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Possible Geothermal District Heating in Sanmartin, Romania

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ABSTRACT

At present, the primary thermal source for both space and tap water heating is supplied by the co-generation power plant located west of Oradea, which has two units fired by natural gas, and three more fired by low-grade coal.

The paper briefly describes the geothermal aquifer, technical solutions for the utilisation of the available geothermal energy for space and tap water heating, and the environmental impact of the proposed technical solution compared to the current situation.

1. INTRODUCTION

Sanmartin is a small village located 7 km east of the City of Oradea, close to Felix Spa. Due to its location, in the vicinity of a large and well-known spa and close to a large town, it has become very popular for building new houses (permanent residences and vacation homes).

At present, space heating and hot tap water is supplied to some private and public consumers by a district heating system. The primary heat is supplied by a combined heat and power (CHP) plant located west of Oradea, about 20 km from the village. The CHP plant, the first unit of which was built in 1966, operates six boiler units and five turbines, with a total capacity of 205 MW_{el} and 180 MW_{th}. Two of the boiler units have been converted to gas with the third one completing conversion in April 2004. The other three boilers are continuing to burn low-grade coal (lignite with an average heating value of about 8.8 GJ per ton) with high sulphur content (2.5% to 3%). The plant has inadequate filtering devices and needs to improve its pollution abatement equipment, if it is to meet tightening standards in the future EU accession.

A second CHP (CET 2) with three boiler units and a capacity of 150 MW_{el} and 150 MW_{th} was built in 1986-87 east of Oradea, about 7 km from Sanmartin, but was only operated for about 15 years. Several accidents forced its shutdown. It was shut down in 2001 and is not expected to restart operations.

Because of overcapacity in the power sector, the first CHP is maintaining operations only because of the commitment to supply heat to Oradea city, the Sanmartin village, and the Felix Spa. The primary network is not only very long, but is also in poor condition, having high fluid and heat losses.

The CHP plant customers pay a flat 20 €/Gcal (about 4.78 €/GJ), which does not cover the full cost of the CHP plant and the distribution network (about 37 €/Gcal, or 8.84 €/GJ). Therefore, the local budget paysalmost 10 €/Gcal to the CHP/DH, and the Central Budget subsidizes the remaining 7 €/Gcal.

Buildings not connected to the district heating system, mainly family houses, are currently using coal and wood fired stoves for space heating or individual boilers fired by wood, LPG, liquid fuels, etc. for space and tap water heating.

The geothermal resource available in the area could supply Sanmartin village with reliable local heat at an affordable price without being subsidised and more stable in time than the heat supplied by the CHP. The use of geothermal energy would also significantly reduce pollutant emission.

As Romania is dedicated to become a member of the European Union in a few years, the legislation relevant for mining (including for geothermal fluids), energy and environment protection is modernised and harmonized with EU principles, supporting the use of renewable energies, including geothermal.

2. THE GEOTHERMAL RESERVOIR

The geothermal reservoir in the Sanmartin area has particular geo-structural conditions. Due to the interconnection of multiple tectonic elements on the contact between the Carpathian Mountains and the Pannonian Basin, as well as to the subsidence of the Borod and Beius intermountain basins, a large number of faults are encountered over less than 20 km^2

The geothermal aquifer in the Sanmartin area is located in heavily fractured limestone between 80 and 175 m deep, and is usually referred to under the name Felix Spa. Although it is separated in space from the Oradea reservoir, both horizontally and vertically, the two geothermal reservoirs are hydro-dynamically connected, being a unified hydro-geothermal system, actually the final part of the Mesozoic regional hydro-structure Padurea Craiului. The natural springs and the wells in the area have a similar hydrodynamic behaviour, with rapid interference effects.

The natural recharge rate was calculated at about 300 l/s based on the only interference test carried out in 1979 (Paál, 1979). The hydro-geological (Cohut & Paál, 1985), hydro-chemical (Ţenu, 1981), and geothermal (Veliciu, 1986) research proved that the reservoir is recharged via a deep pathway along an important structural line (the Velenta fault, oriented NE-SW), excluding the lateral recharge.

