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Geothermal energy and therapy uses in Romanian spas

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Abstract

There are about 160 thermal spas in Romania, of which Felix Spa is the largest and probably the best known. This paper presents the Felix Spa geothermal reservoir and the therapeutic effects of the water extracted from it. As the wellhead temperatures are rather low (40-50°C), some possible energy uses are studied. One possibility presented here is a heat pump assisted heating system for a typical hotel. Another possibility is a heating system for the recovery hospital, for which two options are analysed: 1) Floor heating using only geothermal energy; 2) Space heating with the existing cast iron radiators, with geothermal energy supplying the base load, and with gas fired peak load boilers. The final part of the paper deals with the Calimanesti-Caciulata spa, presenting the results of an INCO-COPERNICUS project carried out in 2001-2002 for design and completion of a heating system using geothermal water and the combustible gases separated from it.

1 Felix Spa

1.1 Introduction

Of about 160 thermal spas in Romania, 23 are of national importance and also internationally recognised for the therapeutic effect of their geothermal waters. Felix Spa is probably the best known of them, and definitely the largest. It is located 10 km SE from Oradea City, in the northwestern part of Romania, in the largest geothermal area of the country.

The existence and development of the Felix Spa is bound directly to the natural thermal springs existent in the area and to the positive effects of the geothermal waters for the health, well known and certified throughout the centuries. One of the first known documents which certifies that the waters near Oradea were well known and appreciated in Europe dates from 1405. Many suppositions were made on the name Felix Spa. Some researchers considered that happy, recovered patients gave the name; others associated the name of the spa with the name of its first superintendent, Helcher Felix.

Felix Spa has a total of more than 7,000 beds, 5,750 of which are in 12 hotels ranging from 1 to 3 stars, and 1,250 beds in villas of different comfort levels. Each hotel has its own treatment facilities. A physical recovery hospital with 150 beds is also operated in Felix Spa. Due to many different problems, mainly managerial and financial, the number of patients coming to Felix Spa for different treatments (depicted in the graph in Figure 1) unfortunately decreased in the last ten years, as well as the number of tourists. The situation was more or less similar for all Romanian spas and resorts, the tourism business showing the first signs of recovery only this year.

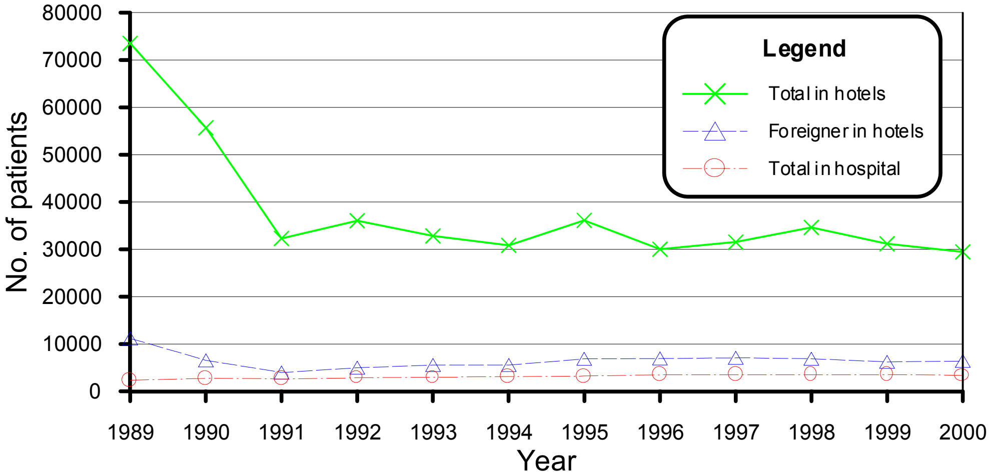

Figure 1: Evolution of the number of patients treated in Felix Spa between 1989 and 2000 (Rosca and Farcas, 2001).

1.2 The geothermal reservoir

The three geothermal reservoirs identified in the Oradea area are quite different from others located in the Pannonian Basin (of which they are a part), or in other sedimentary basins. The main reservoir is almost entirely situated within the city limits of Oradea, the second one is in Felix Spa, 10 km SE from Oradea, and the third near the village Bors, 6 km NW from Oradea.

The Oradea reservoir is located in fractured Triassic limestones and dolomites about 2,200 to 3,200 m deep, and the Felix Spa reservoir is located in two layers of fractured Cretaceous limestones, 45-175 and 200-750 m deep. The extraction history shows that both are open and hydrodynamically connected reservoirs. The interference test of 1984 (Plavita and Cohut, 1990) showed a natural recharge of about 300-350 l/s, which originates in the Apuseni Mountains about 80 km east of Oradea. By the ^{14}C method, the geothermal water from the Oradea and Felix Spa reservoirs was found to be about 20,000 years old. In the Oradea aquifer, the temperature decreases from NW towards SE, and continues to decrease into the Felix Spa aquifer. The geothermal bore holes and natural hot springs in Felix Spa have surface temperatures ranging from 35 to 55ºC.

The chemical compositions of the geothermal fluids in the Oradea and Felix Spa reservoirs are basically the same. The concentration of total dissolved solids (TDS) is up to 1,300 ppm, mostly calcium-sulphate-bicarbonate type, the main elements present being Ca, Mg, Na, K, Li, Mn, and Fe. There are also small quantities of dissolved non-condensable gasses (up to 200 ppm), mainly CH_4 and CO_2 (Cohut and Tomescu, 1993). A very small content of ^{222}Rn (about 23-70 pCi/l) makes the geothermal water undrinkable in general, but also strongly contributes to its therapeutic effect in health bathing.

Calculations based on the chemical composition of the geothermal fluid (and confirmed by practice) show a very low scaling potential, and only at temperatures below 20ºC (Rosca, 1993). The geothermal water from the Felix Spa reservoirs is neutral (pH 6 at 20ºC). Corrosion problems caused by the geothermal fluid have not been reported up to present. As the reservoirs are located in fractured limestones, no sand was reported to exist in the geothermal water.

Out of the 9 geothermal wells drilled in Felix Spa, only 6 are currently in use. The oldest two wells in Romania were drilled in Felix Spa, the first in 1885 (which can still produce up to almost 200 l/s), and the second in 1887 (now closed). All wells are producing in artesian discharge. The total exploitable flow rate in Felix Spa was set by the National Agency for Mineral Resources to 250 l/s annual average, in order to prevent reservoir pressure decline, and to protect the natural reservation of *Nymphaea Lotus*, variety *Thermalis*, a Tertiary remnant which grows naturally in geothermal ponds, a quite uncommon occurrence at this latitude (about 45ºC) and therefore a tourist attraction.

1.3 Therapeutic effects of the Felix Spa geothermal water

The geothermal waters from the Felix Spa are used for prophilaxy, treatment, and physical rehabilitation. They are used in external cures in pools, baths, tubs and all the hydro-thermal therapeutic procedures, including vaginal irrigation. The treatment installations include:

- Baths with thermal mineral water in tubs and pools.
- Kineto-therapy with thermal mineral water in tubs and pools.
- Vertebral traction (elongation in the water and on the table).
- Electro- and hydrotherapy.
- Inhalations.
- Rehabilitation and medical gymnastics.
- Paraffin wrappings.

