Report 13, 1993

ECONOMICAL AND TECHNICAL ASSESSMENT OF SOME GEOTHERMAL DEVELOPMENT SCENARIOS FOR ORADEA, ROMANIA

Marcel Roşca,
UNU Geothermal Training Programme,
ORKUSTOFNUN - National Energy Authority,
Grensasvegur 9,
108 Reykjavik,
ICELAND

Permanent address:
University of Oradea,
Energetics Department,
Str. Armatei Române 5,
3700 Oradea,
ROMANIA

ABSTRACT

This report constitutes the final phase in the author's training at the United Nations University Geothermal Training Programme in Reykjavik, Iceland. The main purpose of the report is to study the technical and economical viability of selected geothermal development scenarios in the Oradea area. It contains a brief description of the geothermal resources and their current utilization in Romania and a detailed description of the current utilization of geothermal energy in the Oradea area.

Technical and economical pre-feasibility studies for a heat pump assisted geothermal heating system for an average hotel in Felix Spa resort and four different geothermal district heating systems for Oradea City constitute the main part of the report. Problems regarding the geothermal reservoir management, chemistry of the geothermal fluids and environmental pollution are also presented here.

The findings of this study show conclusively that further development of geothermal energy utilization in the Oradea area is not only economic, but also has considerable environmental benefits. The CO_2 emission is only 0.15 to 0.3% of the amount of flue gas emission from a coal fired co-generation power plant for the same thermal energy production. The flue gases also contain up to 700 t/year SO_2 and 760 t/year NO_x, whilst the geothermal fluid contains none of these polluting gases.

Some recommendations on the main problems which require a more detailed study are presented at the end of the report.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The exploration for geothermal resources in Romania began in 1962. The drilling of over 200 wells was funded by the government as part of the National Geological Research Programme. All the reservoirs were assessed and their energy potential was estimated. Assuming a reference temperature of 30°C the total power capacity was evaluated to be about 350 MW_t, of which only 130 MW_t is being utilized at present. Figure 1 shows a broad classification of geothermal energy utilization in Romania. Space heating includes heating of houses, schools and commercial space. In agriculture the geothermal water is used for heating greenhouses and stock breeding farms and for fish farming. Industrial uses are wood and grain drying, milk pasteurisation, flax and hemp processing. Recreational and mostly therapeutical bathing in 24 open pools and 7 indoor pools is also very important, the 16 health spas treating over 550,000 people every year.

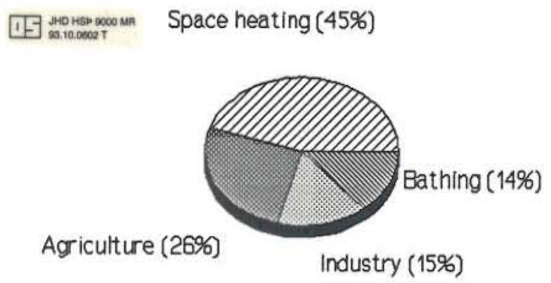

FIGURE 1: Geothermal energy utilization in Romania

Available geological data show that it is possible to locate new reservoirs, however, no new wells have been drilled in the last years. After the oil crisis passed, geothermal research was no longer considered a priority. Full exploitation of the available potential is first to be attained. The existing installations are mainly experimental and the results have been relatively good. Such problems as scaling, corrosion, material and equipment selection are now fairly well understood and solved. Before 1990, information about geothermal utilization experience in other countries was almost inaccessible. As stated by Stefansson (1984 and 1988), specialists are needed in specific fields of knowledge such as geothermal fluid chemistry, reservoir engineering, deep well pumps and geothermal energy utilization. In the last two years this situation has started to improve and the future looks better.

The largest known geothermal area in Romania is situated in the western region of the country and is a part of the Pannonian Basin system. In all, some 28 aquifers have been identified within an area of 2500 km^2. These are confined aquifers with very small if any natural recharge, located in slightly consolidated Pliocene sandstones at depths between 800 and 2100 m. The reservoirs are relatively small and the drawdown depends on the extracted volume. Diagrams presenting drawdown versus cumulative production during 12 to 14 years of exploitation show that on average the fluid extraction of $3\text{-}5 \times 10^5$ m^3 from these reservoirs causes a pressure drawdown of 1 bar. The geothermal fluids contain 4 - 5,000 ppm total dissolved solids (sodium-bicarbonate-chloride type) and up to 2,000 ppm non-condensible gases (mainly methane and small quantities of carbon dioxide). The well head temperatures are between 60 and 100°C. Free flowing the existing wells have a power capacity of 184 MW_t, which can be increased at least threefold through pumping. The current installed power is only 60 MW_t, so further development is not only possible but also probable when investment capital becomes available.

The city of Oradea is situated in the western part of Romania, in the Pannonian Basin geothermal system. The reservoirs identified in the area are very different from the others located in the Pannonian Basin. As the objective of this report is to evaluate the possibilities for further development of geothermal energy utilization in the Oradea area, these reservoirs and their current utilization will be described in more detail in the following chapter.

The data on geothermal resources used in this report are provided mostly by Foradex S.A., which is the company responsible for all prospect drilling in Romania. Detailed up-to-date information on this subject is reported by Cohut (1992).

2. THE ORADEA GEOTHERMAL AREA

2.1 General description

Three geothermal reservoirs have been identified within the city of Oradea and the surrounding area, known as the Oradea geothermal area. The reservoirs are usually named after towns or villages located in or close to the respective geothermal fields. The main reservoir is situated almost entirely within the Oradea city limits. It is hydrodynamically connected with a second reservoir in the Felix Spa Resort, about 10 km southeast from Oradea. The third one is near the village Bors, 6 km northwest from Oradea.

The Bors reservoir is relatively small, with a surface area of 12 km^2. It is a confined aquifer, where every 300,000 m^3 fluid extraction causes 1 bar drawdown. The water has a mineralization of 14,000 ppm total dissolved solids (TDS), mostly sodium chloride. The dissolved non-condensible gases (NCG) are about 2,000 ppm, comprising 70% CO_2 and 30% CH_4. The reservoir temperature is higher than 130°C at the average depth of 2500 m and the wellhead temperature is 118°C. Bors and Oradea reservoirs are both located in fractured Triassic limestones and dolomites at a depth of 2200 to 3200 m. However, the Oradea extraction history shows that it is an open reservoir. In the last 15 years about 50 l/s have been withdrawn on continuous basis without measurable drawdown encountered. Drawdown became significant only when the production rate was increased to 150 l/s. The chemical composition of the fluid is very different from the one in Bors. The concentration of total dissolved solids is 1,000 ppm, mostly calcium-sulphate-bicarbonate. There are small quantities of dissolved non-condensible gases (up to 200 ppm) such as CH_4, CO_2 and He. With the available technology it is not possible to recover the helium, due to its high diffusivity. Comparative data from these two reservoirs is summarized in Table 1 and the actual chemical composition for the area is shown in Table 2.

TABLE 1: Bors and Oradea reservoirs, comparative data

Reservoir	Type	TDS [ppm]	Na [ppm]	Cl [ppm]	Ca [ppm]	SO_4 [ppm]	NCG [ppm]	Temperature [°C]
Bors	closed	14,000	4,500	6,500	185	135	2,000	115
Oradea	open	1,200	20	70	230	570	200	70-105

The reservoir temperature and pressure distribution indicate a hot water upflow between Oradea and Bors. The temperature in the Oradea reservoir decreases from northwest towards southeast in the Oradea aquifer and continues to decrease into the Felix reservoir, with which it is connected. In the Felix Spa Resort there are natural hot springs with temperatures between 35 and 50°C. The chemical composition of the geothermal fluid in the Felix reservoir is the same as in Oradea. By the C14 method the water was found to be about 20,000 years old. The natural recharge for these two aquifers originates in the Apuseni Mountains about 80 km to the east of Oradea.

2.2 Present utilization and possible further development

In the Bors reservoir 5 wells have at present been drilled. Two wells are used for reinjection in order to sustain the reservoir pressure and artesian flow of the wells. During the summer additional cold ground water is injected to compensate for exploitation losses. The other three are used as production wells, two to provide base load and the third for peak load for the heating of 6 ha of greenhouses. The wellhead pressures are 12 and 14 bar respectively for the two base

TABLE 2: Chemical composition of geothermal waters from the Oradea area

	Reservoir	
	Oradea	Bors
Ph	6.0	7.8
Component	ppm	ppm
SiO_2	29.3	17.5
Na	20.0	4,532.1
K	5.0	86.5
Ca	230.7	184.4
Mg	42.4	77.8
CO_2	157.1	1,223.4
SO_4	572.8	134.4
H_2S	0.0	0.0
Cl	70.9	6,560.1
F	0.0	5.3
Al	0.0	0.0
B	0.0	29.3
Fe	36.0	6.0
NH_3	0.9	10.0
Br	0.0	9.0
I	0.0	5.0

load producers (decreasing slightly during the heating season) and each yields 15 l/s at an operating pressure of 7 bar. The maximum flow rate from all producers is 50 l/s in artesian flow under the same operating conditions. The geothermal fluid is partially degassed, passed through heat exchangers and then reinjected. The injection pressure does not exceed 6 bar. In the beginning of exploitation scaling problems were encountered. Scaling is effectively prevented by a combination of thermodynamic and chemical inhibition. The pressure is maintained above the CO_2 saturation pressure in order to prevent too great a decrease in pH and the Romanian antiscaling product Ponilit is additionally injected into the well. It has been found that the most economical way to do this is to keep the pressure at 7 bar whilst the chemical inhibitor is injected into the well at a depth of 450 m by a dosing pump at a rate of 5 g/m^3. The separated gases are currently released into the atmosphere. The environmental pollution is insignificant especially when compared to the flue gases from the coal fuelled co-generation power plant in the vicinity.

It is possible to heat more greenhouses in this area using the geothermal water available in artesian flow from the wells already drilled. If the temperature of the return water is kept as low as possible by temperature-controlled valves and the total flow from the three production wells is used to provide base load, the greenhouse area using geothermal energy could be doubled. It is also possible to increase the flow from the existing wells by using downhole pumps. The production casings are 9⅝" and after acid stimulation the permeability is quite good so that with 8" deep well pumps the flow rate could be significantly increased. Submersible pumps made in Romania have been tested during the last 7 years and have proved fairly reliable. The results of these tests and the experience from reservoirs located in similar rock formations in other countries have been used to estimate the possible increase in flow rate from the existing wells in the Bors reservoir. Cohut (1992) shows that the production can be doubled without causing a significant temperature decrease in the reservoir for at least 15 years.

Of the 12 boreholes that have been drilled into the Oradea reservoir, 11 are used as production wells and 1 for reinjection. Data for all these wells and the current utilization is presented in Table 3.

TABLE 3: Geothermal energy utilization in Oradea, Romania

Well no.	Drilling year	Wellhead pressure [bar]	Wellhead temp. [°C]	Flow rate [l/s]	Utilization
4004	1963	0.6	82	12	- space heating (ca. 90 equ. dwellings*)
4005	1963	0.4	90	10	- greenhouse heating (1.5 ha) (with peak load boiler)
4006	1964	0.3	80	10	- indoor and outdoor swimming pools - indoor swimming pool heating
4081	1973	-	-	-	- reinjection well
4767	1975	2.1	104	26	- industrial space heating (two factories) - hot tap water (ca. 1,000 equ. dwellings) - milk pasteurisation (80,000 l/day) - industrial hot water
507	1979	0.3	90	10	- house heating and hot tap water (Livada village) - intensive fish farming
4796	1981	1.2	84	25	- pilot binary power plant (500 kW) - space heating and hot tap water (University of Oradea)
4797	1981	0.5	72	20	- hot tap water (ca. 4,700 equ. dwellings)
4795	1982	0.2	83	4	- space heating (Agricultural Research Centre) - grain drying
1716	1982	0.4	83	5	- space heating and hot tap water (Oradea airport)
1717	1982	1.1	98	10	- space heating and hot tap water (ca. 400 equ. dwellings)
1715	1983	0.6	70	18	- industrial space heating (two factories) - wood drying (8,000 m^3/year)

* An equivalent dwelling is defined as a 2 room apartment for 2 persons with an annual thermal energy demand of 34,543 MJ for space heating (172 days) and 14,815 MJ for hot tap water (365 days).

Total available flow rate - 150 l/s, average temperature - 85.4°C, total installed capacity - 34.8 MW_t (assuming a reference temperature of 30°C).

The total installed capacity is at present 35 MW_t corresponding to a flow rate of 150 l/s of geothermal water at a mean temperature of 85°C. All the production wells are currently discharged in artesian flow. The well design and the rock formation in both Oradea and Bors reservoirs are similar. Thus the possibility to double the yield of the wells in the Oradea reservoir by pumping is considered a realistic estimation. The possibilities for the utilization of this thermal energy will be studied further in this report. Increasing the production rate to 300 l/s means that all the extracted water has to be reinjected, not only to provide a pollution free disposal method but also to sustain the reservoir pressure. Too great a pressure decline both in the Oradea and Felix reservoirs will eventually cause the natural hot springs there to become dry.