The convective system in the Oradea area is recharged from the East, mainly through the system of faults and fractures delineating the Borod basin, but also through strata surfaces. Cold waters infiltrated in the karstic areas of the Padurea Craiului Mountains are flowing westward and downward, reaching higher temperature layers, and are starting the thermal convection process in the entire Triassic carbonate stack, 500 to 800 m thick.

The variation of the average geothermal gradient in the Oradea area from 2.5°C per 100 meters in the east, to 4.5°C per 100 meters in the west, over only 10 km, while the geothermal heat flux density is constant, can only be the consequence of the convection caused by the inflow of colder water from the east, along a major fracture network know as the Velenta fault, along which the main part of the water is channelled to the Felix Spa area.

2.1 Physical and Chemical Properties of the Water from the Felix Spa Reservoir

In reservoir conditions, the fluid from the Felix geothermal reservoir is a complex sub-saturated solution of dissolved solids and gasses. The content of total dissolved solids (TDS) is 0.9-1.3 g/l, the main ions being Ca, Mg, Na, K, Li, Sr, Mn, and Fe. The phenolic compounds and organic substances are below the lower limits acceptable for surface waters, therefore no further toxicity tests have been carried out. There are low concentrations of non-condensable gasses (NCG), mainly CH_4 and traces of CO_2.

The geothermal water contains, in concentrations above those admissible for potable water, Radium 226 and Radon 222, which is a natural radioactive gas resulting from the disintegration of Radium. The concentrations are between 0.5 and 3.5 pCi/l for ^{226}Ra and between 0.5 and 3.2 pCi/l for ^{222}Rn, which makes the geothermal water undrinkable, but also strongly contributes to its therapeutic effect in health bathing.

The physical properties of the geothermal fluid have been determined for the reservoir conditions in 1980 exclusively based on their variation with the temperature and mineralisation, the values being:

- saturation pressure: 0.2 MPa;
- density: 992 kg/m^3;
- dynamic viscosity: $0.65 \cdot 10^{-3}$ Pa·s;
- compressibility coefficient: $4.55 \cdot 10^{-4}$ MPa^{-1};
- volume factor: 1,033;
- specific heat: 4,162 kJ/kg:
- thermal conductivity: 0.683 W/m/K.

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. As the reservoirs are located in fractured limestones, no sand was reported to exist in the geothermal water.

2.2 The Available Geothermal Energy

The exploitable flow rate (without reinjection) from the Oradea and Felix Spa reservoirs was set by the National Agency for Mineral Resources to 300 l/s annual average (the natural recharge flow rate), in order to prevent reservoir pressure decline during long term exploitation..

Felix Spa is probably the best known of the Romanian spas, and definitely the largest. It 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.

Therefore, the geothermal water supply for Felix Spa was considered a priority. The total exploitable flow rate in Felix Spa was set by the National Agency for Mineral Resources to 210 l/s annual average, in order to prevent the 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 45ºN) and therefore a tourist attraction.

The remaining 90 l/s annual average flow rate can be produced from the Oradea reservoir. A higher exploitation will only be approved by the National Agency for Mineral Resources if at least the additional extracted flow rate will be reinjected.

Out of the 9 geothermal wells drilled in Felix Spa, only 6 are currently in use. The two oldest 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 by artesian discharge.

The geothermal water demand in Felix Spa can only be estimated, as the real consumption is not metered and therefore there are no data available. The geothermal water is only used for health bathing, and the consumption was estimated at 100 – 110 l/s, with the peak load during the summer, when it is used in all outdoor swimming pools for recreational bathing as well.

It can thus be estimated that, from the total flow rate approved by the National Agency for Mineral Resources, about 100 l/s is available for energy uses in the Sanmartin village.