Water from the "Balint" well, which has a Radon content below the admissible limit for drinking, is used in internal cure for patients with digestive, liver and renal illnesses. The actions of the geothermal waters from Felix Spa on the human organism are generated by three factors: the thermal factor, the chemical factor and the mechanical factor. The thermal factor, due to the water temperature, which is used at about 36 - 37^{o}C in external cure in pools, has the following effects:

- Increases the heart rate.
- Increases the cardiac flow.
- Decreases the blood pressure.
- Controls the contractures and the muscular spasms by relaxation of skeletal muscles.
- Controls the chronic osteoarticular, periarticular, and soft tissue pain.
- Rebalances the neurovegetative system.

The chemical factor is represented by the chemical structures of these waters. It determines a skin trans-mineralisation which leads to some of the beneficial effects such as decreasing the blood pressure, entering K, Ca, Mg, Fe with important roles in the muscular and bone metabolism, and important elimination of Na, urea, and acid radicals. During the treatment, the Radon gets through the skin into the blood flow and is eliminated through the lungs. It is disintegrated in three hours after finishing the treatment. It represents a great advantage by avoiding the long action of radiation. The most important effects are:

- Normalisation of the glucidic metabolism.
- Increase of the uric acid elimination, with favourable results in gout and in X metabolic syndrome.
- On the urinary system - increases the diurese (urinary flow).
- Decreases the blood flow in hypertension, and normalises it in hypotension.
- Acts on cerebral circulation and microcirculation, controlling the pain in neuralgia and neuritis.
- Rebalances the neuro-vegetative and hormonal systems.

The mechanical factor is represented in the pools by the hydrostatic pressure according to Pascal’s principle and by the pushing up force according to Archimede’s law. That leads to beneficial effects especially on the locomotor system and on the cardiovascular system.

In conclusion, the main indications for the geothermal waters from Felix Spa are:

- Inflammatory rheumatic diseases, biologically stable (rheumatoid polyarthritis, ankylosing spondylitis, post acute articular rheumatism).
- Degenerative rheumatic affections: spondylosis (cervical, dorsal, lumbar) accompanied or not by cervicobrachialgias, painful lumbar sciatica, arthroses, polyarthroses.
- Abarticular rheumatic affections (tendinoses, tendinites, tendoperiostoses, scapulohumeral periarthritis).
- Posttraumatic affections (posttraumatic articular stiffness, states following articulations surgery, fractures).
- Affections of the central and peripherical nervous system (hemipareses, various pareses and paralyses).
- Metabolic illnesses: obesity, gout, diabetus mellitus.
- Hypertension stad I and II.
- Endocrine illness like hypotiroidia.
- For prophilaxy.

The main target in the last few years has been to improve the comfort and service quality in hotels and restaurants, as well as the treatment facilities. Up to now, investments were mainly focused to renovate the hotels and parks, and in new and modern installations for treatment.

1.4 Possible heating system for a hotel in Felix Spa

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 city limits of the town of Oradea, at a distance of 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 primary agent provides all the thermal energy required for space heating and for hot tap water. Until 13 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 hopefully near future, the hotels will be owned by private companies, and it is to be expected that these companies will consider the possibility to use geothermal energy for space and tap water heating. It seems reasonable to assume that, at least for the first years, the capital available for investment will be rather limited. This could be different if a hotel were to be owned and operated by a foreign company. In any case, a geothermal heating system will be selected, which minimises changes to the current system by making use of the existing installation (i.e. standard cast iron radiators for space heating). Furthermore, modifications due to the new system could 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 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 design outdoor air temperature for the Oradea area is -7°C. Slightly lower temperatures are occasionally encountered but, as Karlsson (1984) 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 maximum temperature demand intensity (Td), defined as the difference between the indoor and outdoor temperatures that has to be replenished by the thermal energy supplied by the heating system, is therefore 25°C for the conditions stated above. The multi-annual average of the number of degree-days is DD = 2,870.

A hotel with 200 rooms is considered average sized for Felix Spa. 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 maximum thermal power demand for heating an average hotel as it was defined above is therefore $P_{u\,max}$ = 437.5 kW.

The maximum number of guests that can be accommodated in this average hotel is approximately twice the number of rooms, which means 400 people. The average daily consumption of domestic hot water per capita is considered to be 100 l/s. 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 temperatures of the fresh and domestic hot water are considered 15ºC and 65ºC respectively. The thermal power required for heating the tap water is therefore P_w = 146 kW. 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 Felix Spa reservoir capacity.

The following geothermal heating system was selected considering available information and the experience gained in this field in other countries (such as Iceland, France, U.S.A.). For the available wellhead temperature of the geothermal water and the maximum inlet and outlet heating water temperatures, systems employing heat pumps were found to be more economic. The basic arrangement of the proposed geothermal heating system for the hotel is presented in Figure 2.

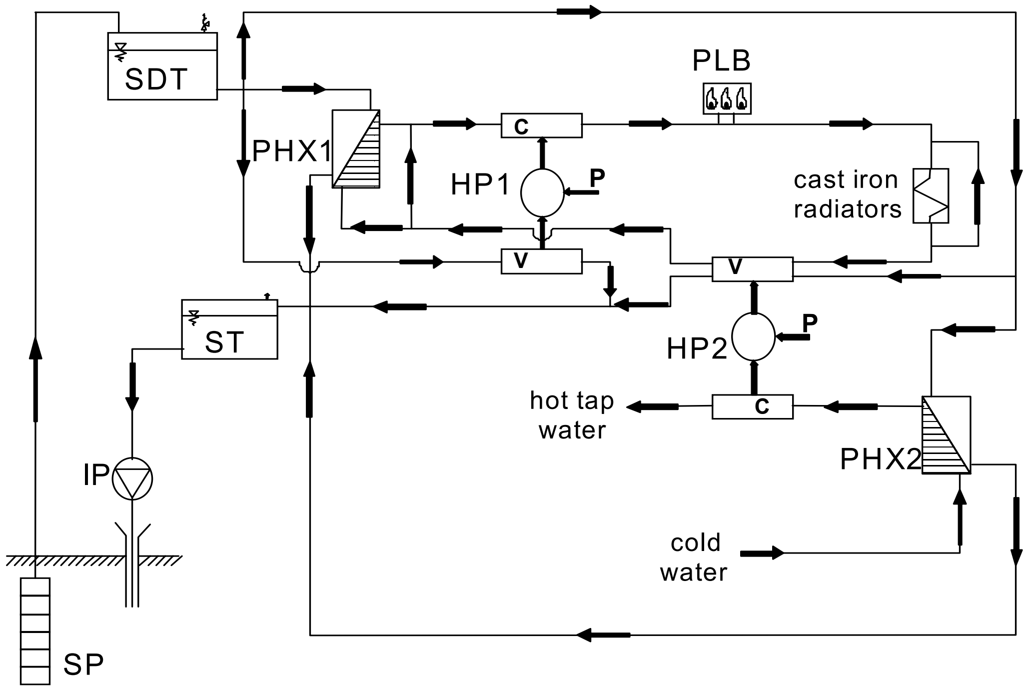

Figure 2: Hotel heating system layout (Rosca, 1993).