At the Felix Spa resort the geothermal water is used for recreational and health bathing, its therapeutic properties being known for a long time. Many native and foreign tourists spend their holidays at the Spa. Almost all the hotels have treatment facilities and highly qualified medical staff providing a wide range of medical treatment. Another tourist attraction is the flower *Nymphaea Lotus Thermalis,* which grows naturally in geothermal ponds. This is quite an uncommon occurrence at this latitude (~45°N). It is a well known fact that the geothermal health bathing combined with international tourism industry is a very lucrative business. This has also proved to be the case at Felix Spa Resort. Further development of the geothermal field for this purpose is possible, should the tourism market demand increases in the future. The market economy is becoming better and established in Romania and it is therefore expected that the hotels will be taken over by private companies within a relatively short time. This should, amongst other things, result in higher quality services and an increase in demand. It is also to be expected that some of these companies will consider the possibility of using the geothermal energy for space and water heating. A pre-feasibility study of a geothermal heating system for a hotel in Felix Spa is therefore presented in the next chapter.

3. HEATING SYSTEM FOR A HOTEL IN FELIX SPA

3.1 Technical calculations

At present all the hotels in the Felix Spa Resort are connected to a central heating system. The thermal energy is supplied by a co-generation power plant situated just outside the Oradea city limits, 6 km from the Felix Spa Resort. The thermal fluid is hot water pumped through a surface steel pipeline insulated with rock wool and aluminium sheet. This hot water provides all the thermal energy required for space heating and for hot tap water. Until 5 years ago, when the power plant was set on line, every hotel had its own heating system, usually powered by a heavy fuel fired boiler. The boilers are still in place, as redundancies to cover the heat demand in case of a failure of the current system. The rooms and all the other facilities are heated using cast iron radiators. A separate network provides the hot tap water.

In the near future, probably by the end of next year, the hotels will be owned by private companies. It is to be expected that these companies will consider the possibility of utilizing geothermal energy for space and tap water heating. In this chapter a pre-feasibility study is presented for a geothermal heating system for a typical average hotel in the Felix Spa Resort, as defined below. The study generally follows the guidelines developed for the Commission of the European Communities by Harrison et al. (1990) and Piatti et al. (1992). For a pre-feasibility study the system is simplified as much as possible to enable relatively fast calculations without an access to highly specialized information. This type of a study yields a rough evaluation of the technical and economical viability of a system for a given set of conditions. The reliability of the results may be improved by spending more money on a complete design project and a detailed economical viability study.

It seems reasonable to assume that, at least for the first years, the capital available for investment will be very limited. This could be different if a hotel were to be owned and operated by a foreign company. Anyhow, a geothermal heating system will be selected, which minimizes changes to the current system. Making use of the existing installation will reduce the capital investment. Any modifications due to the new system could also be carried out during the summer season, when no space heating is required, to eliminate the need of closing the hotel and cutting off its income.

The usual room heaters in Romania are standard cast iron radiators. The number of elements for each room is determined as a function of the room volume or, for buildings of standard ceiling hight, as a function of the floor area of the room. The standard indoor design temperature is 18°C. The incidental heat gains from external sources, such as solar radiation and human activities (cooking, washing, body heat), increase the indoor temperature usually to about 20°C. The thermal power demand for a constant indoor temperature is then a function of the outdoor air temperature and the wind velocity. The design outdoor air temperature for the Oradea area is -7°C. Slightly lower temperatures are occasionally encountered but, as Karlsson (1984) has demonstrated, it is neither economic nor necessary to design the heating system for the minimum measured outdoor temperature because the heat stored in walls, floor, ceiling, furniture etc. tends to level off the indoor temperature variation for short periods of time (up to three days). The temperature demand intensity (T_d) is defined as the difference between the indoor and outdoor temperatures that has to be replenished by the thermal energy supplied by the heating system. For the conditions stated above, the maximum temperature demand intensity is therefore 25°C. In Romania the thermal power supply is regulated by modifying the inflow temperature of the heating fluid into the radiators while keeping the mass flow rate constant. The thermal power transferred from the radiator to the air inside the room has to be equal to the thermal power transferred from the indoor to the outdoor air. For the temperature range the radiators are working in, both the inflow and outflow water temperatures can be approximated as linear functions of the temperature demand intensity. The temperature characteristics of the radiators for this type of regulation are shown in Figure 2.

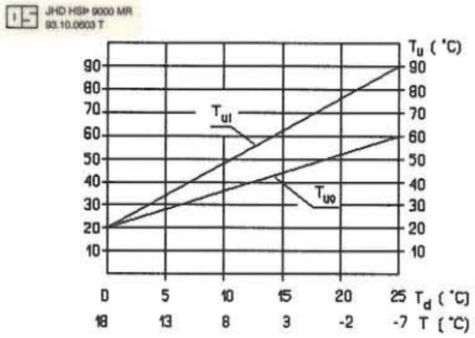

FIGURE 2: Temperature characteristics of linearly regulated radiators

The notations used in Figure 2 are:

T - outdoor air temperature,
T_d - temperature demand intensity,
T_{ui} - radiator water inlet temperature,
T_{uo} - radiator water outlet temperature.

For the maximum temperature demand intensity ($T_{d\,max}$ = 25°C), corresponding to the minimum outdoor air temperature (T_{min} = -7°C), the maximum inlet and outlet temperatures of the radiator water are respectively $T_{ui\,max}$ = 90°C and $T_{uo\,max}$ = 60°C. When the outside air temperature reaches 18°C no energy for heating is needed so, the temperature demand intensity equals 0°C. The room air temperature is in this case about 20°C, due to the incidental heat gains shown above, and so the inlet and outlet radiator water temperatures can be considered to be equal to 20°C. Two straight lines between the points defined above approximate the inlet and outlet temperatures of the radiator water for the entire range of temperature demand intensity, as shown in Figure 2. The slopes of these straight lines can be calculated with Equations 1 and 2 respectively:

$$S_{ui} = \frac{(T_{ui\,max} - T_o)}{T_{d\,max}} \qquad (1)$$

and:

$$S_{uo} = \frac{(T_{uo\,max} - T_o)}{T_{d\,max}} \qquad (2)$$

where

T_o = 20°C and minimum radiator water temperature for T_d = 0°C

The calculated values are: S_{ui} = 2.8 and S_{uo} = 1.6

To calculate the annual heat requirements of a single user or group of users, and the power input from different sources for every temperature demand intensity, it is necessary to know the variation of the total heat rate (or thermal power) demand over the year. The usual method is to determine the variation of the temperature demand intensity with time during one year, using recorded meteorological data. The average number of days where certain values of temperature demand intensity occur is calculated. The decreasing values of temperature demand intensity (usually at a step of 1°C) are plotted on a histogram versus cumulated number of days. As the room temperature demand is constant, the histogram is converted into a curve showing the duration of the temperature demand intensity. Figure 3 shows this curve for the Oradea area. Usually the central heating systems in Romania are turned off when the daily mean temperature of the outside air is above 10°C for three days in a row. Following this procedure, the average heating season for Oradea is 172 days and the minimum temperature demand intensity 5°C.

A parameter useful in evaluating the heat requirement for a certain region is the parameter called number of degree-days. It is defined as the number of days of the heating season for which the temperature demand intensity is above a given value multiplied by the corresponding temperature demand intensity (Karlsson, 1984). The number of degree-days can be calculated from the temperature demand intensity duration curve presented in Figure 3 with the following equation:

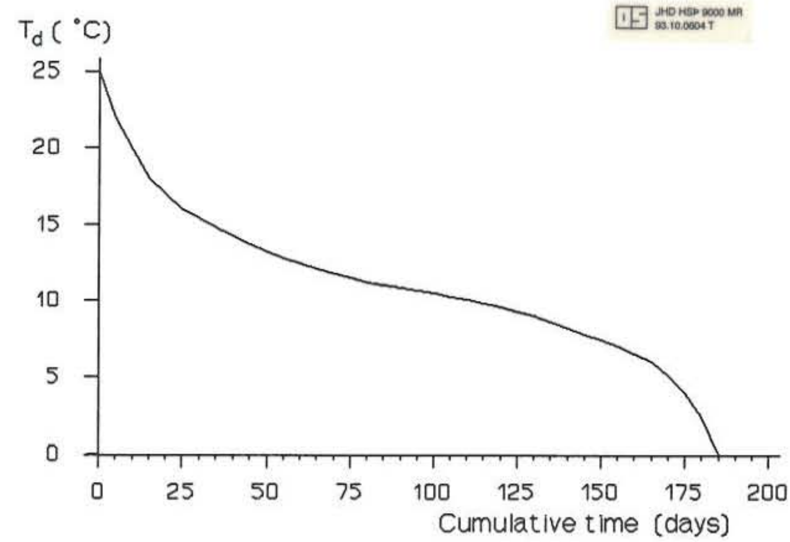

FIGURE 3: Temperature demand intensity duration curve for the Oradea area

$$DD = \int T_d \cdot d\tau \tag{3}$$

where DD - number of degree-days (°C days)
T_d - temperature demand intensity (°C)
τ - time (days)

For the conditions stated above, the number of degree-days for the Oradea area was calculated as being 2,030.

A hotel with 200 rooms is considered an average sized one for the Felix Spa Resort. A standard room is defined as a double-room with a bathroom, having a total volume of 70 m^3. The additional volume required for all ancillary facilities (such as kitchen, dining room, halls, corridors etc.) is 25% of the total room volume and can be considered as an equivalent number of standard rooms. The thermal power required for space heating is then:

$$P_u = N \cdot V \cdot G \cdot T_d = (N_R + N_A) \cdot V \cdot G \cdot T_d \tag{4}$$

where: G - volumetric heat loss coefficient (typical value assumed) = 1 W/°Cm^3
N - total number of standard rooms (including facilities)
N_R - number of rooms (without facilities)
N_A - equivalent number of standard rooms corresponding to facilities

The maximum thermal power demand for heating an average hotel, as it was defined above is $P_{u\,max}$ = 437.5 kW

The parameters N, V and G are building constants and so the temperature demand intensity duration curve (Figure 3) is equivalent to the thermal power demand duration curve (Figure 5 - later), the scale factor being; $N \cdot V \cdot G$ = 17.5 kW/°C.

The maximum number of guests that can be accommodated in this average hotel is approximately twice the number of rooms, which means 400 people (corresponding to 200 double-rooms). The average daily consumption of domestic hot water per capita is considered to be 100 l. In a hotel the total demand is typically 50% higher, including the water for cooking, washing, laundry etc. (excluding geothermal water for health bathing). The fresh water temperature and the standard temperature of domestic water in Romania are, respectively:

T_{cw} - temperature of fresh water (cold) = 15°C
T_{hw} - standard temperature of domestic hot water = 65°C

The heat capacity of the mass flow rate is defined as the product of the mass flow rate and its specific heat (assumed as constant):

$$M = f \cdot \gamma \tag{5}$$

where M - heat capacity of the mass flow rate [W/°C]
f - mass flow rate [kg/s]
γ - heat capacity (mean value assumed as constant) [J/kg°C]

The thermal power required for heating the tap water is therefore:

$$P_w = M_w \cdot (T_{hw} - T_{cw}) \tag{6}$$

where M_w - heat capacity of the tap water mass flow rate = 2.9 kW/°C

The heat capacity of the mass flow rate in the network for space heating is calculated as:

$$M_n = \frac{P_{u\,max}}{T_{ui\,max} - T_{uo\,max}} \tag{7}$$

and the calculated value is: M_n = 14.6 kW/°C

On the thermal power demand duration diagram presented in Figure 5, the thermal power required for heating the tap water (P_w) can be added at the bottom of the graph as a stripe of a constant width for the whole year (365 days), at the same scale factor (17.5 kW/°C). The total heat demand is thus proportional to the area below the thermal power demand duration curve. The purpose of the technical calculations is to depict which part of the total energy demand is supplied by the various energy sources available, such as geothermal energy, electricity and fossil fuel combustion. This will help provide necessary data for the economical assessment of the heating system.

The temperature of the geothermal water in the Felix reservoir ranges between 35 and 55°C. For the purpose of this study it is assumed that geothermal water at a temperature of 50°C is available at the total required flow rate. This is believed to be a reasonable assumption considering that the reservoir is located right below the Resort, so that any temperature drop in the main pipeline is insignificant. The most current reservoir simulation also predicts that an increase in the production rate is possible without significant adverse effects on the reservoir temperature and pressure, provided all the extracted water is reinjected. A better reservoir simulation model needs to be developed for a more accurate evaluation of the capacity of both the Oradea and Felix reservoirs. This problem will, however, not be addressed further in this report.

The following geothermal heating system was selected after considering available information and the experience gained in this field in other countries (such as Iceland, France, U.S.A.). For the available well head temperature of the geothermal water and the maximum inlet and outlet heating water temperatures, systems employing heat pumps were found to be more economical. The basic arrangement of the proposed geothermal heating system for the hotel is presented in Figure 4.

