Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

COMBINED GEOTHERMAL AND GAS DISTRICT-HEATING SYSTEM, CITY OF ORADEA, ROMANIA

Marcel Rosca

University of Oradea, Armata Romana 5, RO-3700 Oradea, Romania

Key Words: District heating, heat load, economics, Oradea reservoir, Romania

ABSTRACT

The City of Oradea, Romania, has a population of about 230,000 inhabitants. Almost 70% of the total heat demand, including industrial, is supplied by a classical East European-type district-heating system. The heat is supplied by two low-grade, coal-fired co-generation power plants. The oldest distribution networks and substations, as well as one power plant, are 35 years old and require renovation or even reconstruction. The geothermal reservoir located under the city supplies at present 2.2% of the total heat demand. By generalizing the reinjection, the production can be increased to supply about 8% of the total heat demand, without any significant reservoir pressure or temperature decline over 25 years. Another potential energy source is natural gas, since a major gas-transport pipeline passes close to the city.

Two possible scenarios are envisaged to replace low-grade coal with natural gas and geothermal energy as heat sources for Oradea. In one scenario, the geothermal energy supplies heat for culinary water heating and the base load for space heating in a limited number of substations, with peak load being produced by natural-gas-fired boilers. In the other scenario, the geothermal energy is only used for culinary water heating. In both scenarios, all substations are converted into heating plants with natural gas as the main energy source.

1. INTRODUCTION

Romania is situated in Central Europe, north of the Balkan Peninsula, and on the lower course of the Danube river. Geologic research carried out between 1960 and 1980 proved the existence of significant geothermal resources in the western part of the country. Over 200 boreholes encountered evidence of geothermal resources. Proven reserves (based on existing wells exploited by downhole pumps) are about 200,000 TJ for 20 years. The total installed capacity of these wells for energy use is 320 MW_t (for a 30°C reference temperature, therefore $\Delta t = t_{wellhead} - 30°C$).

The City of Oradea is located in the Western part of Romania (Figure 1), and has a population of about 230.000 people. The climate is a transitional temperate continental type, with Mediterranean influence. The annual mean temperature in the Oradea area is 10.2°C. Of the total 80,600 homes in Oradea, 55,000 are apartments in blockhouses and are all connected to the district heating system. The other 25,600 are individual houses (usually inhabited by one or two families), of which 2,000 are connected to the district heating system and about 2,600 have individual central heating systems (coal and [mainly] liquid-fuel-fired boilers). About 21,000 houses are heated by brick stoves fired by solid fuels (wood and/or coal), having electric (atypical) or solid-fuel-fired boilers in bathrooms. In almost all homes liquefied petroleum gas (LPG) in steel bottles is used for cooking (with a few hundred exceptions using electric stoves and ovens). The primary thermal agent is supplied to the district heating system by two low-grade coal-fired co-generation power plants (CGPP).

The total thermal energy used in 1998 in the City of Oradea for heating and industrial processes was about 3,000 GWh_t ($2.58 \cdot 10^6$ Gcal) of which, by energy sources:

- CGPP: 2,040 GWh_t: 970 GWh_t residential, 150 GWh_t tertiary sector (social-cultural institutions, administration offices, services, commerce, etc.), 920 GWh_t industrial (of which 660 GWh_t industrial steam), and 150 GWh_t losses in the secondary network;
- wood+coal: 52 GWh_t (for family houses), about 22,500 t;
- heavy fuel: 290 GWh_t (in industry, for own boilers), about 25,.000 tons;
- light fuels: 186 GWh_t (118 GWh_t residential, 35 GWh_t tertiary sector, 33 GWh_t industry), total about 16.000 t;
- electricity: 230 GWh_t (38 GWh_t residential, 92 GWh_t tertiary sector, 100 GWh_t industry);
- LPG: 113 GWh_t (101 GWh_t residential and 12 GWh_t tertiary sector);
- geothermal: 65 GWh_t (30 GWh_t residential, 30 GWh_t tertiary sector, and 5 GWh_t industry).