The system is basically a 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 the well head temperature (T_g). During the periods of time when the heat pump is working at partial loads, it is not desirable to regulate its speed continuously in order to ensure all the time the required inlet temperature for the radiator water. It was 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 regulating 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 insures 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 (out of the heating season), geothermal water at the well head temperature T_g can be fed to the evaporator of the HP2.

It is 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 and 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 economic 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.

The thermal power demand duration curve plotted by using the calculated data is presented in Figure 3. 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:

- Thermal energy from the peak load boiler: $E_b = 86.64$ MWh;
- Thermal energy from geothermal water: $E_g = 1{,}790.21$ MWh;
- Mechanical energy from the heat pump compressors: $E_m = 251.28$ MWh.

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

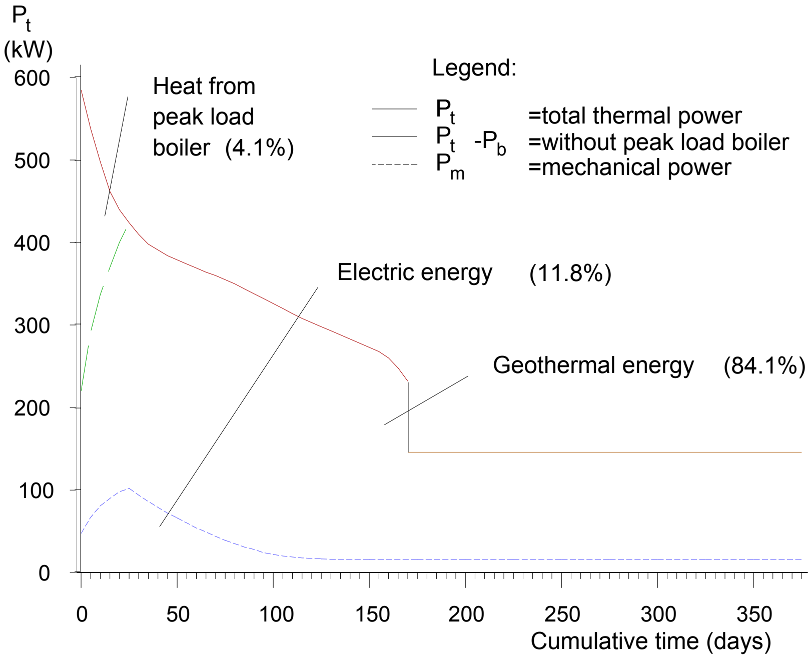

Figure 3: Power demand duration curve (Rosca, 1993).

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

HP2:
- heating power: $P_{h2} = 59$ kW
- mechanical power: $P_{m2} = 16$ kW
- electrical power: $P_{e1} = 19$ kW

The calculated heat transfer areas of the two heat exchangers are $A_{HX1} = 12.6\ m^2$ and $A_{HX2} = 6\ m^2$ respectively.

Considering the existing peak load boiler as an old 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 was calculated as F = 9,790 kg.

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 still suffering a transition process, from a centrally planned system towards a free market economy. In this situation prices are changing fast and at an uneven rate, due to a rather high inflation rate, changes in the subsidising policy, and changes in the taxation. 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 expected to be implemented in the near future, after the privatisation has been concluded and investment capital becomes available either from own resources or from bank loans at acceptable interest rates (current annual interest rates for loans are about 60%, 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 stabilised and the problems outlined above less acute. For the above reasons, it was considered appropriate to carry out the economic appraisal of the project on the basis of economic conditions prevailing in the European Union, all costs being given in Euros.

The capital investment, comprised of purchasing and installation costs for all equipment required for the new heating system, engineering costs, and additional costs due to contingencies, was estimated at $C = 270$ kEuro. It has been assumed that the company finances the investment to the tune of 50% through own capital resources (equity contribution - Q) and 50% by a fixed interest loan raised from a bank (debt contribution - D).

The annual running cost of the project comprises the costs of electricity, boiler fuel and geothermal water, maintenance costs (purchase and stocking of spare parts, wages of maintenance staff) and wages for the personnel required to operate the geothermal heating system, and was estimated at $R = 82.6$ kEuro.

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. For the specific cost of the thermal energy supplied by the power plant of $c_p = 0.043$ ECU/kWh, the annual earnings of the project are $E = 121.9$ kEuro.

The annual running cost and earnings are considered constant for all 20 years of the estimated life span of the project, and inflation is not considered. 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. All the financial rates are also considered constant over the project lifetime. This may not reflect real life practice, but is sufficiently accurate for a pre-feasibility study. A yearly compound period is considered for all payments.

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.

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 materialise) and for lost opportunity (to spend the money on other, more profitable, ventures). For a hotel owning company, a discount rate of $r = 9\%$ is considered to be reasonable. Assuming that the pay back time for the bank loan equals the project lifetime and an annual interest rate of $i = 8\%$, the CRF for the loan becomes: $CRF(n,i) = 0.1019$

The Discounted Cash Flow analysis results are:

- Annual debts charges (annuity): $C = D\cdot CRF(n,i) = 13{,}756.5$ Euro
- Annual depreciation of equity: $p = Q/n = 6{,}750$ Euro
- Total annual tax allowances: $A = C + p + R = 103{,}106.5$ Euro
- Taxable annual earnings: $X = E - A = 18\ 793.5$ Euro
- Annual tax: $T = t\cdot X = 5{,}638$ Euro
- Net earnings after tax: $N = E - R - T - C = 19{,}905.5$ Euro

The indices for evaluating the economical feasibility come out as:

- Net Present Value: NPV = 46,785.4 Euro
- Internal Rate of Return: IRR = 13.6%
- Discounted Pay-back Time: DPT = 11 years

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, although not very high, is still positive. This means 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 not only possible, but most probable that the inflation will be significant in Romania in the near future, although not as high as now and more constant. This means that the interest rates charged on a bank loan 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. The influence of inflation 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 economic viability of this project. Fossil fuel prices are expected to increase in the future, combined with announced environmental energy taxes. This will make a geothermal heating system more profitable.

A detailed reservoir simulation model is required to estimate the potential of the Felix Spa reservoir 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. 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).

1.5 Heating system for the medical recovery hospital in Felix Spa

The medical recovery hospital in Felix Spa was built in the early 1970’s, and since then has provided prophilaxy, treatment and physical rehabilitation to about 60,000 people. The building has four floors, the ground floor for the treatment facilities, the upper three for mainly offices, a small canteen on each floor, and two-bed rooms totalling 50 beds. The outer walls are 25 – 30 cm thick, made of gas-formed concrete bricks. The total surface area of the building is 2,798.13 m^2, and the total volume 7,843.44 m^3. The nominal load for space heating is about 200 kW, and the annual heat consumption is about 2,500 GJ. As in all heating systems in Romania, cast iron radiators are used for space heating (90-70°C type system). The heating agent was initially supplied by heavy fuel oil fired boilers, and at present by primary heating agent from the low grade coal-fired co-generation power plant in Oradea.