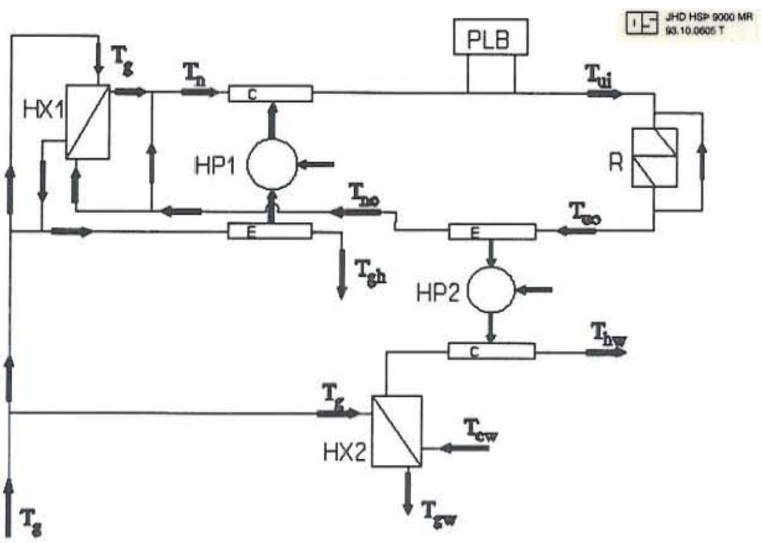

FIGURE 4: Hotel heating system layout

The system is basically heat pump assisted with direct evaporator type. At low partial loads, as long as the radiator water inlet temperature is below 45°C, the heat demand is supplied through direct heat exchange from the geothermal water by the primary heat exchanger (HX1). The condenser of the heat pump (HP1) is by-passed in this case. As the required radiator water inlet temperature increases above 45°C, the primary heat exchanger can no longer supply the total heat demand and HP1 is turned on. The radiator water outlet temperature is increasing at the same time, causing an increase in the geothermal water outlet temperature from the primary heat exchanger. The latter is therefore passed through the evaporator of the HP1 in order to lower the temperature of the waste geothermal water as much as possible. When the network return temperature (T_{no}) reaches 40°C the direct heat exchange through HX1 is no longer efficient and it is consequently by-passed. The evaporator of the HP1 is then fed with geothermal water at well head temperature (T_g). During the periods of time when the heat pump is working at partial load, it is not desirable to regulate its speed continuously in order to ensure the required inlet temperature for the radiator water. It is considered more energy efficient to have the possibility to mix a part of the outlet radiator water with the inlet radiator water. In this way the inlet temperature can be regulated continuously by controlling the mass flow rates of the two streams, while running the heat pump at a certain constant speed. When the required inlet temperature of the radiator water increases above the maximum outlet temperature from the condenser of the HP1, the heat supply is supplemented by the peak load boiler (PLB).

The fresh water is first heated by direct heat exchange up to the intermediate temperature T_{iw} in the heat exchanger HX2. Subsequently it is heated up to the standard temperature T_{hw} = 65°C in the condenser of the second heat pump (HP2). This arrangement ensures a decrease of the radiator water outlet temperature, improving the heat exchange in the HX1. During the time the space heating system is turned off (off heating season), geothermal water at the well head temperature T_g can be fed to the evaporator of the HP2.

In this study it will be assumed that temperature drop along pipelines is insignificant. For a real system temperatures are decreasing along the pipelines due to the heat loss by conduction, convection and radiation from the inner fluid to the ambient air. Since the whole installation is inside the building it is reasonable to assume that this temperature drop is insignificant, as any heat loss along pipelines will contribute to the heating of the building. The results will, however, not be accurate, but still sufficiently representative for the purpose of a pre-feasibility study although the calculations are very much simplified.

The hot tap water consumption is clearly not constant over the period of a day. It can vary by as much as 50% from the mean value. The system has to provide for the total demand at any time, but it is not economical to design the circulation pumps and the heat pump for the maximum load and to run them at variable speed. It is better to have a storage tank with a volume large enough to compensate for the daily variation in demand. Virtually every hotel already has these tanks in the current system, so this aspect will not be discussed further.

At present, room radiators in Romania are equipped with manual flow regulating valves, but they are not reliable, being very prone to sticking and leaking. So it is usual to keep them completely open all the time. When staying in a hotel, people are less inclined to save energy, because they have no incentive. Regulating valves are, however, an important feature in energy saving and as regards personal comfort. The question of changing the regulating valves in the hotel should thus be considered by the owning company. This also means that storage tanks will be needed to cover the daily demand variation. Most of the hotels are already equipped with storage tanks that could be used for this purpose and for a pre-feasibility study it is acceptable to avoid this complication. It is therefore not taken into account in the technical calculations.

The physical properties of water (such as heat capacity, thermal conductivity, viscosity, density or specific volume) vary with pressure, temperature and chemical composition. For the purpose of this study, constant mean values for the total temperature range have been assumed for these properties. The same applies to all types of water, including the geothermal water. The inaccuracy incurred will be negligible due to its low salinity, and the results will still be reliable.

Mainly shell and tube heat exchangers are currently used in heating systems in Romania. For the geothermal heating system considered in this study, new heat exchangers will have to be installed, because the existing ones are designed for higher water temperatures from the co-generation power plant. Stainless steel plate heat exchangers are recommended, considering their advantages, which are

- higher heat transfer efficiency,
- large heat transfer surface area for a relatively small volume,
- not very much higher pressure loss,
- resistance to corrosion,
- easy to clean off scaling,
- not much higher price for the same thermal power,
- produced in Romania.

It will be further assumed that both heat exchangers, HX1 and HX2 in Figure 4, are of this type and used in counter flow. The equations for this type of heat exchangers are identical to those used for common counter flow shell and tube heat exchangers. With these initial assumptions the equations required to calculate the energy consumption from every source are relatively simple, as presented below. The heat transfer rate, or thermal power, (P_{HX}) of a heat exchanger is:

$$P_{HX} = M_h \cdot (T_{hi} - T_{ho}) = M_c \cdot (T_{co} - T_{ci}) = A \cdot U \cdot LMTD = E_x \cdot M_s \cdot (T_{hi} - T_{ci}) \tag{8}$$

where M_h - heat capacity of the hot fluid flow rate [W/°C]
M_c - heat capacity of the cold fluid flow rate [W/°C]
T_{hi} - inlet temperature of the hot fluid [°C]
T_{ho} - outlet temperature of the hot fluid [°C]
T_{ci} - inlet temperature of the cold fluid [°C]
T_{co} - outlet temperature of the cold fluid [°C]
LMTD- logarithmic mean temperature difference between the two fluids [°C]
U - overall heat transfer coefficient [W/°C m^2]
A - area of the heat exchange surface [m^2]
E_x - heat exchanger effectiveness

The logarithmic mean temperature difference (*LMTD*) between the hot and cold fluids across the total heat transfer surface of a counter flow heat exchanger is defined as:

$$LMTD = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln \frac{T_{hi} - T_{co}}{T_{ho} - T_{ci}}} \tag{9}$$

For the counter flow plate heat exchanger the effectiveness is given by:

$$E_x = \frac{1 - e^{-N\cdot(1-R)}}{1 - R \cdot e^{-N\cdot(1-R)}} \tag{10}$$

where R - the ratio of the smaller to the larger heat capacity of the flow rates
N - the number of heat transfer units, given by:

$$N = \frac{U \cdot A}{M_s} \tag{11}$$

The power balance for a vapour compression heat pump can be written as:

$$P_h = P_c + P_m \tag{12}$$

where P_h - thermal power supplied to the heated fluid in the condenser [W]
P_c - thermal power extracted from the cooled fluid in the evaporator [W]
P_m - mechanical power supplied by the compressor [W],

with the thermal powers given by the equation:

$$P_{h(c)} = M_{h(c)} \cdot (T_{ho(ci)} - T_{hi(co)}) \tag{13}$$

where the subscripts denote the following:

h - the fluid heated in the condenser i - inflow
c - the fluid cooled in the evaporator o - outflow

Two coefficients of performance are defined for heat pumps, the coefficient of cooling performance:

$$C_c = \frac{P_c}{P_m} = \frac{P_c}{P_h - P_c} \tag{14}$$

and the coefficient of heating performance:

$$C_h = \frac{P_h}{P_m} = \frac{P_h}{P_h - P_c} = C_c + 1 \tag{15}$$

For an ideal heat pump, working on the ideal Carnot cycle, the coefficient of the cooling performance is given by:

$$C_c = \frac{T_c + 273.15}{T_h - T_c} \tag{16}$$

where T_h - condensation temperature of the working fluid [°C]
T_c - evaporation temperature of the working fluid [°C]

For a real heat pump, in order to make the heat transfer possible over the entire area of the condenser, the condensation temperature of the working fluid has to be higher than the outlet temperature of heated fluid. For the same reason, the evaporation temperature of the working fluid has to be lower than the outlet temperature of the cooled fluid. Usually the temperature difference is 4°C for both the condenser and the evaporator. Also the coefficient of performance of a real heat pump is reduced roughly by half due to the irreversibility of the thermodynamical processes and the mechanical and hydrodynamical losses. An empirical equation for the coefficient of cooling performance of a real heat pump is (Harrison et al., 1990):

$$C_c = \frac{0.5 \cdot (T_{co} - 4 + 273.15)}{T_{ho} - T_{co} + 8} \tag{17}$$

The geothermal water is used for heating both the radiator water and the tap water. The average temperature of the waste geothermal water can be calculated from the energy balance equation:

$$T_{go} = \frac{M_{gn} \cdot T_{gn} + M_{gw} \cdot T_{gw}}{M_{gn} + M_{gw}} \tag{18}$$

where

M_{gn} - heat capacity of the mass flow rate of geothermal water for space heating [kw/°C]
M_{gw} - heat capacity of the mass flow rate of geothermal water for tap water [kw/°C]
T_{gn} - temperature of the waste geothermal water used for space heating [°C]
T_{gw} - temperature of the waste geothermal water used for tap water heating [°C]

Using the equations presented above and the diagrams shown in Figures 2 and 3, calculations were carried out for specific load values, mainly for the temperature demand intensity values at which the operation mode of the system is changed. The temperature demand intensity values for which the system was calculated and their significance for the operating of the system are:

$T_d = 0$°C The space heating system is turned off, only the tap water system is turned on at full capacity (193 days/year).

$T_d = 9$°C The thermal power is transferred to the space heating network water through direct heat exchange by HX1 only.

T_d = 12.5°C — The maximum value for which HX1 is still used and HP1 is operated at half speed.

T_d = 16°C — The HP1 is operated at full speed and the peak load boiler is not yet started (the HX1 is by-passed).

T_d = 20°C — The HP1 is operated at full speed and the peak load boiler is working roughly at half load (the HX1 is by-passed).

T_d = 25°C — Maximum load, the HP1 is operated at full speed and the peak load boiler is at full capacity (the HX1 is by-passed).

For tap water heating it is possible to select a production model heat pump, such as a VDP 3 type, with Refrigerant 12 (R12) as working fluid, produced by Stal Refrigeration AB, Sweden. For the space heating system no series model heat pump was selected, because the problem of the number and series or parallel connections was not considered here. This aspect is to be solved in a design project. Instead, the powers and the coefficients of performance were calculated for every partial load using the equation presented above. The results are presented in Table 4.

TABLE 4: Technical calculation results

Parameter and symbol		$P_u/P_{u\,max}$ (%)					
		0	**36**	**50**	**64**	**80**	**100**
Temperature demand intensity [°C]	(T_d)	0	9	12.5	16	20	25
Outdoor air temperature [°C]	(T)	18	9	7.5	2	-2	-7
Radiator inlet temperature [°C]	(T_{ui})	-	45	55	65	76	90
Radiator outlet temperature [°C]	(T_{uo})	-	35	40	46	52	60
Network outlet temperature [°C]	(T_{no})	-	32	37	43	49	57
Geothermal water outlet temp. [°C]	(T_{go})	20	34.2	32.1	20	20	20
Geothermal water flow rate [l/s]	(f_g)	1.1	4.2	4.2	2.6	2.1	1.4
Geothermal power [kW]	(P_g)	130	277	316.5	322	258	173
" " [%]	(P_g)	89	94.5	86.5	75.9	51.8	29.5
Mechanical power [kW]	(P_m)	16	16	49.5	102	79	47
" " [%]	(P_m)	11	5.5	13.5	24.1	15.9	8.1
Thermal power from boiler [kW]	(P_b)	0	0	0	0	161	365
" " " " [%]	(P_b)	0	0	0	0	32.3	62.4
Total thermal power [kW]	(P_t)	146	293	366	424	498	585

The thermal power demand duration curve plotted by using the calculated data is presented in Figure 5. The area below the curve is proportional to the annual heat demand (by the scale factors used to plot the graph). For the considered average hotel the total annual thermal energy demand is: E_t = 2,128.13 MWh, which comprises:

E_b - thermal energy from the peak load boiler = 86.64 MWh
E_g - thermal energy from geothermal water = 1,790.21 MWh
E_m - mechanical energy from the heat pump compressors = 251.28 MWh

The design powers of the two heat pumps, assuming a mechanical efficiency for the compressor of 90% and an electrical motor efficiency of 95%, are:

HP1: P_{h1} - heating power = 321 kW
P_{m1} - mechanical power = 86 kW
P_{e1} - electrical power = 101 kW