The CGPP provides 68.5% of the current thermal energy consumption of the city, followed by heavy fuel (9.7%), electric energy (7.7%), light fuels (6.3%), LPG (3.8%), geothermal (2.2%), and firewood (1.7%).

2. THE CURRENT DISTRICT-HEATING SYSTEM

Thermal energy is supplied to the City of Oradea by two co-generation power plants of the National Power Company (CONEL), Power Plants Inc. branch, rated at 355 MW_e and 470 MW_t (Cohut and Ungemach, 1997).

CGPP I is located in the industrial area west of the city. Its first boiler-turbine-generator group was set on line in 1965. The total installed capacity is 205 MW_e and 310 MW_t, supplied by five generator groups, three with back-pressure and two with condensing turbines.

CGPP II is located southeast of the city. Its first group was set on line in 1987. At present, it has three groups, all with back-pressure turbines, and the total installed capacity is 150 MW_e and 170 MW_t.

In 1998, the two CGPP consumed 2.96 tons of lignite (with an average lower calorific value H_i = 8,350 kJ/kg) and 33,500 tons of heavy fuel (55% to CGPP I), producing a total of 1.69 TWh_e electric energy, of which 1.06 TWh_e was delivered to the national grid (0.59 TWh_e by CGPP I and 0.47 TWh_e by

CGPP II), the difference being the internal consumption. The total thermal energy delivered in 1996 was 2.55 TWh_t with 1.04 TWh_t as industrial steam for technological processes, and 1.15 MWh_t as hot water for heating (metered at consumption points). The fluid and heat losses in the primary network were estimated by the producer at 0.23 TWh_t (about 9%), but during the cold season, fluid losses in the primary network reach 1,500 m^3/day.

The heating agent is delivered to consumers through a primary piping network (owned by CONEL) which is 73.8 km long (of which 53.8 km is in concrete ducts) with diameters of 150÷800 mm, the metering being accomplished at the consumers' inlets. The network of CGPP I (the only one operated before 1988), has three mains built in 1967÷1972, with a total length of 55 km. It has two junctions with the two mains of CGPP II built in 1988÷1989. Due to their age (and resulting thermal and fluid losses), the primary networks urgently require rehabilitation, the cost of which is estimated at about 60 million $US.

At present, about 157,000 of the 228,000 inhabitants of the City of Oradea use sanitary hot water (s.h.w.) and space-heating agent supplied by the district heating branch (APATERM) of the municipal services company. The current status of district heating in Oradea is depicted in Table 1.

The secondary network owned by APATERM delivers the heating agent and s.h.w. from 194 heat substations to end users. The cold water network is usually distinct. The heating-agent pipes (supply and return) and the s.h.w. pipes are installed in concrete ducts (about 94% of the total 545 km, the other 6% in the building basements). Energy losses are estimated at 18% in the primary network and 12% in the secondary distribution network.

The production, transport and distribution systems are facing severe deficiencies in exploitation, mainly caused by the lack of funds for maintenance and modernization. Sixty-three per cent of the s.h.w. and heating agent pipes are over 15 years old, 33% between 10 and 15 years, 3% between 5 and 10 years, and only 1% less than 5 years.

Most of the secondary network is of steel pipe (zinc-plated for s.h.w.), with rock-wool thermal insulation and tarred paper waterproof insulation. During the last 3÷4 years, 15.4 km of heating and 4.5 km of s.h.w. pipes have been replaced by pre-insulated pipes. Where the old secondary networks are replaced, they are usually set in new lines, so that each staircase in an apartment block has an individual connection, in order to facilitate metering at least at this level, for both space heating and s.h.w. According to the common design, all blockhouses have vertical supply pipes for cold and hot water in kitchens and bathrooms and 3÷4 double pipes (supply and return) for space heating. Therefore, implementation of water and heat metering at apartment level is unlikely for the near future, as the cost of required meters is prohibitive at present.