Temperature and flow rate measurements have been carried out for all wells and natural springs in the area of the Felix Spa reservoir. The average wellhead temperature of the geothermal water from the wells closer to the Sanmartin village is 42°C. Considering a 20°C reference temperature for the heat depleted geothermal water, the heat flux available for energy uses in Sanmartin is:

$$\dot{Q}_g = \dot{m} \cdot c_w \cdot \Delta T = 0.1 \cdot 4.165 \cdot 22 = 9.16 \ \text{MW} \qquad (1)$$

This means that the maximum annual geothermal energy available for the Sanmartin village is about 290,000 GJ (or about 70,000 Gcal). The production cost for this energy should be relatively low, as the wells are already drilled and are all free flowing. If this geothermal energy is used, it will replace heat produced by fuel combustion (low-grade coal and natural gas in the CHP, wood and coal in stoves or LPG and liquid fuels in boilers in many family houses). The resulting pollution reduction is an important advantage, especially for a spa and tourist area.

3. THE HEAT DEMAND OF SANMARTIN VILLAGE

The Romanian national standards (STAS) for space heating refer to buildings with regular thermal insulation, equipped with standard (cast iron) heaters, and under permanent use (with only short term space heating system turn offs). 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.

Based on recorded meteorological data, three climatic areas have been set for Romania, with the daily average outdoor temperatures considered for the calculation of the nominal space heating load set at:

- Area I: -12°C;
- Area II: -15°C;
- Area III: -18°C.

Oradea area, including the Sanmartin village, is of the first type, therefore the daily average outdoor temperature for which the nominal load for space heating is calculated should be –12°C.

The lowest multi-annual average value of the daily average temperature in Oradea (data recorded by the Meteorological Institute) is -4.9°C, with a minimum of about -7°C. The design outdoor air temperature for the Oradea area will thus be considered as -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 absolute 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 (T_d), 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. The temperature demand intensity duration curve for the Oradea area is depicted below in Figure 1.

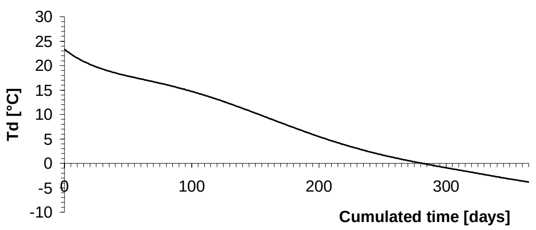

Figure 1: Temperature demand intensity duration curve for Oradea area

In the design practice, the nominal heat load of a building can be estimated with a good approximation using equation (2):

$$\dot{Q}_{sh} = K \cdot V \cdot \Delta T \qquad (2)$$

where:

- $\dot{Q}$ [W] – nominal heat demand
- V [m^3] – air volume to be heated
- $\Delta T = T_i - T_o$ [°C] – difference between the indoor and outdoor temperatures
- T_i [°C] – indoor temperature (18°C)
- T_o [°C] – outdoor temperature (-7°C)
- K [W/m^3/°C] – global heat loss coefficient

According to data supplied by the Sanmartin town hall, the total area of the buildings in the village is 55,055 m^2. For a standard 3 m height for residential buildings in Romania, the total air volume for space heating load calculation is V = 165,165 m^3.

The older buildings have a poor thermal insulation, having thin brick or concrete walls with no additional insulating layers, and poor quality windows. The new family houses (and a few older ones which have been renovated) have much better insulation (thicker walls, polyurethane layers, "thermopan" glass windows). The average global heal loss coefficient has therefore been estimated as K = 1 W/m^3/°C.

With these values, and using equation (2), the nominal space heating demand for the entire village is:

$$\dot{Q}_{sh} = 1 \cdot 165.165 \cdot 25 = 4{,}129.1\,\mathrm{kW} \cong 4.13\,\mathrm{MW} \qquad (3)$$

The results obtained by this method are close enough to those obtained by the more accurate and more detailed method specified by STAS 1907/68, if the global heat loss coefficient value is reasonably well estimated.

The annual heat consumption is equal to the surface area of the heat load duration curve (and therefore proportional to the number of degree-days), which is identical to the temperature demand intensity duration curve (Figure 1), having on the vertical axis the heat flux instead of the temperature demand intensity. In Romania, according to current legal regulations, the heating systems supplied by CHP's are turned on when the daily average temperature is below 10°C for three successive days, and is turned off when it is above 10°C for three successive days. Therefore, in quite a few fall and spring days the indoor temperatures go well below the standard 20°C.