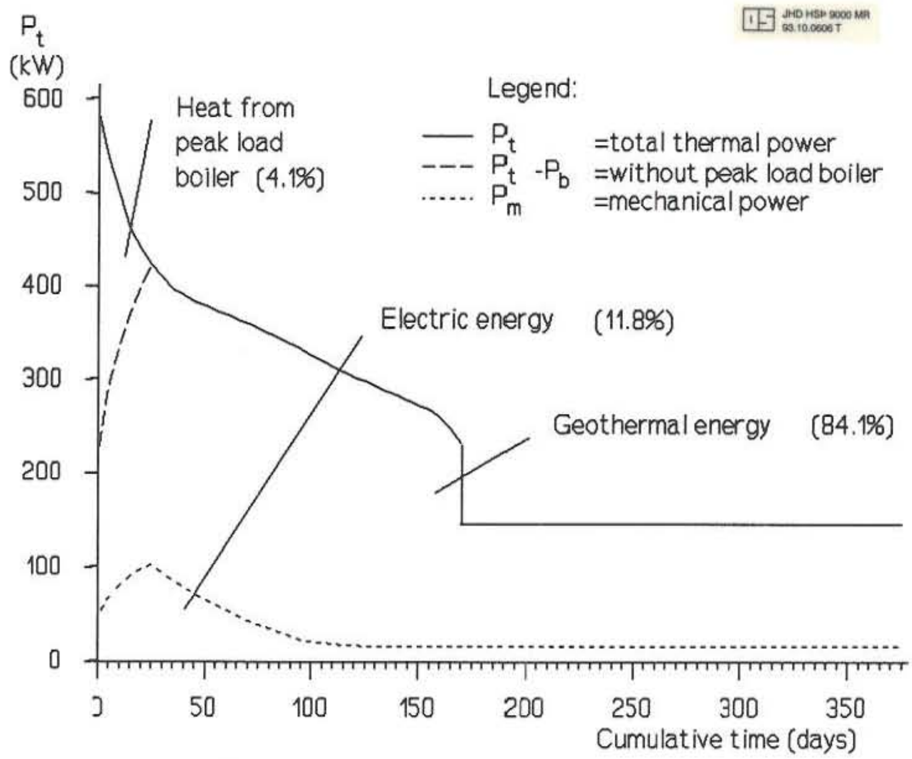

FIGURE 5: Power demand duration curve

HP2: P_{h2} - heating power = 59 kW
P_{m2} - mechanical power = 16 kW
P_{e2} - electrical power = 19 kW

The heat transfer areas of the two heat exchangers are:
A_{HX1} = 12.6 m^2
A_{HX2} = 6 m^2

Considering the peak load boiler as a common one, with an efficiency of 75%, fired by heavy fuel oil with a low calorific value of 11.8 kWh/kg, the annual fuel consumption is; F = 9,790 kg

3.2 Economical appraisal

The economical appraisal of the geothermal heating system for the average hotel in the Felix Spa resort was carried out basically following the methodologies presented by Harrison et al. (1990) and Piatti et al. (1992). The Romanian economy is now suffering a transition process, from being a centrally planned system towards a free market economy. In this situation prices are changing fast and at an uneven rate, due to a high inflation rate, changes in the subsidizing policy, changes in the taxation system and different types of governmental control on the exchange rate of the national currency, the Romanian Leu (ROL). The general tendency of prices is to approach international market values, energy prices being among the quickest to follow this trend. The project under study here is not expected to be implemented in the near future, at least not until the privatization has been concluded and investment capital becomes available either from own sources or from bank loans at acceptable interest rates (current annual interest rates for loans range from 90% to 100%, due to high inflation rates). By the time the possibility to implement a project of this type qualifies for consideration, the Romanian economy will probably be fairly stabilized and the problems outlined above less acute. For the above reasons, it was considered appropriate to carry out the economical appraisal of the project on the basis of economical conditions prevailing in the European Economic Community.

The capital investment comprises purchasing and installation costs for all equipment required for the new heating system, engineering cost and additional costs due to contingencies. The new equipment required for the geothermal heating system of the hotel under study are:

- C_{MN} - main piping network for the geothermal water supply, including supply and return pipelines, valves and meters (for flow, temperature and pressure)
- C_{HP} - heat pumps for tap and radiator water heating (regulating and control systems are usually included in commercial models)
- C_{SN} - heat centre network, including stainless steel plate heat exchangers, pipelines, valves and control system

All other necessary equipment, such as storage tanks, user supply and return pipelines complete with valves (for rooms and ancillaries), circulation pumps and the boiler, already exist at the hotel. The total capital investment cost (C_T) can thus be calculated as follows:

$$C_T = C_{MN} + C_{HP} + C_{SN} \tag{19}$$

with

$$C_{MN} = c_n \cdot P_t \cdot K_1 \tag{20}$$

where
- c_n - specific cost of a reference network = 150 ECU/kW
- P_t - design thermal power value for the system = 585 kW
- K_1 - non-dimensional correction coefficient depending on the difference between the design supply and return temperatures [ΔT]

$$K_1 = 1 + 0.2 \cdot \frac{30}{\Delta T} \tag{21}$$

The cost of the heat pumps and their prime movers (i.e. electric motors) and also the cost of the hotel heating station is estimated as follows:

$$C_i = C_{oi} \cdot \left(\frac{P_i}{P_{oi}} \right)^{n_i} \tag{22}$$

where
- C_{oh} - reference cost of a heat pump with the P_{oh} thermal power = 700 kECU
- C_{om} - reference cost of an electric motor with the P_{om} shaft power = 100 kECU
- C_{os} - reference cost of a heating station with the P_{ot} thermal power = 250 kECU
- P_{oh} - thermal power of the reference heat pump = 4 MW
- P_{om} - shaft power of the reference electric motor = 1 MW
- P_{os} - thermal power of the reference heating station = 10 MW
- P_h - total design thermal power of the heat pumps [MW]
- P_m - total design shaft power of the electric motors [MW]
- P_s - total design thermal power of the heating station [MW]
- n_h - scale factor for heat pumps = 0.8
- n_m - scale factor for electric motors = 0.7
- n_s - scale factor for the heating station = 0.65

The total engineering cost for a heating system with a design thermal power of less then 10 MW is estimated to be 8% of the investment cost. Additional costs due to contingencies are estimated as 5% of the total investment cost, including engineering.

The total capital investment is thus: C = 270 kECU

The annual running cost of the project comprises the cost of electricity, boiler fuel and geothermal water, maintenance cost (purchase and stocking of spare parts, wages of maintenance staff) and wages for the personnel required to operate the geothermal heating system. The total annual maintenance cost is estimated as 2% of the capital investment. The geothermal heating system for an average hotel is not a large one, so that a single worker is required to operate it. The annual wage of this worker is 25 kECU. The specific costs of the different forms of energy are:

- c_e - specific cost of electric energy = 0.050 ECU/kWh
- c_g - specific cost of geothermal energy = 0.020 ECU/kWh
- c_b - specific cost of thermal energy supplied by boiler = 0.020 ECU/kWh

The annual running cost of the project is: R = 82.6 kECU

The annual earnings of the project are considered to be the costs of continued running of the former heating system which is to be discontinued. The maintenance costs and wages are considered to be approximately the same.

The specific cost of the thermal energy supplied by the power plant is: c_p = 0.043 ECU/kWh

The annual earnings of the project are then: E = 121.9 kECU

The annual running cost and earnings are considered constant for the entire estimated life span of the project. Since these payments are made at different times, they have different economic value and their sum has no simple meaning. A discounted cash flow analysis is usually adopted to compare the Present Value of Future payments (*PVF*), as these have an equal economic value. The present value of sequence of future payments made over n compounding periods, at a constant discount rate *r*, is calculated using the following equation:

$$PVF = \sum_{j=i}^{j=n} \frac{F_j}{(1+r)^n} \tag{23}$$

The constant annual payment which repays a present loan (*P*) and interest, at a given interest rate (*r*), over the project lifetime, is called Annuity (*A*) and is calculated as follows:

$$A = P \cdot \frac{r \cdot (1+r)^n}{(1+r)^n - 1} \tag{24}$$

The Capital Recovery Factor (*CRF*) over a period of (*n*) years at the interest rate (*r*) is defined as:

$$CRF(n,r) = \frac{r \cdot (1+r)^n}{(1+r)^n - 1} \tag{25}$$

The *CRF* may be used to calculate the present value of any constant stream of payments over a given period of time. The present values (P) of the annual running cost and earnings over a project lifetime of (n) years is calculated as:

$$P = \frac{A}{CRF(n,r)} \tag{26}$$

The formulation of appropriate indices for quantifying the various aspects of the financial value of a project requires that the economical environment be defined first. For the purpose of this report it has been assumed that the company finances the investment to the tune of 50% through own capital resources (called equity contribution; Q) and 50% by a fixed interest loan raised from a bank (called debt contribution; D). The calculated values for equity and debt are:

$$Q = D = 135 \text{ kECU}$$

The company owning the hotel is a taxable company. The annual taxation rate for a company of this type is t = 30%. All expenses, such as running cost, debt repayment and usually the annual depreciation of equity, are tax deductible, called tax allowances. The annual earnings of the project, as defined above, are tax allowances while the current heating system is in use, but because it is not paid any more when the new system is employed, it is added to the revenues of the company and so becomes a taxable quantity.

It is further assumed that the whole of the investment cost is committed at the beginning of the project, before its operation starts. After plant commissioning only running costs, debt charges and taxes have to be paid. The project lifetime is assumed to be n = 20 years and inflation is not considered. This means that all payments remain constant in real values over the entire lifetime of the project. All the financial rates are also considered constant over the project lifetime. This may not reflect real life practice, but is sufficiently accurate for this study. For the purpose of this report, a yearly compound period is considered for all payments.

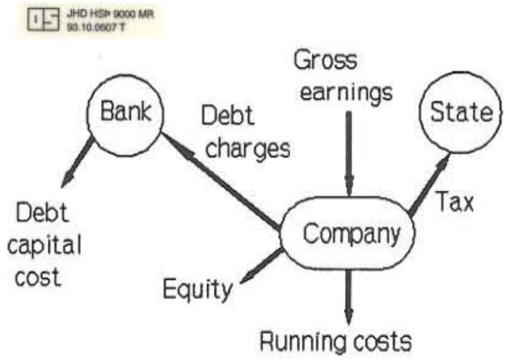

FIGURE 6: Financial system of the project

The financial system of this project is presented in Figure 6. Financial data for this system are calculated below. The discount rate (r) required to calculate the *CRF* depends on how the company perceives the worth of money. It should compensate the company for future risk (expected payments that may not materialize) and for lost opportunity (money spent on other, more profitable, ventures). For a hotel owning company a discount rate of r = 9% is considered to be reasonable. Then, for a lifetime of n = 20 years and the financial system defined above, the CRF comes out as: $CRF(n,r)$ = 0.1095

Assuming that the pay back time for the bank loan equals the project lifetime (i.e. n = 20 years) and an annual interest rate of i = 8%:

The *CRF* for the loan; $CRF(n,i)$	= 0.1019
Annual debt charges (annuity); $C = D \cdot CRF(n,i)$	= 13,756.5 ECU
Annual depreciation of equity; $p = Q/n$	= 6,750 ECU
Total annual tax allowances; $A = C + p + R$	= 103,106.5 ECU
Taxable annual earnings; $X = E - A$	= 18,793.5 ECU
Annual tax; $T = t \cdot X$	= 5,638 ECU
Net earnings after tax; $N = E - R - T - C$	= 19,905.5 ECU

Indices for evaluating the economical feasibility of this system can now be defined and calculated. These are the Net Present Value (*NPV*), the Internal Rate of Return (*IRR*) and the Discounted Pay-back Time (*DPT*). Another index currently used for economic appraisals is the Discounted Unit Cost, but it has no real meaning for this financial system, so it will not be considered further.

The *NPV* is defined as the present value of the total earnings of the project over its lifetime, after the present values of all expenses have been deducted. A positive value of this index means that the project is economically viable. For the financial system defined above, the *NPV* can be calculated with the following equation using the *CRF* for the considered discount rate (r):

$$NPV = \frac{N}{CRF(n,r)} - Q \tag{27}$$

The *IRR* is defined as the discount rate which ensures that the project breaks even over its lifetime, for a fixed level of revenue. It is calculated by a trial and error method or graphically. The *IRR* is considered to equal the value of the discount rate (d) for which the following function is zero:

$$(NPV)_d = \frac{N}{CRF(n,d)} - Q \tag{28}$$

The *DPT* is defined as the number of years required to pay back the initial investment, at the discount rate (r). After this time, the present value of the net earnings equals the equity (Q). A value of this coefficient, which is lower than the project lifetime, indicates that the project is economically viable. For the financial system defined above, the *DPT* can be calculated graphically or by trial and error, using the following equation:

$$(PVN)_j = \frac{N}{CRF(j,r)} \tag{29}$$

The results of the trial and error method for calculating the *IRR* and the *DPT* are presented in Tables 5 and 6 respectively. The calculated values for the financial indices are:

NPV = 46,785.4 ECU   *IRR* = 13.6%   *DPT* = 11 years

TABLE 5: Results of the *IRR* calculations

d	10	11	12	13	14
CRF(n,d)	0.11745	0.12557	0.13387	0.14235	0.15098
$(NPV)_d$	34,466.7	23,514.0	13,683.0	4,831.2	-3,163.3

TABLE 6: Results of the *DPT* calculations

j	14	13	12	11	10
CRF(j,r)	0.12843	0.13357	0.13965	0.14695	0.15582
$(PVN)_j$	154,987.2	149,030.6	142,537.8	135,460.7	127,746.7

3.3 Discussion

Technical and economical calculations have only been carried out for the system presented in Figure 4. Other possibilities were considered before this particular one was selected. A basic assumption was that required modifications of the existing heating system should be minimized, implying that the room heaters should not be changed. This means that the return temperature of the radiator water for the maximum temperature demand intensity would be higher than the well head temperature of the available geothermal water. The inlet temperature of the radiator water is also higher than the geothermal water well head temperature over a wide range of outdoor temperatures. The difference could be supplied by the peak load boiler only. In this case the use of geothermal water would, however, be minimal, the boiler supplying most of the demand. Another possibility could have been to use the hot water from the co-generation power plant instead of the peak load boiler. This would not increase the geothermal energy utilization and would also increase the return temperature to the power plant, which is not desirable. The use of heat pumps was therefore considered the best choice.

