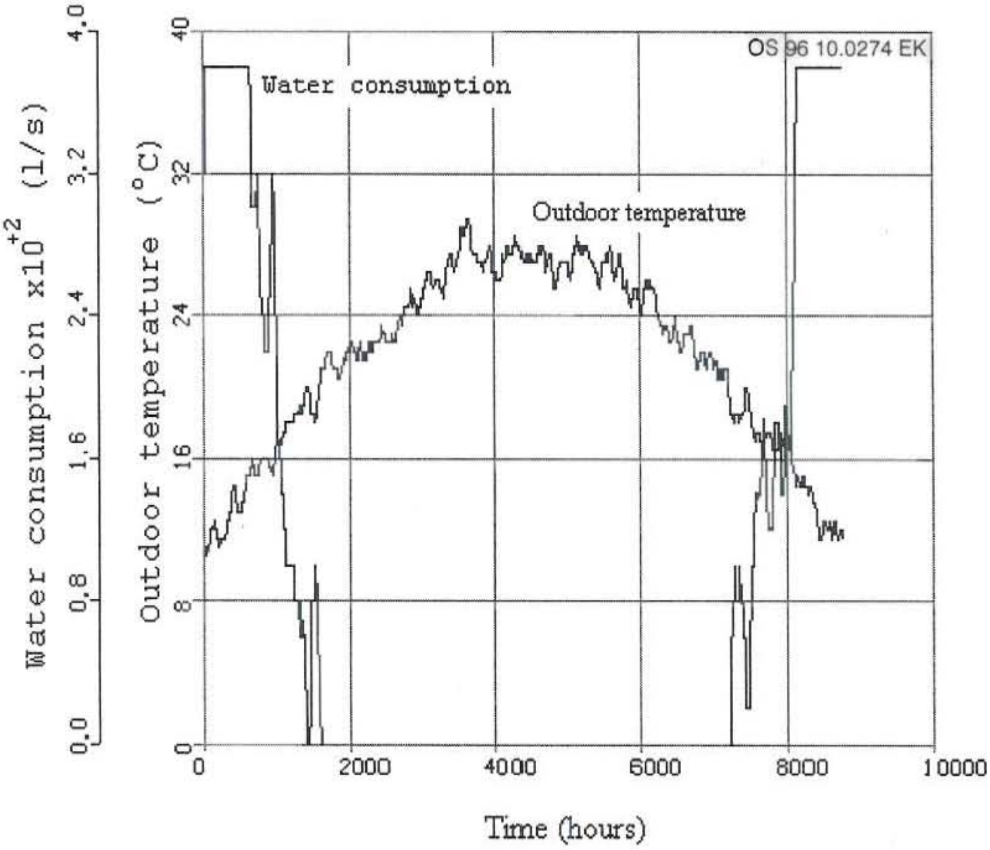

FIGURE 21: The outdoor temperature during the year and the consumption of hot water

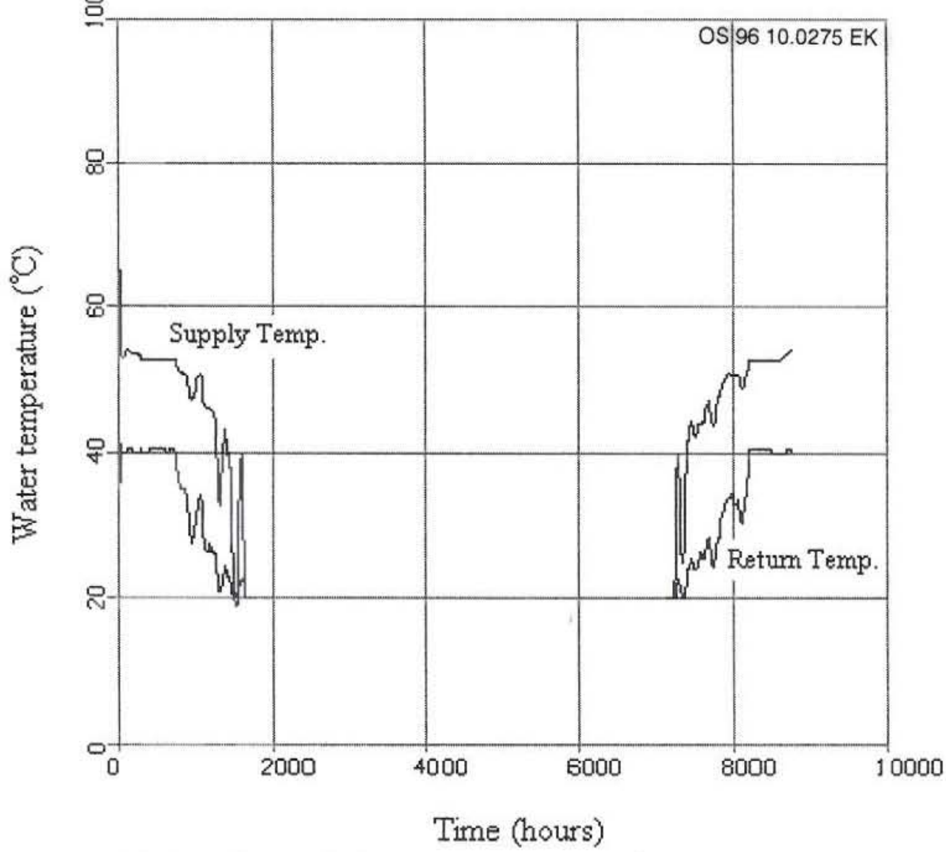

FIGURE 22: Radiator supply and return water temperature

As mentioned, all the heat demands can be covered by the geothermal water without the use of a peak load station. If 1000 houses are going to be heated by means of geothermal energy, the amount of water needed during the maximum heat demand season is 38 l/s (or 3,283 m^3/day) while the capacity of the hot spring Lefkada has been estimated at 10,000 m^3/day (Table 1).

5. CONCLUSIONS

- A real swimming pool construction is more complicated than the model that is described in this report. It takes into account more economic factors and comprises more auxiliary equipment and spaces. It was not the objective of this report to present a full design study of a swimming pool but to give a good idea of the operation of the pool itself. From the calculations presented it is shown that the swimming pool needs about 8 kg/s (or 691 m^3/day) of hot saline water (59°C). This amount of water is only a small fraction of the flow rate values presented in Table 1 for some of the existing hot springs.

- If we assume that 1,000 houses are going to be heated by means of geothermal energy, the amount of water needed during the maximum heat demand season is 38 l/s (or 3283 m^3/day). Comparing this value with the capacity of the springs (Table 1), we could infer that the hot spring Lefkada is able to cover a big part of the town´s heat demands. The feasibility of a district heating system does not depend only on the sufficiency of the energy resource but also on economic factors like oil price, investment cost, maintenance cost, etc.

- It seems that the energy potential of the hot springs in Ikaria is high enough for many kinds of low-enthalpy geothermal utilizations. On the other hand, in order to implement any kind of geothermal utilization, commercial and market potential data have to be collected and a feasibility study on investment options must be carried out.

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