A geothermal heating system can easily be turned on and off whenever necessary, so that it can cover the entire heat demand, even at very low partial loads. Therefore, the average heating season for a geothermal system in Sanmartin village is 270 days.

The annual thermal energy consumption for space heating of the entire Sanmartin village is about 43.6 TJ, (about 12.1 GWh, or about 10,500 Gcal).

The heat flux required for the hot sanitary water heating is proportional to the number of persons to be supplied by the system (2,646, according to data from the town hall), the average flow rate required by one person ($1.4 \cdot 10^{-3}$ kg/s), the specific heat capacity of water (4.17 kJ/kg/°C), and the difference between the standard hot tap water temperature (50°C) and the average cold water temperature (10°C for Oradea):

$$\dot{Q}_{hw} = n \cdot \dot{m} \cdot c_w \cdot \left(T_{hw} - T_{cw}\right) \qquad (4)$$

where:

- n [-] – number of persons supplied
- $\dot{m}$ [kg/s] – average flow rate per person
- c_w [kJ/kg/°C] – specific heat capacity of water

- T_{hw} [°C] – standard hot tap water temperature
- T_{cw} [°C] – average cold water temperature

With the above data and using equation (4), the heat flux required for heating the sanitary hot water (constant all year round) for the entire population of the Sanmartin village is:

$$\dot{Q}_{hw} = 2{,}646 \cdot 1.4 \cdot 10^{-3} \cdot 4.17 \cdot 40 = 617.9\ \text{kW} \quad (5)$$

The annual thermal energy consumption for tap water heating of the entire Sanmartin village, for a constant consumption all year round, is about 19.5 TJ, (about 5.4 GWh, or about 4,700 Gcal).

The total annual thermal energy consumption for both space and sanitary hot water heating of the entire Sanmartin village is about 63.1 TJ, (about 17.5 GWh, or about 15,200 Gcal).

The maximum heat flux demand of Sanmartin village ($\dot{Q}_d$) is the sum between the nominal heat flux needed for space heating and the heat flux needed for tap water heating:

$$\dot{Q}_d = \dot{Q}_{sh} + \dot{Q}_{hw} = 4.13 + 0.62 = 4.75\ \text{MW} \quad (6)$$

This only represents 51.86% of the heat flux from the geothermal water flow rate available for energy uses in the Sanmartin village. Even if the estimation of the maximum heat flux demand is not very accurate, it is obvious that the available geothermal energy will be sufficient to supply the new housing developments in the Sanmartin village area.

The maximum heat flux available from the Felix Spa geothermal reservoir is 19.24 MW, which has been calculated for the 210 l/s annual average flow rate approved by the National Agency for Mineral Resources, and for the 42°C and 20°C wellhead and reference outlet temperatures respectively, as used to calculate the heat flux available for Sanmartin village. The possible utilisation of this maximum heat flux is depicted in Figure 2.

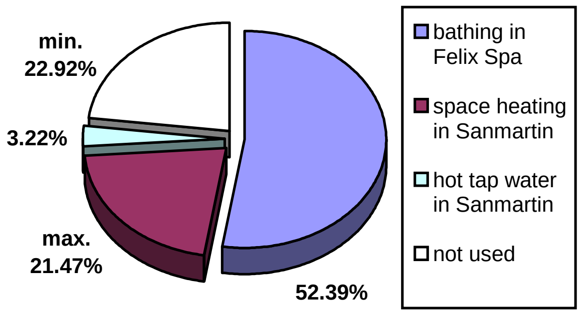

Figure 2: Utilisation of the heat flux available from the Felix Spa geothermal reservoir

Of the 19.24 MW, the annual average heat flux used in Felix Spa for health and recreational bathing is 10.08 MW (52.39%). Of the remaining 9.16 MW, about 0.62 MW (3.22%) could be used for hot tap water heating in Sanmartin, and the maximum heat flux needed for space heating for all buildings in Sanmartin is 4.13 MW (21.47).

A minimum of 4.41 MW (22.92%) remains unused, which goes up to 8.54 MW (44.39%) during the warm season, when no space heating is require. This allows for the development of the possible geothermal heating system in Sanmartin to new houses to be built in the future, or for some energy uses in Felix Spa.