The geothermal well 4011, located closest to the hospital, has a wellhead temperature of 49.5°C and a wellhead pressure of +14 mH_2O at a production flow rate of 100 l/s. The geothermal water is used as hot tap water (average flow rate 0.6 l/s) and for hydro-kineto-therapy in tubs and in one indoor and one outdoor swimming pool (at 36-37°C). The nominal load for hot tap water heating (including bathing) is about 90 kW, and the annual heat consumption is about 2,840 GJ.

Although the medical equipment was well maintained, renewed and kept as much as possible up-to-date, that was about all the low budget of the Ministry of Health could afford. The building now badly needs a thorough renovation, but unfortunately nobody knows when the needed funds will be available. The management of the hospital investigated the possible solutions for supplying the thermal energy for space heating from other sources, such as geothermal water and natural gas (as a distribution network is planned to be built in Oradea in the near future, and might later be extended to Felix Spa). Two technical solutions were investigated:

1. To change the space heating system to floor heating, which would allow for the geothermal energy to cover the nominal load, but at a higher capital investment cost.
2. To keep the existing cast iron radiators, use geothermal energy to supply space heating base load, and to use natural gas fired boilers for peak loads. This option should obviously have a lower capital investment cost.

The calculations have been carried out following a methodology similar to that used for the hotel (above). In both cases, the heating agent (secondary fluid) for space heating will be chemically treated water, heated by geothermal water in plate heat exchangers up to 46°C. For the first technical solution, the space-heating load will be regulated by controlling the flow rate of the thermal agent, while keeping the inlet temperature constant. For the second technical solution, the secondary fluid flow rate is constant, and the inlet temperature will be controlled. The geothermal energy will supply the base load for space heating, up to a temperature demand intensity (T_d) of 12°C, higher loads being supplied by the natural gas fired peak load boiler. About 30% of the annual heat consumption for space heating (750 GJ) will be supplied by about 21,000 m^3_N of natural gas.

In both cases, the replacement of the geothermal water supply pipe will be required (pre-insulated buried pipe was considered). As the well is only about 500 m from the hospital, it should be almost no temperature drop in the supply pipe. In order to decrease the geothermal water temperature down to 36-37°C for health bathing, the inlet geothermal water (having almost the wellhead temperature) will be mixed with heat depleted geothermal water. For this reason, and because reinjection might become mandatory in the future (except for the water used for bathing), geothermal water will no longer be used directly as hot tap water, but it will be used to heat up cold water (in plate heat exchangers). In this way, the outlet temperature of the heat depleted geothermal water will decrease, a lower volume of water being needed per year for the same heat consumption.

The estimated capital investment cost will be the same for both cases; for the primary (geothermal) network (about 10,000 USD), and for the control and monitoring equipment (about 28,000 USD). The capital investment cost for the heat plant (plate heat exchangers, circulation pumps, piping, fittings, etc.) will be about 13,500 USD for the first technical solution, and about 16,000 USD for the second, due to the peak load boiler. The capital investment for the first option will also include about 37,500 USD for the secondary network (floor heating system), whereas no additional cost is needed for the second option. Therefore, the total capital investment is 54,000 USD for the second option and 88,000 USD for the first one (34,000 USD higher).

Only the energy costs have been considered for the annual running costs of the two analysed technical solutions. The annual electric energy cost will be about 1,500 USD for each of them (mainly for the circulation pumps). For the second option, the 21,000 m^3_N of natural gas will cost annually 3,150 USD (at the current price of 150 SUD / 1,000 m^3_N). At present, the hospital (property of the Ministry of Health) is purchasing the geothermal energy from the Felix Tourist Company S.A. (still State owned, but going to be privatised, which has the long-term concession to exploit the geothermal reservoir), at a unit price of about 2.5 USD/GJ, about half of the unit price of heat supplied by the co-generation power plants. It is not clear how this unit price will change in the future, but in the current condition the annual cost of the geothermal energy will be about 13,350 USD for the first technical solution, and about 11,475 USD for the second. Therefore, the total annual energy cost will be 14,850 USD for the first option, and 16,125 USD for the second (1,275 USD higher).

In conclusion, in the current energy market conditions, the difference of 34,000 USD in the capital investment cost (higher for the first option) will be recovered from the difference in the annual energy cost only (higher for the second option) in about 26.7 years, which is a rather long time. However, by the time the funds will be available, the energy market might be quite different, as well as the property status of the involved institutions, so that the economic feasibility will have to be assessed again.

2 The Calimanesti-Caciulata spa

2.1 Introduction

The Calimanesti-Caciulata spa is located at the southern limit of the Southern Carpathians, at the downstream end of the Olt river defile, between the Vinturarita calcareous massif in the western part and the Olt river's left bank in the eastern part (Figure 4), on the E15 A highway, 18 km north of Ramnicu Valcea and 18 km south of Sibiu. The Calimanesti-Caciulata spa has 2,500 beds in 1 to 3 star hotels (of which Hotel Cozia has its own treatments facility), and 570 beds in 1 to 4 star villas. The Institute of Physical Medicine, Balneology and Medical Recovery, of the "Carol Davilla" Medicine and Pharmacy University of Bucharest has a clinic in the Calimanesti-Caciulata spa.

2.2 Therapeutic effects of the mineral and thermo-mineral waters

The mineral water springs from this area are first mentioned in the chronicles of the Roman campaigns, and by the middle of the 19th Century these waters were bottled and sold in France, being similar to the waters of some French spas (Chapelle, Eaux Bonnes, and Chatelguyon). The cold mineral waters (8-10°C) from the 12 natural springs in the area contain sulphate, chlorine, sodium, iodine, brome, calcium, etc., and are used in internal cures for the treatment of kidney diseases (nephritis and pielitis, having diuretic and anti-inflammatory effects), liver, bile, bladder, and stomach diseases (stimulates the gastric and bile secretions, favours the glycogen retention in the liver). These waters also have an anti-allergic effect and decrease the pathologically high glycaemia.

The shallow thermo-mineral waters (produced by 9 shallow wells) are of the sulphate-sodium-chlorine-brome-iodine type, with calcium, having a TDS up to 18 g/l. The deep thermo-mineral waters (produced by 3 wells about 2,500 m deep) are of the sodium-chlorine type, with calcium and iodine, having a TDS of about 2 g/l. These waters are used in external cures for the treatment of stabilised inflammatory rheumatism, degenerative rheumatism (arthrosis, spondilosis), degenerative articulation diseases of elderly people, peripheral neural diseases (neuralgia, neuritis, etc.), chronic gynaecologic diseases, and (by inhalation) for the treatment of some respiratory system diseases (rhino-pharingitis, chronic sinusitis, chronic bronchitis, bronchic asthma).

2.3 The geothermal reservoir

The crystalline rocks are assigned to two overthrust nappes: the Getic Nappe and Overgetic Nappe, being represented by two complexes belonging to the Sebes-Lotru series: the paragneiss complex that is situated in the lower part; and the paragneisses with amphiboles complex, in the upper part of the series. The Overgetic Nappe crystalline is represented by the Cozia gneiss's complex that belongs to the Cumpana-Cozia series (Figure 4).