Due to age and inadequate waterproof insulation of the rock-wool thermal insulation, the exteriors of nearly all secondary-network steel pipes are corroded. Their insides are also corroded by oxygen dissolved in the water. In 1997, more than 2,000 repair jobs were needed to stop leakage in the secondary network (an average of 10 jobs per day during the cold season!).

The rehabilitation of secondary networks more than 15 years old (about 340 km) will take several years if funded exclusively by APATERM. The rehabilitation of 65 km of secondary networks at the operability limit has been estimated at 8 million $US, which translates to a unit cost of about 120 $US per meter..

3. THE ORADEA GEOTHERMAL RESERVOIR

The Oradea geothermal reservoir comprises two distinct and hydrodynamically connected aquifers, the Triassic Oradea aquifer and the Cretaceous Felix Spa aquifer. Although a significant natural recharge exists, exploitation of these two aquifers with a total flow rate of 300 l/s induces a pressure drawdown which is counteracted by reinjection. The total installed capacity (with the drilled wells) is over 30 MW_t.

The Felix Spa reservoir is currently exploited by 6 wells, 50÷450 m deep. The total flow rate available from these wells is 210 l/s. The geothermal water has wellhead temperatures of 36÷48°C and is used only for recreational and health bathing (Rosca, 1993).

The Oradea aquifer is located in Triassic limestone and dolomite, at depths of 2,200÷3,400 m, with an approximate areal extent of 113 km^2. This aquifer is exploited by 12 wells, with a total artesian flow rate of 140 l/s and well head temperatures of 70÷105°C. The water is of calcium-sulfate-bicarbonate type, with no scaling or corrosion potential. There are no dissolved gases, and the TDS is lower than 0.9 to 1.2 g/l. The reservoir is bounded by faults. There are also internal faults in the reservoir, dividing it into four blocks which do not cause discontinuities in the circulation of the water in the reservoir. The main circulation is from the north-eastern part of the reservoir, along preferential pathways represented by the fault system at the boundary (Figure 2).

Between 1970 and 1980, 12 geothermal wells were drilled in the Oradea *"intra muros"*. The depths of these wells range between 2,500 and 3,400 m, with well head temperatures of 70 to 105°C, and artesian flow rates of 5 to 35 l/s. All wells are currently in commercial exploitation for direct uses: space heating, s.h.w., greenhouse heating, timber drying, milk pasteurization, bathing, etc., the geothermal energy being delivered through local networks in the neighboring area.

Due to artesian discharge and limited reinjection of the heat-depleted geothermal fluid, the annual geothermal energy utilization is only 65 GWh_t, far below the reservoir potential.

The main target of a geothermal program for Oradea is the development of the existing production and distribution infrastructure. Implementation would be by: artificial production using deep well pumps; the conversion of low-productivity wells into injection wells, to maintain the reservoir pressure and dispose of the heat depleted fluid; and connection of 5 geothermal doublets with the district heating system (Cohut et al., 1996).

The proposed system will provide a fourfold increase in geothermal energy production, from 65 to 250 GWh_t/yr. 205 GWh_t/yr. will be for s.h.w. only. Year-round delivery to 80,000 people will be provided by 45 substations. As shown by numerical simulation of the Oradea geothermal reservoir, injection of heat-depleted geothermal fluid in the tapped aquifer will prevent reservoir pressure decline, with no significant thermal breakthrough over 30 years of production (Antics, 1996).

The capital investment cost for the full proposed geothermal development program has been estimated at 9 million $US. A discounted cash-flow analysis of the project shows attractive indices: net present value of about 1.7 million $US, discounted pay-back time of 6.6 years, and internal rate of return of 20%, at a discounted unit price of 12.5 US/MWh_t.

4. THE NATURAL GAS SUPPLY

Natural gas can supply the medium and long term heat demand of the City of Oradea and its surroundings, provided a new entity is created to furnish financial backing for development and operation of the distribution network.