4. POSSIBLE TECHNICAL SOLUTIONS FOR GEOTHERMAL ENERGY UTILISATION

The geothermal water wellhead temperatures in Felix Spa being below 50°C, classical district heating systems can not be considered. Standard cast iron radiators are usually sized for 90°C inlet and 70°C outlet temperatures at nominal load, or 80°C and 60°C respectively.

As mentioned before, the average temperature of the geothermal waters available from the wells closest to the Sanmartin village is 42°C. By using a plate heat exchanger, the secondary fluid can only be heated up to maximum 40°C, which is below the standard value for the hot tap water temperature.

Two types of heating systems will be presented below, differing by the secondary fluid, namely air or water.

4.1 Space Heating Systems with Air

One possibility is to ventilate warm air heated by the geothermal fluid with a rather low temperature. Water-to-air heat exchangers with large enough heat exchange areas can heat the air up to 25 – 30°C, a part of the outflow air being recirculated. The available geothermal water temperature can cover the space heating base load. Peak load boilers can be used at very low outdoor air temperatures, to increase the water temperature. An additional boiler is needed to increase the hot tap water temperature up to the standard value of 50°C.

This type of system could be economic to use mainly for large size buildings, such as blocks of flats, school, town hall, etc. For small individual houses the cost of equipment (ventilator, water-to-air heat exchanger, air ducts, water pipes, valves, fittings, automation, etc.) and their installation is rather high.

Another option, very popular at present mainly in developed countries, is to use a reversible "water-to-air" heat pump for air conditioning. In this case, the same equipment is used for both heating and cooling, only the refrigerant flow being automatically reversed as required by the outdoor conditions.

When space heating is needed, the heat flux extracted by the refrigerant in the vaporizer can be supplied directly by geothermal water, or by an intermediate fluid (water) heated in heat exchangers by geothermal water and piped to each consumer.

When space cooling is needed, the heat flux is extracted by the refrigerant in the vaporiser from the indoor air, the condenser being cooled in the outdoor air or by cold water. For large size buildings, mainly in spring and fall, the system can provide cooling in certain rooms (on the sunny side), and heating in the other rooms.

The advantages of reversible heat pumps are:

- provide high thermal comfort all year round;
- have a high energy efficiency;
- cause no on site pollutant emissions;

- have relatively small size;
- are flexible, compatible with any building;
- are reliable, with low maintenance costs;
- silent operation.

The total cost of these type of installations is not very high, and in the right energy market prices it is usually paid back in 4 to 6 years. The running cost for cooling might not be affordable at present for a many of the village inhabitants in Romania, but this is expected to change in the mid term future. People building new houses in Sanmartin village (close to Felix Spa), have higher than average living standard and are willing and can also afford to pay for good thermal comfort in their houses.

4.2 Floor Heating Systems

From all possible space heating systems using water as the thermal agent, only two can be considered in Sanmartin village if the low temperature geothermal fluid is to be used, namely floor heating and heat pump assisted systems.

Obviously, the simplest system is floor heating. It only requires heat exchangers (usually plate type, which can easily be disassembled and cleaned in case of scaling) in which the geothermal water is heating the secondary fluid for space heating up to 40°C. The secondary fluid is then distributed to all consumers, where it flows through pipes laid under the floor tiles. The heat supply is controlled by regulating the flow rate (using variable speed drives for the circulation pumps), while the inlet temperature is kept constant. It is a very efficient system mainly for new buildings, having a relatively low cost, and also being reliable, comfortable, and aesthetic (no visible radiators). One important advantage is that, as only low temperature water is circulated through the distribution network, the heat losses are lower than in classical systems.

The buildings should be supplied with thermal energy through two heat exchangers. The first one will be used for energy supply to the ground floor heating systems, and the second for sanitary water preheating. The preheated water will feed the water heaters or the boilers of the buildings. Alternatively, if additional energy savings are desired, the water heaters or the boilers can be replaced by heat pumps.