Different arrangements employing heat pumps have also been considered. The experience of existing geothermal heating systems shows, that a heat pump assisted system would be the most economic for the geothermal water temperature available and the radiator water temperature constraints. This type of system is currently used in all cases where similar conditions exist. The system selected for this study is basically of heat pump assisted type. It also incorporates the possibility of being operated as a direct heat exchange system for low load demands and as a heat pump only system with peak load boiler for high demands. This enables higher overall efficiency to be obtained, though the operation of the system is more complicated.

Other technical solution arrangements are also viable. The well head temperature of the geothermal water in the Felix reservoir is one that suits various low temperature room heater systems, i.e. floor, wall and/or ceiling heating. Provided the geothermal water is not cooled to below 20°C, it can be used directly in these heating systems without causing scaling problems. This type of heating requires no heat exchangers and incidental temperature losses will be minimal. The variations in heat demand can be met by regulating the geothermal water flow rate and mixing a portion of the return water with the inlet water. The return water temperature can also be regulated by temperature controlled valves, insuring optimal use of the geothermal water. This requires, on the other hand, a total refurbishing of the existing heating system since floor heating is currently not used in Romania.

The minimum outlet temperature from the evaporators of both heat pumps, that is the minimum cooling temperature of the geothermal water, was selected as 20°C. The main reason was to avoid silica scaling (chalcedony - see Chapter 4.2), whilst maintaining a reasonable coefficient of performance for the heat pumps. The maximum outlet temperature from the condensers of both heat pumps has been selected as 65°C. This is the standard temperature for hot tap water in Romania and it is also higher than the maximum return temperature of the radiator water. This reduces the thermal energy necessary from the peak load boiler while maintaining the coefficient of performance at a reasonable value. The energy balance for the HP1 has been made on a theoretical basis, assuming that the heat pump operates at optimum parameters for every load. Under real conditions, when the heat pump is operated at partial loads the coefficient of performance will be slightly lower than the theoretical value. The load of the heat pump will also not be regulated continuously to follow the demand variation. It is usually recommended that the heat pump be operated at constant partial loads in one or two steps and additional regulating effected by varying the flow rates. This type of operation also seems to decrease the COP slightly. For these reasons, the curve for the mechanical power in Figure 5 is only of informative value. For a more accurate calculation, a certain heat pump has to be selected. At the moment this is quite difficult, since available data sheets from the producers are no longer up to date. Commercial heat pumps typically used freon as working fluid, but as fluorocarbons (CFS) are considered the main threat to the ozone layer, their use is no longer permitted. Studies are now under way to find and develop other working fluids. From available information, it seems that the best results have been obtained by Sabroe (Denmark), using ammonia. Due to its higher heat capacity, the real COPs are higher than those for freon.

On the basis of the financial premises considered above, the project is shown to be economically viable. The net present value over the 20 years of the project lifetime is positive, though not very high, meaning that the project is profitable, so the company will not lose money if the decision is made to change the heating system to a geothermal one. The discounted pay back time of 11 years is fairly reasonable at about half the project lifetime. The internal rate of return (*IRR* = 13.6%) is also a reasonable one, higher than the considered discount rate (r = 9%). Before a binding decision can be made, a more detailed economic appraisal is recommended. The study should be based upon the financial situation existing at the specific time and also take account of available financial forecasts. It is most probable that the inflation will continue to be high in Romania in the near future, but possibly more stable than it is now. This means that the interest rates on bank loans will be considerably higher than the 8% rate considered in this study. When the investment can be made from own capital resources, as equity, the internal rate of return is higher in inflationary conditions, which should also be considered in an economic feasibility study. The *IRR* value calculated above (13.6%) is probably on the low side for a small company, particularly during the initial stages in the operation of a hotel. Changes of energy prices will also affect the economical viability of this project. Fossil fuel prices are expected to increase in the future, due to depletion of the resources, combined with announced environmental energy taxes. This will make a geothermal heating system more profitable.

4. HEATING SYSTEMS FOR ORADEA CITY

4.1 Reservoir management

In order to maximize the economic feasibility of a geothermal project, it is important to develop the geothermal reservoir at full capacity. This means a selection of a production and reinjection program that will maintain the temperature and the water level (or well head pressure) at reasonable values over the envisaged time of exploitation. For this purpose, a reliable reservoir simulation model is required. Also, the reservoir has to be monitored (computerized or manual) on a regular basis. The collected data is used to detect any adverse effects on the reservoir as soon as possible and to improve the simulation model, adjusting it to match the production and response history. The model is then used to forecast the behaviour of the reservoir for different production scenarios. It is assumed that a computerized system for monitoring the Oradea geothermal reservoir will not be available in the near future. A programme for manual monitoring of this reservoir, designed after Stefansson (1993), is presented in Table 7.

TABLE 7: Monitoring frequency and sensitivity

Parameter	Frequency	Sensitivity
Production from each well	daily	0.1 m^3
Injection in each well	weekly	0.1 m^3
Total production from reservoir	weekly	1 m^3
Total injection into the reservoir	weekly	1 m^3
Well head temperature	daily	0.1°C
Well head pressure or water level	daily	0.1 bar
Injection pressure	weekly	0.1 bar
Chemical composition - complete	twice per year	
- simple	weekly	O_2, SiO_2, Na, Cl, Ca
Temperature logs	once every summer	0.1°C
Pressure logs	once every summer	0.01 bar

For reservoir simulation models, weekly or monthly average values of extracted and injected water are usually used. It is recommended, however, that these parameters be monitored daily. The worker will visit every well, recording the instantaneous flow rate [l/s], the cumulated flow since the last reading, the well head temperature [°C] and the well head pressure or water level [bar]. A visual checking of the well head equipment will also be required. The problems encountered at each well will be recorded and reported for repairing as required. Minor repairs could be carried out on the spot by the worker, who monitors the wells. Incentives, such as public appreciation of the work or even a bonus, should be used to stimulate the worker to act promptly when deficiencies are discovered. The total production and injection flows (m^3) will be recorded weekly for comparison with the value calculated by summation of well data. The well head pressure (or water level) should be measured in production and injection wells and also in observation wells outside the production area, when available. Complete chemical analysis of the extracted water should be carried out at least once a year or, even better, every spring after the production is stopped and every fall before the production is started. It is also recommended that the concentration of certain components be measured weekly. For the geothermal water from the Oradea reservoir the concentrations of Ca, Mg and SiO_2 are significant and should be checked weekly. For the Bors reservoir, however, it is more important to check Na and Cl weekly, since they control the salinity of the geothermal water. Changes in the concentrations of these components could give advance warning of water inflows from different aquifers, usually colder.

Data acquired by monitoring could give advance warning of undesirable future developments within the reservoir, such as a pressure or temperature decrease. This should enable the company exploiting the reservoir to decide timely counter-measures. Correct decisions have to be made regarding changes in production and injection strategies, changes in the position of the deep well pumps, timing and siting of additional wells and changes of well design. The management of a geothermal reservoir has been found to be most efficient when it is exploited by only one company, preferably the same one that runs the heating system. A company responsible for all problems, such as reservoir maintenance and environmental pollution, tends to consider these problems carefully and make the right decisions.

4.2 Chemical problems

It is possible to predict the scaling potential of geothermal brines for which fairly accurate chemical data are known. One possibility is to calculate the solubility of different minerals in the brine (Q) and to compare it with the theoretical solubility (K) of the respective minerals. Usually logarithms of these values (*logQ* and *logK*) are calculated using computer programs. The log solubility of different minerals in the geothermal waters from both the Oradea and Bors reservoirs was calculated over a range of temperatures from the well head temperature down to 10°C. The computer program WATCH, version 2.0/1993 developed by the Icelandic Water Chemistry Group was used for the calculations. The scaling potential is estimated by calculating:

$$\log\left(\frac{Q}{K}\right) = \log Q - \log K \tag{30}$$

The calculated relative log solubility values for some of the minerals existing in the geothermal water from the Bors reservoir are presented in Table 8.

TABLE 8: Relative log solubility of minerals in geothermal water from the Bors reservoir

Temp.	*log(Q/K)*					
[°C]	Fluorite	Calcite	Sil. amorph.	Chalcedony	Talc	Chrysotile
115	-0.166	2.024	-1.446	-0.861	6.534	5.925
100	-0.068	1.882	-1.360	-0.737	5.734	4.852
90	0.003	1.792	-1.301	-0.651	5.209	4.128
80	0.079	1.704	-1.239	-0.560	4.686	3.392
70	0.160	1.618	-1.174	-0.464	4.161	2.653
60	0.250	1.535	-1.105	-0.363	3.631	1.856
50	0.347	1.454	-1.033	-0.257	3.098	1.049
40	0.454	1.377	-0.957	-0.144	2.567	0.218
30	0.573	1.304	-0.877	-0.025	2.041	-0.637
20	0.705	1.238	-0.793	0.101	1.531	-1.514
10	0.855	1.180	-0.702	0.236	1.046	-2.405

A positive value for the relative log solubility of a mineral means that the solution is over-saturated with respect to that particular mineral and, theoretically, it should start to precipitate. Experience gained in different fields utilizing geothermal water shows, however, that minerals do not start to precipitate as soon as the solution becomes over-saturated. Experimental data for low temperature geothermal waters in Iceland show, for example, that calcite starts to precipitate only when *log(Q/K)* values exceed 0.38 (Bai Liping, 1991). At present, no experimental data are available to the author regarding other minerals or geothermal brines from other countries. It is, however, evident, from the data presented in Table 8, that no silica (SiO_2) will precipitate, neither in the form of amorphous silica, nor as chalcedony. It is also obvious that calcite ($CaCO_3$) and magnesium silicates, such as chrysotile ($Mg_3Si_2O_5(OH)_4$) and talc ($Mg_3Si_4O_{10}(OH)_2$), are heavily over-saturated and will most certainly precipitate at high temperatures. This can also be seen in the diagram presented in Figure 7.

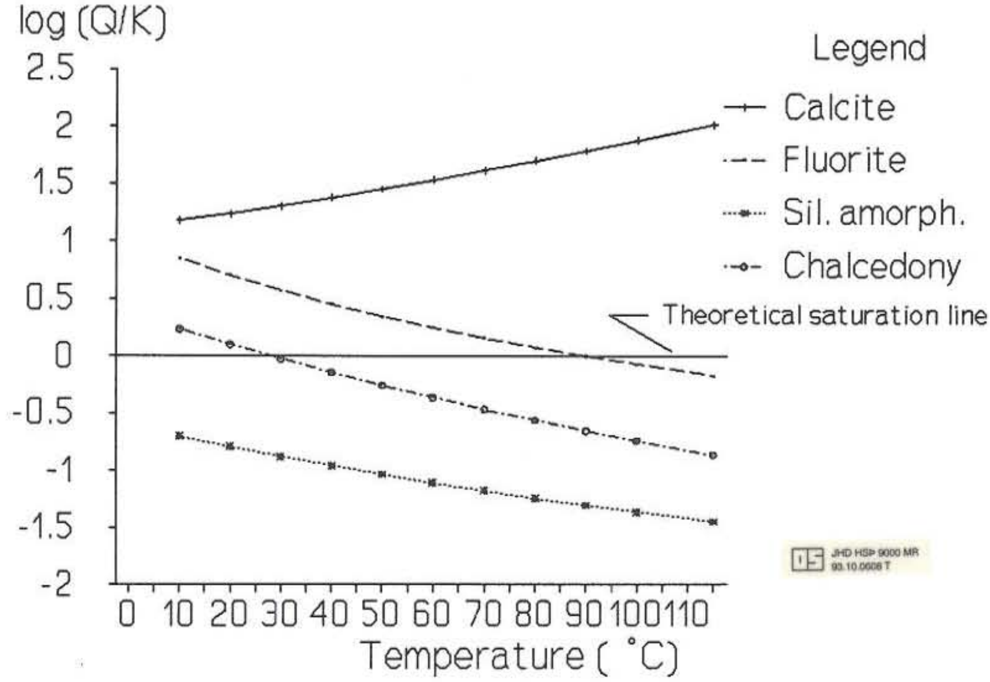

FIGURE 7: Scaling potential of minerals in geothermal water from the Bors reservoir

The values for chrysotile and talc are so high, that there is no doubt about their potential of scaling and were therefore not depicted on this diagram. It is possible that the fluorite could start to precipitate when the temperature decreases below 90°C, but experimental results are needed before an accurate solution to this problem can be given. Similar results for the geothermal water from the Oradea reservoir are presented in Table 9 and the diagram in Figure 8. The concentration of dissolved solids in this water is relatively low (about 1,200 ppm) and so most of the minerals show no real scaling potential. The solution is slightly over-saturated with respect to anhydride ($CaSO_4$), but no scaling problems have been encountered at high temperatures. When the temperature of the geothermal water decreases below 50°C it becomes over-saturated with respect to chalcedony. No real scaling problems are expected, however, until the temperature decreases below about 20°C. More experimental data is required in order to determine the exact temperature at which scaling starts. On the basis of the available data it is still reasonable to recommend not to cool this water below 20°C, in order to prevent possible chalcedony scaling.