The sedimentary formations include the deposits overthrust by the Getic Nappe, Overgetic Nappe and the sedimentary deposits formed after these two overthrust. Previous geological and hydrogeological research assumed that thermo-mineral water is mixed into sedimentary deposits located above overgetic crystalline rocks (the Cumpana-Cozia series), but the deep geothermal wells 1006 and 1008 evidenced a thickness of these sediments exceeding 3,260 m. The overlap of the sedimentary deposits overthrust by Overgetic Nappe above Getic Nappe sedimentary deposits could be the key of this considerable thickness. This observation allows the inference that carbonate rocks of the Vinturarita calcareous massif continue at the base of sedimentary deposits supplying the thermo-mineral waters.

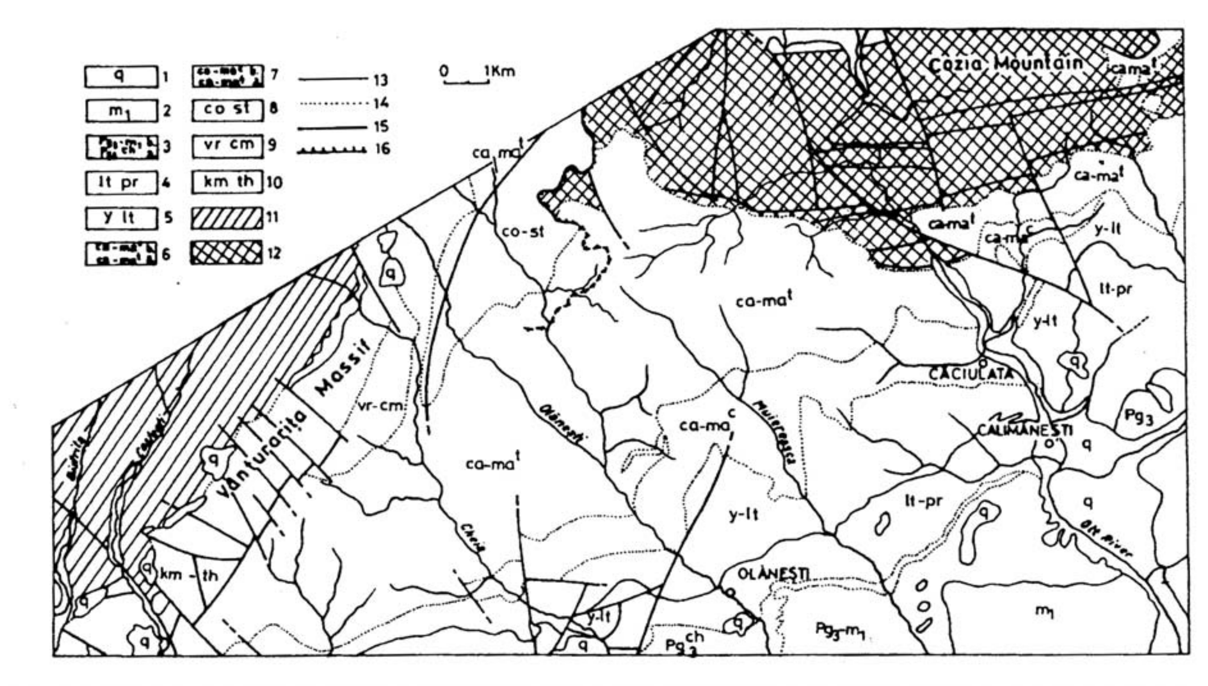

Figure 4: - Geological map of the Vanturarita - Calimanesti zone (Blaga, 1977).

Legend: Quaternary (*q*): 1 - sands, gravel with marls intercalation; *Lower Miocene (m_1,): 2* – Muereasca Sandstones; *Lower Miocene - Oligocene:* 3a. Pucioasa Marls (Pg_3. + m), 3b. Cheia Conglomerates (Pg_3^{ch}); *Eocene:* 4 - Olanesti Marls (lt - pr), 5 - Calimanesti Conglomerates (y - lt); ***Getic Nappe,*** Upper Cretaceus: 6a. Turnu Sandstone (ca - ma^t), 6b. Caciulata Series (ca - ma^c); 8 - gritty, conglomerates, carbonate deposits and quasitlyschy grity deposits: 9 - marls and clays with sandstone intercalations and polimictic conglomerates (co -st); *Jurassic:* 10 - :breccious limestones; *Upper Proterozoic:* 11 - Sebes - Lotru crystaline series; ***Overgetic Nappe***, Upper Cretaceous: 7a. Turnu Sandstone (ca - ma^t), 7b. Caciulata Series (ca - ma^c); *Upper Proterozoic:* 12 - Cumpana - Cozia crystaline serie; 13 - geological boundary; 14 - lithological boundary; 15 - fault; 16 –overthrust boundary.

Two significant hydro-geological cross sections through the Calimanesti-Caciulata reservoir are given in Figure 5. The interpretation of available hydrogeological parameters lead to the conclusion that a complex mixing process of three water types in different proportions combined with a redox process determines the main chemical and physical properties of the thermal and mineral reservoir waters (Mitrofan et al., 1993; Slavoaca et a1., 1991; Blaga, 1977). The three water types are:

- Thermal karstic water (meteoric waters from karstic massifs which cover a large intake area) which supplies the underground water reservoir from depth.
- Mineral and thermal water, chemically similar to brine linked to oil reservoirs, illustrated by the dominant methane content of the solution gas phase.
- Locally infiltrated waters from the Olt river.

The presence of hydrogen sulphide is related to reduction reactions generated by anaerobic sulphate reducing bacteria (*Desulfovibrio Desulfuricans*, *D. Gigas, D. Africanus*) developing in organic matter. Presence of methane and ammonium-like, free and dissolved gases, C_2H_6, C_3H_8, C_4H_{10} and dissolved chemical compounds as HCO_3, Fe, Mn, are strong arguments in favour of main redox reactions.