4.3 Heating Systems with Heat Pumps and Fan-Coils

Although floor-heating systems are very effective in terms of geothermal energy utilization, their application is limited to new buildings only. In existing buildings, in order to completely eliminate burning of fossil fuels, existing high temperature heating systems should be replaced by low temperature ones. A water source low temperature heating system, instead of radiators based on free convection, usually has a central air-handling unit for conditioning ventilating air, coupled with a series of fan-coils for space heating. These are commercially available water to air heat exchangers based on forced convection.

Such a system is under construction in Langadas, a small town near Thessaloniki in Greece, for heating and cooling of several public buildings, including schools, the revenue service building, and the spa hotel. Overall heating needs of the buildings amount to 1.5 MW_{th} approximately, which will be supplied by water source heat pumps placed in cascade, fed by 25 l/s of groundwater 22-36 ºC available at the local spas premises (Mendrinos et al, 2002). The heat pumps will supply 40-45ºC water to the buildings during winter, and 7ºC water during summer. The flow chart of the Langadas district heating scheme is presented in Figure 3.

When completed, the project will include the district-heating scheme for the greenhouse (880 kW) and the spa hotel of Loutra (350 kW), as well as the schools and other public buildings (1,220 kW) in the town of Langadas. Where required, air-conditioning (cooling) will be also provided. Greenhouse heating will be achieved by direct utilisation of groundwater of 36°C. Heat pumps will be used for the heating and cooling of the buildings. During winter, they will heat a closed water circuit conveyed to the consumers, by pumping the necessary heat out of the groundwater, lowering its temperature. During summertime the heat pumps will withdraw heat from the water circuit feeding the buildings, and will deliver it to the groundwater. The hydraulic network has been designed in order to use commercially available standardised water source heat pumps with a ratio of useful energy over electricity consumption (C.O.P) higher than 4.

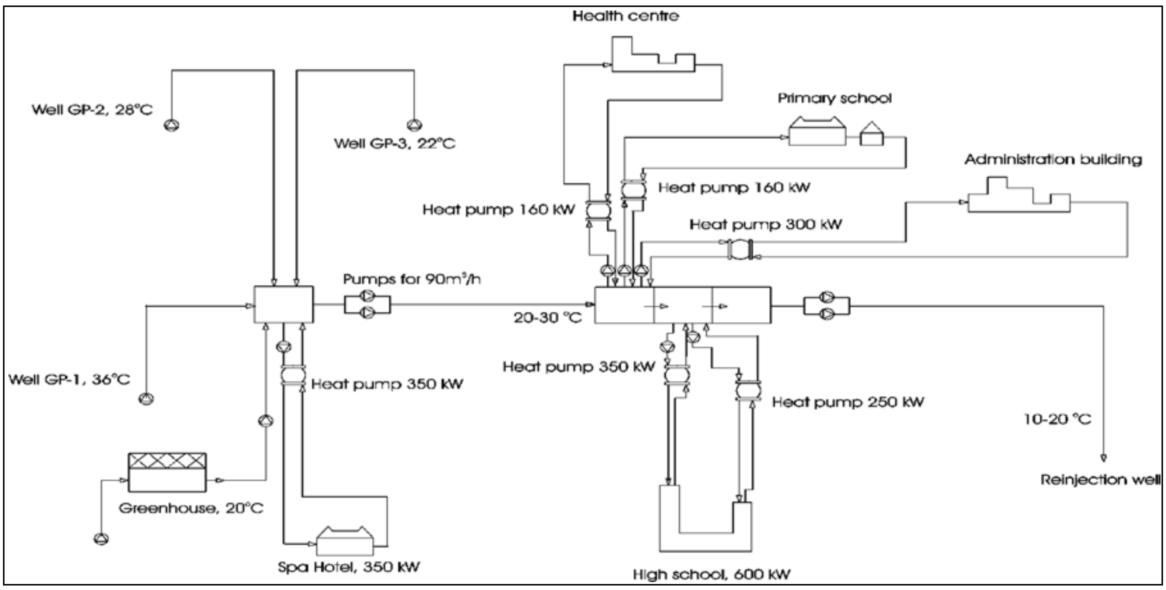

Figure 3: Langadas district heating layout

The groundwater will be produced at the spas by three wells, one of 36°C temperature feeding the greenhouse, one of 28°C feeding the heat pumps during the winter (heating) period, and one 22°C feeding the heat pumps during the summer. Groundwater chemical properties allow its direct use at the heat pumps without the intervention of a heat exchanger.