The relative log solubility values of talc and chrysotile are here well below zero, meaning that the respective concentrations are below the saturation limit by a large margin. The values for these two minerals were, therefore, not depicted on the diagram presented in Figure 8.

TABLE 9: Relative log solubility of minerals in geothermal water from the Oradea reservoir

Temp. [°C]	*log (Q/K)* (-)					
	Anhydride	Calcite	Sil. amorph.	Chalcedony	Talc	Chrysotile
90	0.132	-0.648	-1.040	-0.390	-4.050	-5.653
80	0.036	-0.790	-0.983	-0.304	-4.722	-6.528
70	-0.058	-0.927	-0.923	-0.213	-5.392	-7.420
60	-0.150	-1.060	-0.859	-0.117	-6.060	-8.328
50	-0.238	-1.156	-0.791	-0.015	-6.721	-9.254
40	-0.322	-1.305	-0.719	0.094	-7.373	-10.198
30	-0.401	-1.415	-0.642	0.210	-8.010	-11.159
20	-0.475	-1.515	-0.560	0.334	-8.662	-12.136
10	-0.545	-1.603	-0.472	0.466	-9.211	-13.123

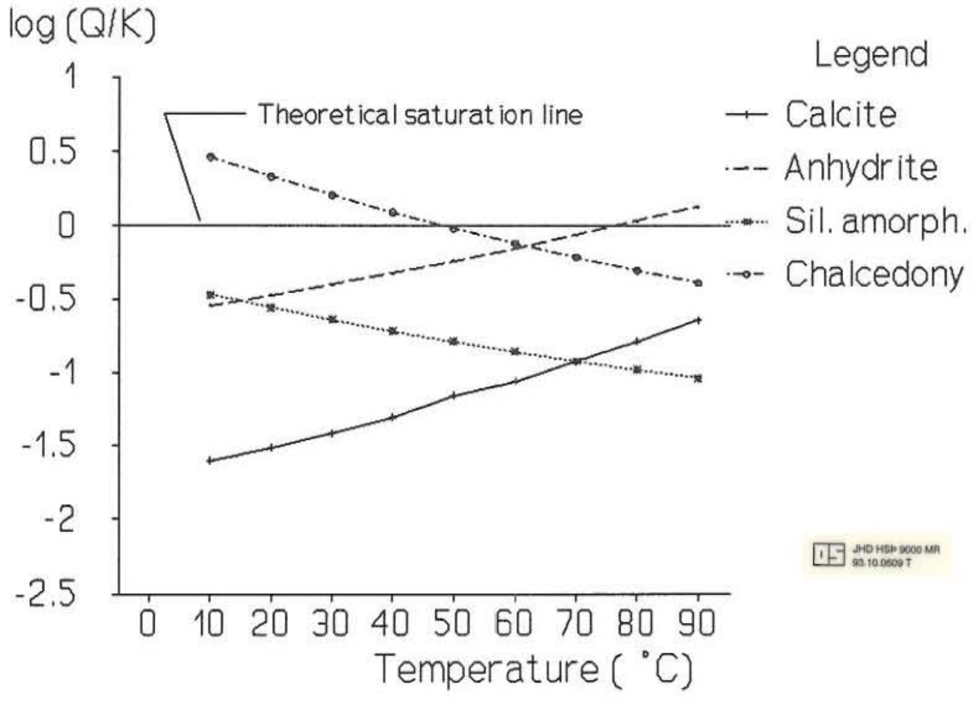

FIGURE 8: Scaling potential of minerals in geothermal water from the Oradea reservoir

The geothermal water from the Bors reservoir is slightly basic (pH = 7.8 at 20°C), whilst that from the Oradea reservoir is neutral (pH = 6 at 20°C). Corrosion problems caused by either of these two geothermal waters have not been reported up to the present. Both the Bors and Oradea geothermal reservoirs are located in fractured limestones and dolomites. No sand has been reported to exist in the geothermal water from these reservoirs. It is therefore to be expected that the deep well pumps will not be damaged by sand erosion.

4.3 Modification of the existing heating system

4.3.1 Technical calculations

The current central heating system in Oradea was initially designed to use the condenser cooling water from the back pressure steam turbines in the older co-generation power plant (CGP1) located just outside the western City limits. Later, about 6 years ago, a new co-generation power plant (CGP2) was built outside the eastern City limits of Oradea. The district heating system was modified to use also waste hot water from this power plant. The Felix Spa resort is also supplied with hot water from the CGP2. From the main supply pipelines the hot water is distributed to substations, where it is used for heating both domestic and space heating water for users in the vicinity. The space heating water is circulated between substations and users in a closed loop network. Separate pipelines are used for domestic hot water supply from the substations to the users. It is not possible to combine the two networks at present, since the space heating water and pipeline networks are dirty. All substations have the necessary storage tanks to compensate the daily variations in demand. The heating is carried out in two stages, in two heat exchangers, for both the domestic and radiator water, in order to ensure minimum return temperature of the primary water. The return water from the substations is collected in two main return pipelines and pumped back to the two power plants. The temperature of the primary water is manually regulated to suit the outdoor temperature, the supply temperature between 75 and 130°C, the return temperature between 30 and 50°C. At present the heat demand is greater than the supply, mainly because the power plants keep the condenser pressures of the turbines at relatively low values in order to produce more electric power for the national grid. The heat demand is also increasing due to population growth and construction of new buildings. Further increase in geothermal energy utilization will certainly improve the current situation.

It has been previously assumed (see Chapter 2) that the flow rates from each existing well could be at least doubled by using deep well pumps. The total flow rate of the geothermal water available for further development is thus 150 l/s, with an average temperature of 85.4°C, after mixing the discharge from all the wells together. The lowest well head temperature is 70°C. The standard temperatures in Romania are 65°C for domestic hot water and the maximum inflow temperature 90°C for space heating. On the basis of these values, a possible solution has been considered, which is to split the wells into two groups and to use the geothermal water with a temperature of 83°C and above for space heating and water with a temperature below 83°C for domestic water heating. The group of colder wells will yield a flow rate of 60 l/s at an average temperature of 74.7°C. The warmer group will, on the other hand, yield a flow rate of 90 l/s at an average temperature of 92.6°C.

Three different alternatives are proposed for using the geothermal water from the Oradea reservoir all based on using deep well pumps. One is to use the total flow for domestic water heating only. This will be called Case A. The second is to use the total flow for both domestic water and space heating, called Case B. The third alternative is to group the wells into two groups as described above, using the lower temperature for domestic hot water heating only and the higher for both domestic hot water and space heating. This will be called Case C.

The layout for Case A system is presented in Figure 9. The deep well pumps send the geothermal water to the storage and degassing tank (SDT). From there, it is fed by the circulation pump (CP1) to the plate heat exchanger (PHX) and the storage tank (ST1). The injection pump (IP) is used to reinject the spent geothermal water. The domestic water is supplied to the storage tank (ST2) from the municipal fresh water network. It is passed through the PHX and collected in the storage tank (ST3). The domestic hot water from the ST3 is

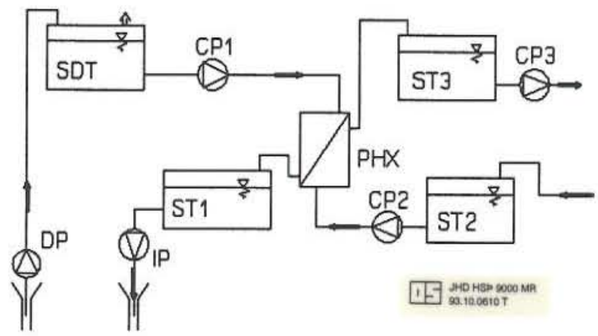

FIGURE 9: Case A system layout

distributed to the users by the circulation pump (CP3). As the average temperature of the total available geothermal water is 85,4°C, no primary water from the power plant is required for heating the domestic water to the standard temperature of 65°C.

The layout for the Case B system is presented in Figure 10. The geothermal water supplied by the downhole pumps (DP) is collected in the storage and degassing tank (SDT). The average temperature being 85.4°C (lower than the maximum radiator inlet temperature), the geothermal water is heated in the plate heat exchanger (PHX2) using primary water from the power plants at high temperature demand intensities. When the radiator inlet temperature is lower than the geothermal water temperature, the outflow is partly mixed with the inflow water at a ratio that will provide the required inlet temperature.

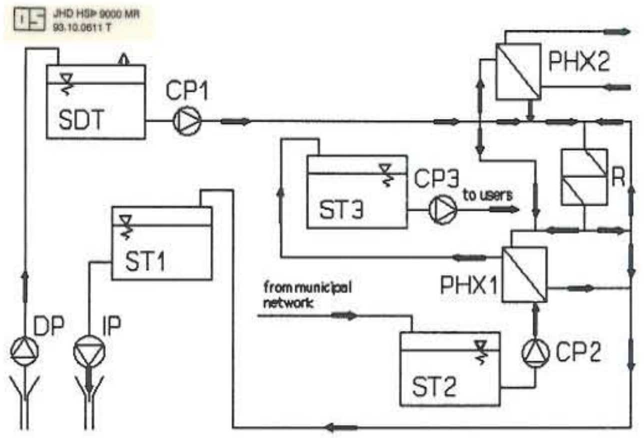

FIGURE 10: Case B system layout

The return water from the radiators is mixed with the geothermal water at a ratio which ensures a temperature of 70°C for the mixture. This water is used in the plate heat exchanger (PHX1) for heating the domestic water. The fresh water from the municipal network and the domestic hot water are collected in storage tanks (ST2) and (ST3) respectively, which compensate the daily variations in demand. The spent geothermal water is collected in the storage tank (ST1) and is reinjected by injection pump (IP).

The Case C system is basically a combination of Cases A and B. The flow rates and temperatures of the geothermal water will, however, be different in this case. The average temperature of the geothermal water from the wells with a well head temperature of 83°C and above is 92.6°C. This temperature is high enough to eliminate the need for the plate heat exchanger (PHX in Figure 9) and primary water from the power plant.

In heating system design the parameter of equivalent dwelling is often used in evaluating energy demand. The Romanian standard defines an equivalent dwelling as a two room apartment for two persons, with an annual heat demand of 34,543 MJ for space heating and 14,815 MJ for domestic hot water. The domestic hot water demand is constant the year round, whilst the space heating season is 172 days per year. The radiators used in Oradea city are the same as those used in the Felix Spa resort and the temperature characteristic shown in Figure 2 thus valid for this case also. The temperature demand intensity duration curve for the Oradea area is shown in Figure 3. The equations used for the technical calculations are Equations 1 to 11, presented in Chapter 3. The temperature drop in the main supply pipelines is assumed to be 0.5°C and non-existent in the main return pipelines. The return geothermal water temperature has been assumed to be about 20°C. The temperature drop in the distribution system between substations and users has been assumed to be 1°C both for the supply and the return pipelines.

It will be further assumed that the Municipal District Heating Company has the sole responsibility for the geothermal reservoir. The company will have to purchase, install and run downhole pumps for all producing wells. Four new injection wells have to be drilled to enable the reinjection of the total flow rate of the spent geothermal water. The circulation pumps currently used in the heating substations can be used for the new system. The power required for a hydraulic pump is calculated with the following equation:

$$P_p = f \cdot \frac{\Delta p}{\rho \cdot \eta} \tag{31}$$

where
P_p - electrical power required for pumping [W]
f - mass flow rate of pumped fluid [kg/s]
Δp - pressure increased by pumping [Pa]
ρ - specific mass of pumped fluid [kg/m^3]
η - overall efficiency of the pump, including the electric motor = 70%

It has been assumed that the systems in all three cases are designed to supply domestic hot water for as many equivalent dwellings as possible. In this way, the number of equivalent dwellings supplied with domestic hot water in Cases B and C will be greater than the number of equivalent dwellings supplied with space heating water. The numbers of equivalent dwellings in each case have been calculated to minimize the return temperature of the geothermal water. This type of system requires a large and relatively complicated pipeline network for supplying the geothermal water to a large number of substations, but maximizes the recovered thermal energy. The average fresh water temperature is 15°C and the minimum return temperature of the geothermal water has been assumed 20°C. For these values, the active area of the heat exchangers is within reasonable limits and no scaling problems are expected to be encountered (see Chapter 4.2). The substations supplied with geothermal water for domestic hot water only will also have a separate network supplying the primary water for space heating. As these networks already exist, only the network for the geothermal water has to be installed. The technical calculation results for the space heating systems in Cases B and C are presented in Tables 10 and 11 respectively.