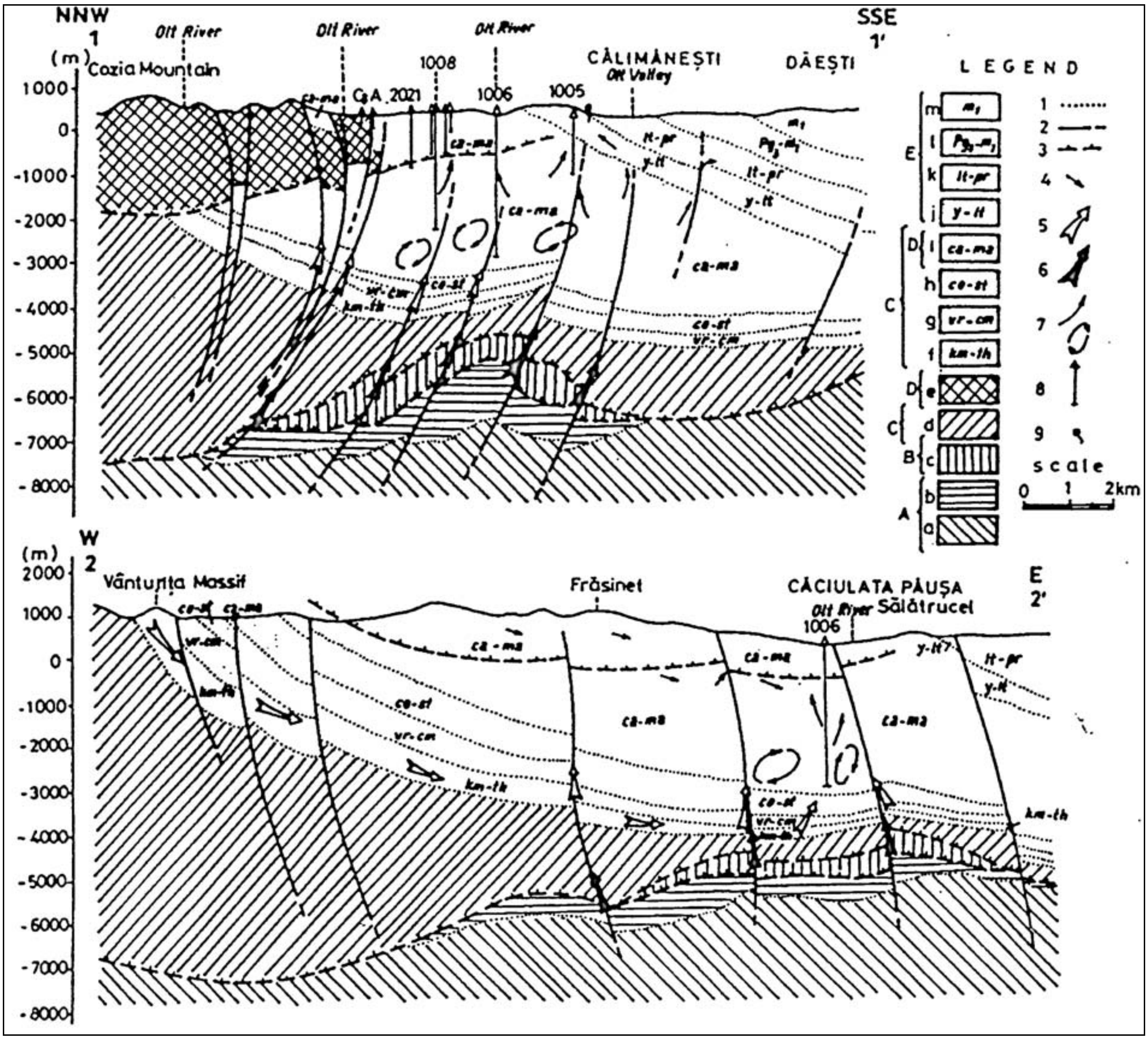

Figure 5: - Hydrogeological cross section. (Golita, 1974).

Legend: ***A - Danubian Domain:*** a - crystalline basement; b – sedimentary formations; ***B - Severin Nappe; C - Getic Nappe;*** d - crystalline rocks (Sebes - Lotru series); f – brecious limestones; g - marls and clays with sandstone intercalation and polimictic conglomerates; h – gritty conglomerate, carbonate deposits and quasiflyschy gritty deposits; i - gritty deposits (Turnu Sandstone) and marls, sandy clays with sandstone intercalation (Caciulata Series) ***D - Overgetic Nappe;*** e- crystalline rocks (Cumpana - Cozia Series); I - gritty deposits (Turnu Sandstone) and marls, sandyclays with sandstone intercalations (Caciulata Series); E - Sedimentary formations formed after getic and overgetic overthrusts; j - conglomerates, sands and breccias (Calimanesti Conglomerate Series), k - Olanesti Marls Series; l - conglomerates, sandstones, clays (Cheia Conglomerates) and black clays, marls, sands (Pucioasa Marls); m –sandstones with marls intercalation (Muiereasca Sandstones); 1 - fault; 2 - overthrust boundary; 3 - waters of infiltration proceeded from local precipitation; 4 - karstic water inflow; 5 - mineral water inflow similar brine; 6 - water of the thermomineral reservoir; 7 - water wells; 8 - mineral spring.

The mixing between mineral and thermal waters with compounds resembling petroleum reservoir brines was proved by Golita, 1974. The most important argument was the chemical similarity between the mineral water from Calimanesti-Caciulata and the water from oil well 614-Bunesti (about 40 km south-west).

Locally infiltrated (meteoric and stream) waters flow through Senonian and Eocene deposits. Piezometric head distributions allowed mixing with local infiltration waters only at shallow levels. Mixing at greater depths may be possible only by aquifers that are supplied at high elevations. Local infiltration waters are responsible for the cooling of the thermomineral waters. The geological map shows that the infiltration intake area is more important in the southern part and less important in the northern part (Bivolari zone) where occurrence of thermal waters has been reported since Roman times.

In order to estimate the reservoir parameters, in October 2000, a relevant well test, using a slick line / quartz memory gauge, was carried out for well 1006 Caciulata (which was selected for the INCO-COPERNICUS project). The well 1006 Caciulata was drilled in 1982 to a final depth of 3,250 m. The well is completed with a 7" casing from top to 2,399 m. The inflow of geothermal water in the well is via open hole between 2,499 – 3,250 m. The well is equipped with a 3½" production tubing from the surface down to 2,266 m.

The test consisted of recording pressure and temperature profiles under dynamic and static conditions and also bottom hole pressure transients i.e. buildup for 14 hours and draw down for 23 hours. Processing of downhole pressure drawdown and buildup sequences, at an average 40 m^3/h self flowing discharge rate, led to the following reservoir / well interface parameters:

- Permeability thickness (kh) = 3,500 mD·m
- Skin factor (s) = 20

Those evidence a low permeability reservoir and a poorly developed well which would definitely require, in the perspective of a significantly increased production via artificial lift instead of the present self flowing mode, alongside well stimulation by acid spotting.

Miklos Antics carried out a computer simulation of the Calimanesti-Caciulata reservoir, in order to estimate its behaviour during a long-term exploitation. The computer code TOUGH2 PC Version, developed by Karsten Pruess at the Earth Science Division, Lawrence Berkeley Laboratory, University of California, was employed for the simulation of the geothermal reservoir. Based on the available geological information, a three dimensional multi-layered model consisting of six stacked layers has been set up. The governing assumptions on which the simulation runs have been based on are:

- The layers are horizontal;
- The reservoir is homogeneous in lateral extent with constant layer thickness;
- The fluid in the reservoir is pure water.

A variable size, squared mesh, grid was selected for the horizontal discretisation. In order to better calibrate the model from available data for well 1006, a radial grid with variable permeability was set up around the well. The boundary conditions were assigned according to the hydro-geological model of the area i.e. vertical inflow from North to South, and lateral inflow from the Olt valley. Considering the fractured nature of the reservoir, the grid space assigned to layer AD has been post processed with the MINC (Multiple Interacting Continua) feature of the simulator taking into account that (i) fractures occupy 5% of the unit volume of the rock; (ii) fractures are spaced in three directions at 50 m; and (iii) local flow occurs between the fracture and the matrix space. Furthermore, the matrix space was assigned a porosity of 1% and a permeability of 0.1 mD (Ungemach et al., 2001).

The natural state conditions of the reservoir were simulated by allocating to the bottom layer a heat source with a unit flux of 80 mW/m^2. The simulation was run for a long period of time, 2.3 million years (corresponding to the development of the reservoir over geologic time), until steady state conditions were reached.