In order to minimise the use of groundwater, the applications have been placed in cascade (series). This configuration is achieved by placing water tanks in series. One of them, which serves the hotel heat pump, is located at Loutra. There, groundwater from the outflow of the greenhouse, as well as from the 28°C and 22°C wells will be collected. Then, the geothermal water will be conveyed under low pressure (3 bar) with maximum flow rate 90 m³/h at 2.2 km distance approximately, to the town of Langadas, within a buried PE pipe Ø280, where it will feed the heat pumps present at that location. The heat pumps of Langadas are all concentrated in one location, where the closed loop piping networks conveying hot/cold water to the consumers have been connected.

After use, the groundwater will flow to the reinjection well at 10°C temperature, which will be drilled at a distance of 1.35 km from the heat pumps. Through the reinjection well, the groundwater will be conveyed back to the same underground horizons it will originate from. That way, only heat will be withdrawn from the ground and the system's sustainability will be achieved.

4.4 Proposed Scheme for Sanmartin Village

All buildings connected at present to the district heating system supplied by the CHP in Oradea have radiators sized at nominal load for 90°C inlet and 70°C outlet temperatures. The situation is similar in most buildings which have individual boilers fired by different types o fuel (wood, coal, fuel oil, LPG, etc.). By using heat exchangers only, the geothermal water temperature being only 42°C, it can only cover very low partial loads, and can not even supply the standard sanitary hot water temperature of 50°C.

In case it will be decided not to modify the space heating system inside the existing buildings currently connected to the district heating system, a heat pump assisted system has to be used. The basic arrangement of the proposed geothermal heating system for the Sanmartin village is presented in Figure 4.

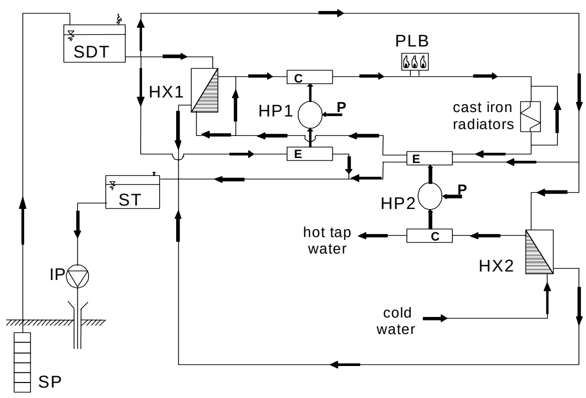

Figure 4: Heat pump assisted heating system layout

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 44°C, the heat demand is supplied through direct heat exchange from the geothermal water by the primary heat exchanger (HX1). The condenser (C) of the heat pump (HP1) is by-passed in this case. As the required radiator water inlet temperature increases above 40°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 (E) 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 35°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 wellhead 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 HP1, the geothermal 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} = 50°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 more economic to have a storage tank with a volume large enough to compensate for the daily variation in demand. Actually all substations already have these tanks in the current system.

5. ADVANTAGES OF GEOTHERMAL HEATING SYSTEMS

5.1 Energy Efficiency

The total annual heat demand of the Sanmartin village could be met by geothermal energy if all buildings were to be renovated and equipped with floor heating systems. The energy efficiency, and mainly the exergy efficiency, would be maximised in this case, as the maximum difference between the heating fluid temperature (40°C) and the indoor air temperature (20°C) would only be 20°C.

The energy and exergy efficiencies are also high when space heating systems with air are used. The energy efficiency of heat pump assisted systems is obvious. For the envisaged temperature difference, the efficiencies of currently available commercial heat pumps are about 4. This means that only 25% of the supplied heat flux is consumed as electric power, the other 75% being extracted in the evaporator from a low temperature heat source, in this case geothermal.