TABLE 10: Case B space heating system results

Parameter	$P_u/P_{u\,max}$ (%)					
	20	40	60	80	92	100
Temperature demand intensity [°C]	5	10	15	20	23	25
Outdoor air temperature [°C]	13	8	3	-2	-5	-7
Radiator inlet temperature [°C]	34	48	62	76	84	90
Radiator outlet temperature [°C]	28	36	44	52	57	60
Network inlet temperature [°C]	35	49	63	77	85	91
Network outlet temperature [°C]	27	35	43	51	56	59
Geothermal water outlet temp. [°C]	30.9	27.8	24.9	21.6	20	21.6
Geothermal water flow rate [l/s]	10.7	21.7	36.1	59.3	77.6	77.6
Geothermal power [kW]	359	1,274	3,022	6,459	9,421	9,421
Heat from power plant [kW]	0	0	0	0	0	19

TABLE 11: Case C space heating system results

Parameter	$P_u/P_{u\,max}$ (%)					
	20	40	60	80	92	100
Temperature demand intensity [°C]	5	10	15	20	23	25
Outdoor air temperature [°C]	13	8	3	-2	-5	-7
Radiator inlet temperature [°C]	34	48	62	76	84	90
Radiator outlet temperature [°C]	28	36	44	52	57	60
Network inlet temperature [°C]	35	49	63	77	85	91
Network outlet temperature [°C]	27	35	43	51	56	59
Geothermal water outlet temp. [°C]	35.8	31.8	27.9	23.9	22.5	20.0
Geothermal water flow rate [l/s]	7.4	14.8	24.6	38.4	48.9	59.1
Geothermal power [kW]	247	742	2,061	4,180	5,738	7,914

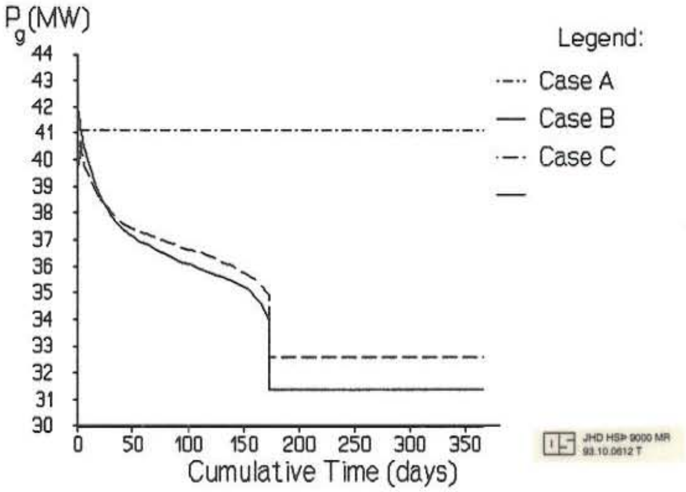

FIGURE 11: Heat demand duration curves for Cases A, B and C

The power demand duration curves for Cases A, B and C are presented in Figure 11. The general results calculated for the three geothermal heating systems studied for Oradea City are presented in Table 12.

TABLE 12: Comparative general results for Cases A, B and C

Parameter	Case A	Case B	Case C
Geothermal water production [m^3]	$4.73 \cdot 10^6$	$4.15 \cdot 10^6$	$4.27 \cdot 10^6$
Heat from geothermal water [GJ]	$1{,}294 \cdot 10^3$	$1{,}052 \cdot 10^3$	$1{,}093 \cdot 10^3$
Heat from power plant [GJ]	0	0.0025	0
Electric energy for pumping [MWh]	1,502	1,319	1,356
Heat exchangers total area [m^2]	1,250	100	1,900
Overall energy saving [GJ]	$1{,}290 \cdot 10^3$	$1{,}048 \cdot 10^3$	$1{,}089 \cdot 10^3$
Overall coal saving [t]	219,360	178,060	185,050

4.3.2 Economical appraisal

The geothermal wells are currently owned by the drilling company Foradex S.A. It has been previously mentioned that the geothermal field and the wells will be taken over by the Municipal District Heating Company. For the economical appraisal of the geothermal heating systems for all three cases considered above, it is thus assumed that the District Heating Company will have to purchase all existing wells and to drill 4 new reinjection wells. The capital investment therefore, comprises the cost of the 12 old wells, drilling 4 new wells, and the main distribution network, including downhole pumps, injection pumps, storage tanks and pipelines. The total investment cost has been calculated considering the engineering cost as 6% of the capital investment and 5% of the above costs have been allowed for contingencies. All costs have been estimated according to Piatti et al. (1992).

The cost of a new well has been estimated as a function of the total well depth. The spent geothermal water is currently reinjected into the same aquifer, so that the depth of the reinjection wells has to be about 2.2 km. For low enthalpy wells drilled in sedimentary rocks in this range of depths, the specific cost is 660 kECU/km. The cost of well utilities is evaluated as 200 kECU for each well. The cost of an old well has been considered equal to the price of a new well, as these are proved to be in good operating condition.

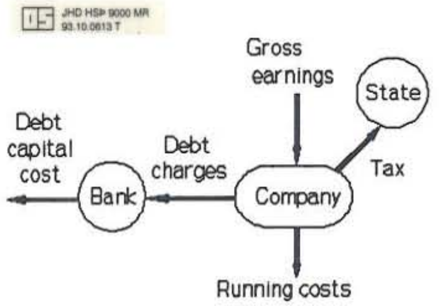

FIGURE 12: Financial system for Oradea city projects

The running cost comprises maintenance, wages for the personnel operating the system, and the electric energy for running the pumps. The maintenance cost has been estimated as 1% of the total investment cost. Four workers and one clerk are required for running the geothermal heating systems in all three cases. The annual wages are 35 kECU for the clerk and 25 kECU for each worker. The specific cost for electricity has been considered 0.050 ECU/kWh. The earnings for the three cases are the incomes from selling the thermal energy at a price of 0.043 ECU/kWh. The project life time has been assumed 20 years. It has been further assumed that the total capital cost will be covered by a bank loan at an annual interest rate of 10% with a pay back time assumed equal to the project life time. The company pays 30% tax on income. A discount rate of 6% has been assumed reasonable for a municipal company. The diagram of the financial system for all three cases considered above is presented in Figure 12. The general assumptions made in Chapter 3.2 as well as equations 19 to 26 are valid for these cases.

Since no investment is made from the company's own capital resources ($Q = 0$), equations 27 to 29 can not be used for calculating the economic indices of the three geothermal heating systems considered for Oradea City. The equations used to calculate the Net Present Value (*NPV*), the Internal Rate of Return (*IRR*) and the Discounted Pay-back Time are presented below:

$$NPV = \frac{N}{CRF(n,r)} \tag{32}$$

$$(NPV)_d = \frac{(E-R)\cdot(1-t)}{CRF(n,d)} - \frac{C\cdot(1-t)}{CRF(n,r)} \tag{33}$$

$$\frac{(E-R)\cdot(1-t)}{CRF(j,r)} - \frac{C\cdot(1-t)}{CRF(n,r)} = 0 \qquad (34)$$

The economical calculation results for the three cases are presented in Table 13.

TABLE 13: Comparative economical results for Cases A, B and C

Parameter		Case A	Case B	Case C
Capital investment [kECU]	(*I*)	34,625	34,841	34,640
Annual running cost [kECU]	(*R*)	1,785	1,810	1,786
Annual earning [kECU]	(*E*)	17,173	14,311	14,777
Annual debt charges [kECU]	(*C*)	4,067	4,092	4,069
Tax allowance [kECU]	(*A*)	5,852	5,902	5,855
Taxable income [kECU]	(*X*)	11,321	8,409	8,922
Annual tax charges [kECU]	(*T*)	3,396	2,523	2,677
Annual net earnings [kECU]	(*N*)	7,925	5,886	6,245
Net present value [kECU]	(*NPV*)	77,901	67,500	71,617
Internal rate of return [%]	(*IRR*)	33.0	26.5	27.5
Discounted pay-back time [years]	(*DPT*)	3.6	4.4	4.2

4.4 New housing developments

4.4.1 Technical calculations

It is possible to use the available geothermal water from the Oradea reservoir for a district heating system supplying the future housing developments. This will be further called case D.

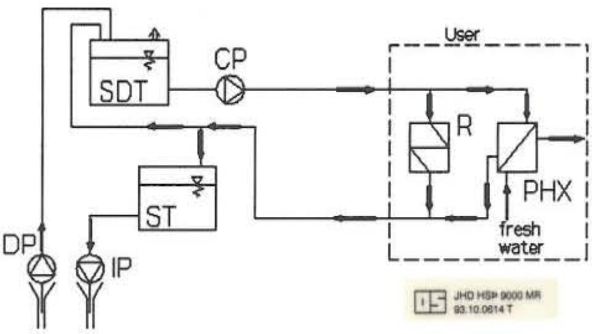

FIGURE 13: Case D system layout

The flow diagram of the system studied for this case is presented in Figure 13. Downhole pumps (DP) pump the geothermal water to the storage and degassing tank (SDT). From there, it is pumped by the circulation pumps (CP) into the distribution network to the users. A user is defined here as a building with one or more apartments and/or other utilities. The geothermal water is used directly in the radiators for space heating. Domestic hot water is provided by heating fresh water through direct heat exchange in stainless steel plate heat exchangers (PHX) located at the user. The spent geothermal water is collected in the return main pipeline. The return flow is divided between the SDT and the storage tank from where it is reinjected by the injection pump (IP). In the SDT the fresh and the spent geothermal water flows are mixed to maintain the required supply temperature. The heating system is assumed to be the 80/40/-7 type (at minimum outdoor temperature -7°C the radiator inlet and outlet temperatures are 80°C and 40°C, respectively). The heat supply for different temperature demand intensities is modified by regulating the flow rate of the geothermal water supply. This requires that temperature controlled regulating valves be installed at each radiator and at the user outlet pipeline.

At each user, the radiators will be connected in parallel and the temperature drop regulated at 40°C in each radiator. The geothermal water outlet temperature from the PHX is assumed 20°C. An average temperature drop of 0.4°C has been assumed in the pipelines from the wells to the SDT. The temperature drop in the distribution system has been assumed 1°C in the supply and 0.5°C in the return pipelines. This means that the geothermal water has to leave the SDT at a temperature of 81°C, after mixing with the return water. The system has been calculated to supply the maximum number of equivalent dwellings with both space heating and domestic hot water. A maximum of 5,160 equivalent dwellings can be supplied with both space heating and domestic hot water, at the maximum geothermal water flow rate of 150 l/s. The thermal power duration curve is presented in Figure 14 and the technical calculation results in Table 14.

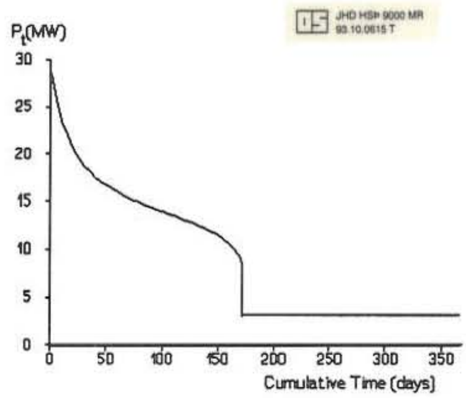

FIGURE 14: Thermal power duration curve for Case D

TABLE 14: Technical calculation results for Case D

Parameter	$P_u/P_{u\,max}$ (%)					
	0	20	40	60	80	100
Temperature demand intensity [°C]	0	5	10	15	20	25
Outdoor air temperature [°C]	18	13	8	3	-2	-7
Network outlet temperature [°C]	19.5	33.7	36.1	37.1	37.7	38.0
Geothermal water flow rate [l/s]	11.6	39.3	67.0	94.7	122.3	150.0
Geothermal power [MW]	3.1	8.2	13.3	18.4	23.4	28.5
Electrical power [kW]	13	45	77	108	140	171
Annual geothermal water [m^3]	$1.5 \cdot 10^6$					
Annual geothermal heat [GJ]	280,000					
Annual electric energy [GJ]	1,584					
Annual energy saving [GJ]	278,316					
Annual coal saving [t]	33,252					

4.4.2 Economical appraisal

The economical pre-feasibility study for Case D has been carried out using the same initial assumptions as in Cases A, B and C. The investment cost is a function of the maximum thermal power of the heating system. The geothermal water return temperature for Case D is higher than in the previous cases, so the maximum thermal power is lower. The annual earnings are also lower, since the total thermal energy sold in a year is lower than in the previous cases. The results of economic calculations are presented in Table 15.