Since there were no production history data available, the model was calibrated on the data provided by the transient pressure tests. There were three models considered: one analytical and two numerical, respectively. The analytical model is a double porosity slab model with infinite boundary and changing wellbore storage. The changing wellbore storage was introduced due to the two-phase flow regime that occurs in the wellbore.

Based on the calibrated model, a long-term production simulation was run for 20 years, considering the seasonal variation of the production flow rates: 11 kg/s in winter (7 months/year), and 6 kg/s in summer (5 months/year), i.e. a yearly average discharge of about 9 kg/s. It can be observed from Figure 6 that in the future, the reservoir behaviour will be very stable, an average 14 bar drawdown being noticed at the end of the last winter period. However, in the meantime the well will recover during the summer production period.

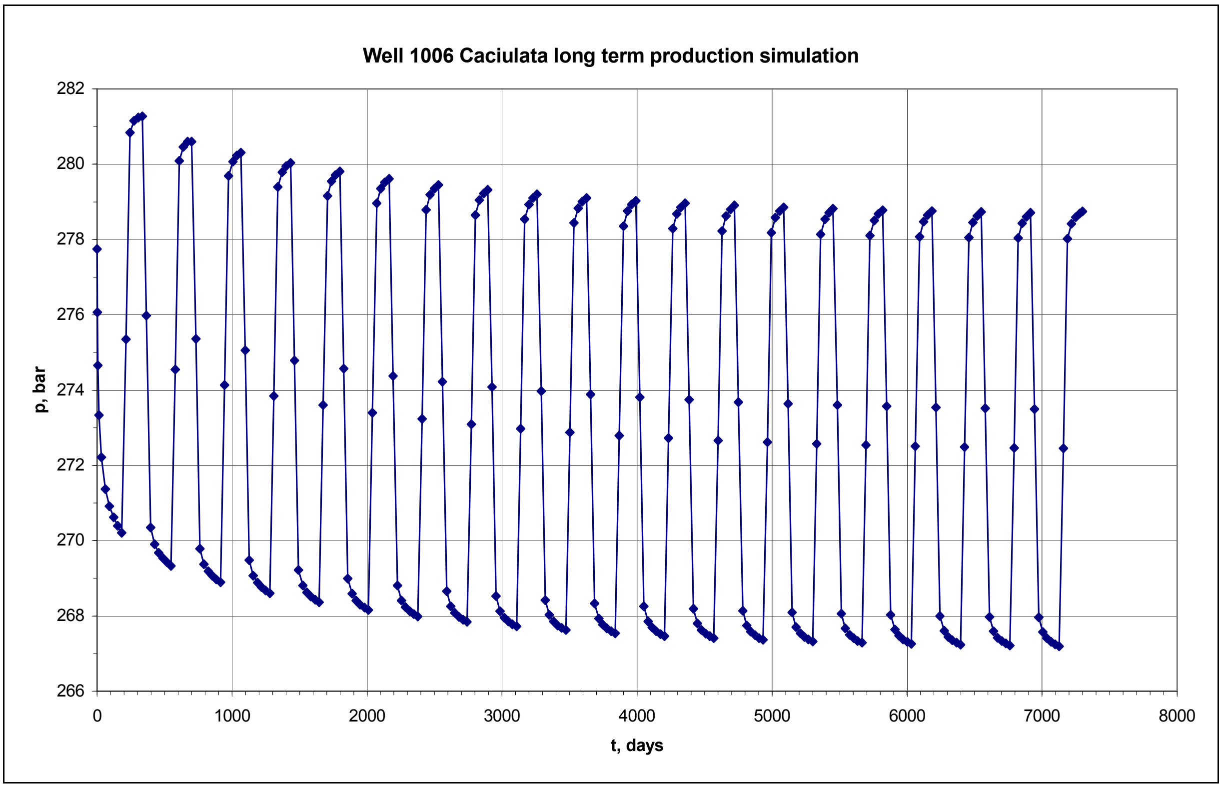

Figure 6: Long term production simulation (by Miklos Antics, from Ungemach et al., 2001).

2.4 Energy supply and demand appraisal

The well 1006 can produce in artesian discharge up to 16 l/s geothermal water with a well head temperature up to 96°C. The geothermal water from well 1006 has a TDS of 18.62 g/l, the main components being chlorine (9.2 g/l), sodium (3.1 g/l), and calcium (2.0 g/l), other components being potassium, phosphate, sulphate, silica, bicarbonate, magnesium, aluminium, and iron. The gas water ratio for a 6 l/s water production flow rate was determined at 2.2 m^3_N/m^3, with an average moisture content of 0.4 kg/m^3_N. The composition of the gases separated from the geothermal fluid produced by well 1006 is given in Table 1. Based on these data, the lower heating value of the separated combustible gases was calculated to be H_i = 28,801 kJ/ m^3_N.

The well operates during winter at a maximum flow rate of 16 l/s geothermal water (57.6 m^3/h), so the corresponding flow rate of the associated combustible gases will then be 126.72 m^3/h. During summer, the well operates at a maximum flow rate of 6 l/s geothermal water (21.6 m^3/h), so the corresponding flow rate of associated combustible gases will then be 47.52 m^3/h. The annual average geothermal water flow rate is 9 l/s (32.4 m^3/h), therefore the annual average flow rate of the associated combustible gases is 71.28 m^3/h.

Table 1: Composition of the associated combustible gas phase (Ungemach et al., 2001).

Gas component	Value [%]
CH_4	79.54
C_2H_6	0.2588
C_3H_8	0.1188
$i\text{-}C_4H_{10}$	0.0146
$n\text{-}C_4H_{10}$	0.0202
$i\text{-}C_5H_{12}$	0.0037
$n\text{-}C_5H_{12}$	0.0022
C_6H_{14}	0.0003
N_2	14.70
CO_2	1.04

By using the associated combustible gases as fuel, the maximum heat flux available by burning it is close to 0.7 MW, therefore an economy of 791 tons can be achieved from these gases alone. Considering a reference outlet temperature of 30°C, the maximum heat flux available from the geothermal water nears 3 MW.

As a result, the investment expenses incurred for building the recovery plant for geothermal gas should be paid back in a short period of time. After processing, the collected data will set up the basis for selecting the type and optimising the design of the combustible gas recovery plant. The on-site analysis showed that, for a first glance, conditions are favourable for implementation on well 1006, owing to the nearby heat load and the availability of onsite housing facilities.

The main users supplied at present with geothermal heat consist of two hotels and a few villas located close to the production well. The geothermal water is used for both space heating and sanitary hot water supply. The heat depleted geothermal brine is used downstream for health and recreational bathing in outdoor and indoor swimming pools, as well as for balneology in the treatment facilities of both hotels suggesting cascading direct uses of geothermal heat.

The larger of the two hotels has a nominal heat demand nearing 700 kW, of which about 175 kW for sanitary hot water and 525 kW for space heating. Under the climatic conditions prevailing in the Caciulata area, the annual heat load is equivalent to about 2,900 degree-days. The annual heat consumption of this hotel is therefore 710 GJ (2,550 MWh), of which 180 GJ (640 MWh) is mobilised by sanitary hot water and 530 GJ (1,910 MWh) by space heating.