An important energy efficiency improvement of using a local heat source is the significant reduction of transmission heat losses. The closest geothermal well is just outside the Sanmartin village. New primary and secondary networks of pre-insulated pipes should have overall heat transmission losses below 10%. At present, the district heating system is supplied by the CHP in Oradea, which is about 20 km far from the Sanmartin village, and the temperature drop in the primary network only is about 20°C. Furthermore, water losses are not unusual.

5.2 Economic Advantages

At present, the CHP plant customers pay a flat 20 €/Gcal (4.78 €/GJ). The full production cost of the CHP, including the distribution, is about 37 €/Gcal (8.84 €/GJ). The local budget pays almost 10 €/Gcal to the CHP/DH, and the Central Budget subsidizes the remaining 7 €/Gcal.

The geothermal wells are already drilled (with funds for geological research from the State Budget), and are not used up to their capacity. Therefore, the capital investment for a new geothermal heating system would only include the primary and part or all of the secondary networks, depending on the selected technical solution. Therefore, the heat selling price could be below 20 €/Gcal. The customers will not pay more than at present for a better quality service, and the local budget will save the money currently paid to the CHP, which could be used for other purposes.

5.3 Environmental Advantages

The geothermal waters from the Felix Spa and Oradea reservoirs have a low content of dissolved solids and gasses, none of them causing any chemical pollution. The radioactivity of the geothermal water is higher than that of surface waters in the area, mainly due to ^{222}Rn, which is a gas. In case the heat depleted geothermal water is not reinjected, ^{222}Rn is dissipated into the atmosphere. The radiation level is much too low to be considered hazardous for people living their entire life in the area. Even more, ^{222}Rn is the most important chemical factor for the therapeutic effect of the Felix Spa geothermal water.

At present, most of the heat depleted geothermal water is drained into the Peta stream, and part of it into the sewage system. This does not create any thermal pollution, as the Peta stream originates from a natural warm spring, and is therefore naturally warmer than regular surface waters.

One potential negative environmental impact that can occur is the aesthetic impact, which can be important mainly in a tourist area, but which can easily be avoided by the proper design and completion of a new geothermal district heating system.

The most important environmental impact could be the caused by the overproduction from the Felix Spa or Oradea geothermal reservoirs. This can cause a reservoir pressure decline and subsequently a flow rate decline in the spring supplying the geothermal ponds with *Nymphaea Lotus*, a natural reservation, and therefore a tourist attraction. The National Agency for Mineral Resources is responsible for regulating and checking the Oradea and Felix Spa geothermal reservoirs exploitation strategy in order to prevent this possibility.

The positive environmental impact of using the geothermal energy is that a renewable energy source will replace heat currently produced by burning fossil fuels. The Oradea CHP boilers are fired by natural gas and low-grade coal. Individual houses not connected to the existing district heating system burn wood, coal, heavy fuel oil or LPG. As the fuel quantities by types of fuel used are not known, the pollutant emission savings have not been calculated, but it is clear that significant quantities of CO, CO_2, SO_2, NO_x, fly ash, and particles will not be released into the atmosphere by a geothermal district heating system.

6. CONCLUSIONS

Even as approved by the National Agency for Mineral Resources for artesian production, the potential of the Felix Spa geothermal reservoir is high enough to also supply, in addition to the Felix Spa demand, the entire Sanmartin village heat demand, including future housing developments in the area.

A detailed feasibility study is necessary in order to select the most technically and economically viable geothermal scheme, among the possible technical solutions for a geothermal district heating system in the Sanmartin village. The selected system should provide a good quality service to all consumers, at a cost not higher than the one they are paying at present. This will at least save the local budget the funds currently paid to the Oradea CHP to cover the difference to the production and distribution cost, funds which could be used for other purposes.

Correct design, completion, and operation of the selected geothermal district heating system will have a beneficial impact on the environment. The water from the Felix Spa reservoir does not generate any pollution. The use of the renewable geothermal energy will replace heat otherwise produced by fuel combustion, and therefore will avoid the emission into the atmosphere of significant quantities of CO, CO_2, SO_2, NO_x, fly ash, and particles.

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