TABLE 15: Economical calculation results for Case D

Parameter		Value
Investment cost [kECU]	(*I*)	33,552
Annual running cost [kECU]	(*R*)	469
Annual earning [kECU]	(*E*)	3,345
Annual debt charges [kECU]	(*C*)	2,691
Annual tax allowance [KECU]	(*A*)	3,160
Annual taxable revenue [kECU]	(*X*)	185
Annual tax [kECU]	(*T*)	56
Annual net earning [kECU]	(*N*)	130
Net present value [kECU]	(*NPV*)	1,491
Internal rate of return [%]	(*IRR*)	7.0
Discounted pay-back time [years]	(*DPT*)	17.75

4.5 Discussion

The geothermal heating systems studied in cases A, B and C are all very profitable. The main reason for this high profitability is that the distribution pipeline networks from the substations to users are already installed and not included in the capital cost of the project. This reduces the capital investment required for the modification of the existing heating system. It has also been assumed that geothermal water will be used for tap water heating for as many equivalent dwellings as possible in all three cases. Since the average fresh water temperature is 15°C, the geothermal water can be cooled down to 20°C, maximizing the heat recovered from the available flow rate, thus maximizing the revenues from thermal energy sales. Case A has the highest economic value simply because the maximum available flow rate of geothermal water is used all the year round. Thus the recovered thermal energy is maximized, the load factor being 100%. In Cases B and C the load factors are 81.2% and 84.4% respectively, due to the decrease in thermal energy conversion associated with space heating.

The economy of the Case D system appears to be marginal. There are three main reasons for this low profitability: high investment costs, high return temperature of the geothermal water and low load factor. The investment cost is high because a new system has to be built. It has also been assumed that the Municipal District Heating Company has to purchase the existing geothermal wells from the drilling company. The geothermal water return temperature is relatively high during the heating season, due to the high outlet temperature of the currently used radiators. The geothermal water is used for both domestic hot water and space heating for a given number of equivalent dwellings. The required geothermal water flow rate and the heat recovered from it is relatively low during the summer, when space heating is not necessary. Thus, the load factor of this system is relatively low. When the space heating system is turned off, the geothermal water flow rate is reduced to about 8% of the maximum demand, causing also a higher temperature drop in the supply pipelines, due to the decrease in fluid velocity. A reduced production rate will, however, have a good influence on the geothermal reservoir, allowing the pressure and temperature to recover during the summer.

The overall efficiency of the geothermal water utilization could be increased by cascading it through heaters with different temperature demands. Cascaded uses are common practice in countries where geothermal heating systems are currently utilized, such as Iceland and France.

In heating systems of this type, the users are divided into two groups, called high temperature and low temperature users, respectively. The high temperature users are those which use steel sheet or cast iron radiators, requiring high inlet temperature for space heating. The low temperature users are those using floor, wall or ceiling heating, enabling lower inlet and outlet temperature.

The capital investment and the economic indices of Case D should not be compared with those of Cases A, B and C, since these systems are totally different, requiring only modifications of the existing system. The Case D parameters should be compared with those associated with the building of a new system of the type currently in use in Romania. The investment cost of the Case D system should be lower than the investment cost of the current type of system, since no additional pipeline is required for domestic hot water and no substations with heat exchangers and pumps. The specific cost per surface area for the relatively small size plate heat exchangers at the users is higher than the specific cost for large heat exchangers, but the capital investment is still lower because new substations are not needed. Relevant data for a new system of the current type were not available to the author of this report. This study should be reviewed when the necessary data becomes available and the results compared with results of Case D.

5. ENVIRONMENTAL ASPECTS

5.1 Emission of liquid and gaseous pollutants

Concentration of polluting substances present in the geothermal water from the Oradea area and permissible values for water intended for human consumption and irrigation are presented in Table 16.

TABLE 16: Concentration of various pollutants

		Concentration (ppm)					
		TDS	Cl	B	As	H_2S	Phenols
Maximum permissible	Human cons.	1,000	250	30	0.05	0.05	0.0
	Irrigation	7,000	200	0.75	1.0	1.0	0.2
Geothermal water	Bors	14,000	6,560	29.3	0.0	0.0	0.7
	Oradea	1,200	71	0.0	0.0	0.0	0.0

The geothermal water from the Bors reservoir has a high concentration of dissolved solids, some of them dangerous to the environment. The Boron (B) concentration is just below the permissible concentration in water intended for human consumption. The permissible Boron concentration in water used for irrigation is, however, only 0.75 mg/l (it accumulates in plants) and therefore it is not acceptable to discharge the spent water on the surface. The Chloride (Cl) concentration is much higher than the permissible limit in water intended for human consumption. It contains also diverse phenolic compounds, having an unpleasant smell (Cohut and Tomescu, 1993). Since all the extracted geothermal water from the Bors reservoir has to be reinjected to maintain the reservoir pressure, the presence of polluting solids in this water is of very limited environmental concern, only in the case of reinjection breakdown. The only pollutant emissions of concern are the gases dissolved in this water. There is no dissolved hydrogen sulphide (H_2S) and the concentration of ammonia (NH_3) is very low (10 ppm). Of environmental concern is the carbon dioxide (CO_2), having a concentration of 1,223 ppm. It is partly retained in solution by maintaining an over-pressure of 7.5 bar, but a portion is discharged into the atmosphere, CO_2 being considered one of the main factors causing the so called greenhouse effect. The amount of CO_2 discharged into the atmosphere from the geothermal water is, however, several orders of magnitude lower than that produced by a coal fired co-generation power plant for the same thermal energy production. The presence of Radon (Rn222) in a concentration of 23 to 70 pCi/l is also reported in this geothermal water, making it unacceptable for human consumption.

The geothermal water from the Oradea and Felix reservoirs has a very different chemical composition. From all components mentioned above, it contains only chloride (Cl) in a concentration of maximum 70 mg/l and carbon dioxide (CO_2) in a concentration of 157 mg/l. The spent water has also to be reinjected in order to maintain the reservoir pressure. The annual amount of CO_2 released into the atmosphere from the geothermal water used in Cases A, B, C and D studied above, compared to the amount released by coal fired power plants producing the same thermal energy, is presented in Table 17. The calculation was carried out for a perfect combustion of coal with 60% Carbon (C) and a Low Calorific Value of 8,370 kJ/kg. The flue gases from the power plant also comprise solid particles and toxic gases such as sulphur dioxide (SO_2) and nitrogen oxides (NO_x). Power plants fired by low grade coal, as those in Oradea City, also produce large quantities of ash, which requires expensive pollution free means of disposal.

TABLE 17: Comparative pollutant emission

Case	Pollutant emission (t/year)					
	Geothermal	Power Plant				
	CO_2	CO_2	Particles	SO_2	NO_x	Ash
A	743	482,592	117	688	760	43,872
B	652	391,732	95	558	617	35,612
C	671	407,110	99	580	641	37,010
D	236	73,155	25	149	164	6,650

5.2 Discussion

Surface disposal of the spent geothermal water from the Bors reservoir is not acceptable, due to its high concentration of polluting substances, such as Rn, Cl, B and phenolic compounds. For the same reasons this water is not suitable for human consumption. Since the reservoir is located in fractured limestones and dolomites, it is possible to reinject the spent brine into the same aquifer. This provides pollution free disposal and also helps sustain the reservoir pressure, which is important for this closed and relatively small reservoir. The emission of polluting gases from the geothermal system for greenhouse heating is relatively low, since most of the non-condensible gases are retained in solution in order to prevent scaling problems.

Harmful substances in the Oradea reservoir are low. The total concentration of dissolved solids is just above the admissible limit for human consumption. Possibly, this water can be used directly as hot tap water by mixing it with fresh water. Before implementing such a project, a detailed study has to be carried out to predict the scaling potential of different minerals, such as silicates and magnesium silicates and the likelihood of corrosion. For any other types of systems using this geothermal water the chemical pollution is not a problem. Considerably less atmospheric pollution is associated with the use of geothermal energy, than with burning low grade coal to produce the same amount of thermal energy.

Surface disposal of the geothermal water from the Oradea reservoir is possible, from a chemical pollution point of view, by disposing of the spent water into the municipal sewage system. In this case the capital cost of the pipeline networks is minimized, since no return pipelines are required. The natural recharge of the Oradea reservoir is relatively low, requiring the reinjection of almost all extracted water for maintaining the reservoir pressure. Thus, a single pipeline geothermal system should be used only when water from other sources is available at or close to the injection site. The Oradea and Felix reservoirs are hydrodynamically connected. A pressure decrease in the Oradea reservoir will affect the Felix reservoir, eventually causing the disappearance of the natural hot springs there and endangering the existence of rare plants, such as *Nymphaea Lotus Thermalis.*

Methane (CH_4) is a significant component of the non-condensible gases in the Bors geothermal reservoir. It could be used to fire a peak load boiler, enabling an increase in the geothermally heated greenhouse area. The geothermal water from Oradea also contains helium (He) at a concentration of 0.5 to 0.8 Nm^3/m^3 (about 45 to 72 mg/l). Helium has a very high diffusivity (even in metals), but is not considered pollutant. The equipment available makes it impossible to separate and recover these gases. That possibility could, however, increase the economic viability of any geothermal project in Oradea.

6. CONCLUSIONS AND RECOMMENDATIONS

The study presented in this report shows that it is both technically and economically viable to use the geothermal water from the Felix reservoir for domestic hot water and space heating in the Felix Spa resort. Since the temperature of the geothermal water is low (50°C), heat pumps are required to attain the existing high temperature (90/70°C) space heating system based on cast iron radiators.

The reservoir simulation model available at present shows that the current geothermal water production from the Oradea reservoir could be doubled by using downhole pumps. This production rate is not sufficient to supply the total thermal energy demand for both domestic hot water and space heating in Oradea City. The results of this study show that the greatest energy saving is obtained when the available geothermal water is used for tap water heating only, the load factor in this case being 100%. About 5,200 equivalent dwellings in the City can thus be supplied with hot tap water. The study also shows that it is possible to use part of the geothermal water for space heating, reducing the production during the summer.

The utilization of geothermal energy reduces environmental pollution very considerably compared to producing the thermal energy in a co-generation power plant fired by low grade coal, such as is the case in Oradea. The annual emission of flue gases is up to about 500,000 t CO_2, 700 t SO_2, 760 t NO_x and 117 t particles. The geothermal energy utilization reduces the CO_2 emission by 98% and the others, such as SO_2 and NO_x by 100%. By reinjection of all spent geothermal water, the pollutant emission from the geothermal heating system becomes insignificant.

A detailed reservoir simulation model is required to estimate the potential of both the Oradea and Bors reservoirs and the optimum production strategy. A feasibility study is recommended for a geothermal space heating system for the Felix Spa resort, using low temperature heating, such as air, floor, wall or ceiling heating. A feasibility study is also recommended for a district heating system based upon cascaded uses of the geothermal water from the Oradea reservoir. The users could be divided into two groups, one with high temperature (90/60°C) room heaters (cast iron or steel sheet radiators), the other with low temperature (50/20°C) heaters (floor, wall or ceiling heating).

It is finally recommended to carry out feasibility studies for some of the geothermal utilization scenarios presented in this report. The assistance of an experienced consulting company, for example Virkir-Orkint (Iceland) would be valuable in this respect and also assistance in soliciting investment capital, partially or totally, from an international bank, such as the Nordic Investment Bank or the European Bank for Reconstruction and Development.

ACKNOWLEDGEMENTS

I am deeply grateful to Dr. Ingvar B. Fridleifsson, Director of the United Nations University Geothermal Training Programme in Iceland, for giving me the honour of being the first Romanian to attend this programme.

The high scientific level of all the lectures helped me gain valuable knowledge about geothermal energy and its utilization.

I would like to express my gratitude to Oddur Bjornsson, Ph. D., Project Manager of the Fjarhitun hf, Engineering Consulting Company, for his critical review of a part of this report.

I am specially grateful to my advisor, Dr. Einar T. Eliasson, for his continuous guidance and kind encouragement during the elaboration of this report.

REFERENCES

Bai Liping, 1991: Chemical modelling programs for predicting calcite scaling, applied to low temperature geothermal waters in Iceland. UNU G.T.P., Iceland, report 3, 45 pp.

Cohut, I., 1992: Current status and prospects of the Romanian geothermal industry. Paper presented at the International seminar on geothermal energy, Oradea, Romania, 5 pp.

Cohut, I., and Tomescu, A., 1993: Nature of the geothermal fluids in Romania and means to control undesirable effects. Paper presented at the International seminar on environmental protection by the use of geothermal energy, Zakopane, Poland, 4 pp.

Harrison, R., Mortimer, N. D., and Smarason, O. B., 1990: Geothermal heating: a handbook of engineering economics. Pergamon Press, Oxford, U. K., 558 pp.

Karlsson, T., 1984: Geothermal district heating. The Icelandic experience. UNU G.T.P., Iceland, report 4, 116 pp.

Piatti, A., Piemonte, C., and Szegö, E., 1992: Planning of geothermal district heating systems. Kluwer Academic Publishers, Dordrecht, The Netherlands, 308 pp.

Stefansson, V., 1984: Utilization strategy for geothermal fields in Romania. Report to the United Nations on the mission Rom-82-005 to Romania, United Nations, New York, USA, 42 pp.

Stefansson, V., 1988: Research and utilization of geothermal resources. Phase II. Report to the United Nations on the mission Rom-82-005, United Nations, New York, USA, 76 pp.

Stefansson, V., 1993: Monitoring of geothermal fields. Management of geothermal reservoirs, - lecture notes. UNU G.T.P., Iceland, 99 pp.