The smaller hotel has a nominal heat demand nearing 500 kW, of which ca. 125 kW is for sanitary hot water and 375 kW for space heating. The annual heat consumption of this hotel is therefore 505 GJ (1,820 MWh), of which 125 GJ (455 MWh) address sanitary hot water and 380 GJ (1,365 MWh) space heating.

The villas connected to the geothermal heating system have a total nominal heat demand of ca. 300 kW, of which 75 kW for sanitary hot water and 225 kW for space heating. The total annual heat consumption of these villas is therefore 305 GJ (1,100 MWh), of which 75 GJ (280 MWh) allocated to sanitary hot water and 230 GJ (1,100 MWh) to space heating.

The total nominal heat demand of the geothermal heating system stands at about 1.5 MW, of which 375 kW is allocated to sanitary hot water and 1,125 kW to space heating. The total annual heat consumption of all users connected to the geothermal heating system amounts to ca. 1,520 GJ (5,470 MWh), of which 380 GJ (1.375 MWh) supply hot tap water and 1,140 GJ (4,095 MWh) to the space heating demand.

The geothermal brine used for balneotherapy requires a temperature close to 37°C. When the outlet temperature of the heat depleted geothermal water is not high enough (during the hot season and at low heating loads), it is mixed with the source geothermal water. The annual average outflow temperature of the total amount of geothermal water used for the heating system averages therefore 40°C. Considering 10% heat losses in the system, the maximum geothermal water flow rate required by the heating system is close to 7 l/s, the nominal geothermal installed power standing at 1.9 MW (of which 0.2 MW address medical uses).

A comparison should be made between different types of fuels that can be used for household needs (cooking, heating, etc.), considering that there is no natural gas distribution network in the area. Many potential users welcome the idea of using a gas fuel fed by a pipe network an attractive issue indeed, as storage problems no longer exist, nor residues, nor pollution with ash or pollutant gases whatsoever. In the area of Calimanesti-Caciulata spa, all potential users are eager to use combustible associated gases from geothermal water to meet their domestic needs. The potential users agree to support investment costs for the gas distribution network from the test well to the consumers, but if and only if the supply is ensured daily over at least 2-3 years. Accordingly, they intend to sign a firm contract with the well owners. At these conditions, the well owners agree to sign this contract with end users of combustible gases only after a probative period demonstrating the feasibility of the concept. To the author's knowledge, no contract was signed as yet.

Close to the test well is located another large hotel, with a capacity exceeding 200 rooms, which now uses geothermal water for heating, and requires a clean fuel such as combustible gas for cooking and laundry. Near the well is also located a restaurant and several private buildings which are candidate customers.

2.5 The combustible geothermal gases separation plant

A storage and degassing tank already existed on site, close to the well head, but the separated combustible gasses were wasted and lost (burned at end of a pipe). In order to upgrade the existing degassing vessel performance, the specialists of ICPET Bucharest (the Thermal Energy Research and Design Institute - the technical co-ordinator of the INCO project) and of the GeoProduction Consultants (the scientific co-ordinator of the INCO project) performed a thorough redesign of the geothermal combustible gas processing line. In so doing, the governing rationale consisted of perfecting and complementing the hardware available on site, rather than implementing a new separation/processing system.

The exercise addressed the design of a degasser outfit, a droplet separator and a gas cooler (Figure 7), achieving gas drying and cooling performance compatible with end users' requirements.

- degasser dome: added to the top of the existing horizontal separator vessel, it aims at accommodating the two phase mixture by enhancing the separated gas escape and reducing (draining) water carry over. It elsewhere contributes to lowering gas outlet temperatures;
- droplet separator: acts as demister, therefore diminishing significantly the geothermal gas moisture (carry over and condensate water). As a matter of fact, target design figures allow decreasing by one order of magnitude the former moisture content, which therefore drops from 40% to less than 5% wt a value adequate for downstream geothermal gas utilisation. A silica gel cartridge could be added as a supplementary drying facility to achieve close to 1% moisture content;

- gas cooler: it achieves the ultimate, season wise, drying and cooling figures.

	summer	winter
outlet temperature, °C	32.5	25.5
moisture content, %wt	4	3

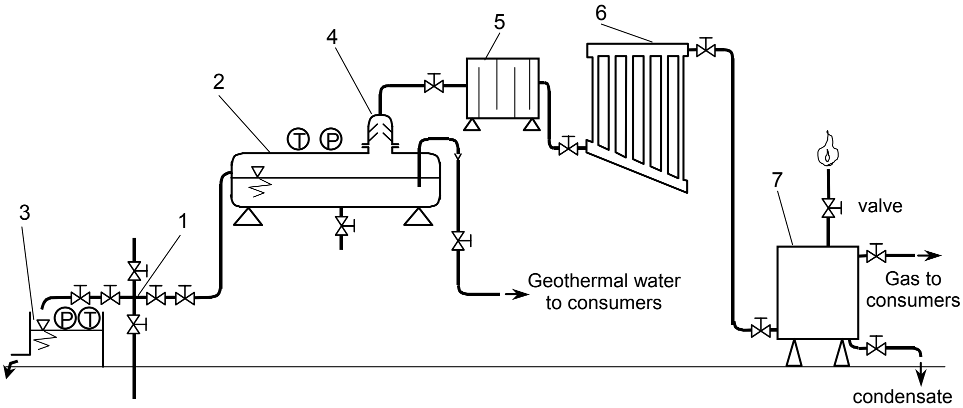

Figure 7: Layout of the plant fitted with equipment for associated combustible gas recovery (Ungemach et al., 2001).

Legend: P – sampling point; T – temperature measurement point; 1 – well head; 2 – degasser; 3 – water flow measurement vessel; dome with chicanes; 5 – droplet separator; 6 – cooler; 7 – gas stocking vessel; 8 – hydraulic valve

The aforementioned degassing, demisting, and cooling equipment was assembled on site in compliance with a compact design, easily accessible to monitoring and maintenance by staff, and environmentally safe with liquid drain pipes, a H_2S filter, and backup air fan facilities added accordingly.

In the future, the following segments need to be finalised:

- Evaluation of existing and potential uses of geothermal heat and separated geothermal gas over the whole Caciulata, Cozia and Calimanesti area;
- Impact assessment of replicate developments of the geothermal gas processing/recovery concept within the neighbouring Central/Eastern European countries enjoying similar, gas rich, geothermal fluid environments and end uses.

Last, but not least, future development prospects, on the investigated area, are appealing and innovative in scope. The geothermal separated gas potential can be readily estimated at about 1.4 million m^3_N (CH_4 equivalent)/yr at present (self flowing discharge) ratings. Would the wells be adequately stimulated by acidising, and their production sustained by artificial lift, this figure could realistically rise up to 2.6 million m^3_N/yr.

This energy source, independently from geothermal water heat exchange, could meet a variety of local demands: heating, hot tap water, domestic uses and, ultimately, power generation. The latter could be designed according to a cogeneration cycle, securing 1 MW_{el} and 1.3 MW_t installed power and heat capacities.

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