Investment for the construction of a natural gas distribution network in the city has been approved by government decision. The distribution network will be connected to the main gas transport pipeline running north-south about 6 km west of the city. For the technical and economic assessment of the project, the Municipality of the City of Oradea contracted a feasibility study for an installed flow rate of 110,000 Nm^3/h, able to deliver an annual volume of natural gas of about $350 \cdot 10^6$ Nm^3).

The natural gas will mainly be used for:

- cooking;
- space and tap water heating in buildings not connected to the district heating system (about 23,600, mainly in two-family houses) in the existing district heating system by installing gas fired boilers in the substations or individually for large buildings. The boilers will provide the thermal energy for both space and tap water heating, or for space heating only in the substations where the s.h.w. will be heated with geothermal energy;
- industrial companies, for space and tap water heating, as well as for process heat;
- district heating systems to be developed in satellite communities (Felix - 1 Mai Spas, Episcopia, Sanmartin);
- future housing and industrial developments in Oradea.

The Municipality of Oradea City organized a tender for the association with a commercial company experienced and able to invest in the development and operation of the natural gas distribution network Three possible scenarios have been considered for the natural gas utilization in the City of Oradea, namely:

- **minimal:** the natural gas distribution network on the left bank of the Criºul Repede river, limited to areas not connected to the district heating system (300 GWh$_t$/yr.) and to certain industrial consumers currently using light fuel and electric energy (about 450 GWh$_t$/yr.), with an average consumption of $80 \cdot 10^6$ Nm^3/yr., and a capital investment of almost 22 million $US;
- **medium:** the extension of the minimal scenario by about 200 GWh$_t$/yr. for space heating in 45 substations in 5 areas in which the geothermal energy will provide s.h.w., and by 500 GWh$_t$/yr. for industrial users currently supplied by the CGPP, totaling an average consumption of 1,450 GWh$_t$/yr., of which $150 \cdot 10^6$ Nm^3/yr. natural gas, at a capital investment of $48 \cdot 10^6$ $US;
- **maximal:** supplying about 98% of the total heat demand in 2005, namely 2,850 GWh$_t$/yr. ($300 \cdot 10^6$ Nm^3/yr. natural gas consumption), at a capital investment of $75 \cdot 10^6$ $US.

5. SCENARIOS FOR IMPLEMENTATION

Uncertainties concerning the future of the two CGPP from Oradea (arising from the condition of their equipment; the decrease in electrical energy demand; the difficulties in lignite and heavy fuel supply; the major difficulties in fulfilling the environmental protection legal requirements; and mainly by the lack of funds for re-technologisation and modernization), mandate the consideration of alternative options for the medium- and long-term heat supply for the City of Oradea. The modernization and re-technologisation of the CGPP, as well as the rehabilitation of the primary heating networks, will only be taken into consideration by CONEL if they are profitable, and if CONEL can find the necessary financial resources. At present, and for the next 5÷10 years, these conditions have a high level of uncertainty.

To conceive an energy strategy, it is necessary to know the unit prices of different energy sources, and to have at least a short term forecast of their evolution. For our project, this information is summarized by (Table 2), based on data from the European Commissions forecasts and on estimates by the Institute for Energy Studies and Projects, which is part of CONEL. Based on forecasted unit prices of different types of thermal energy for the year 2000, it is obvious that natural gas (at 8.6 US/MWh_t$) and geothermal energy (at 12 US/MWh_t$) are the least expensive. For comparison, thermal energy from CGPP will reach a minimum 17.2 US/MWh_t$ if CONEL does not invest in the rehabilitation and modernization of its CGPP.

Therefore, two scenarios were considered for district heating, using natural gas and geothermal water as energy sources. As an example, only one geothermal doublet is presented in this paper (out of five envisaged for the entire city), namely the one in the Iosia district, as this would be the most complex one.

In both scenarios, geothermal water is pumped from deep wells, stored, degassed, filtered, then pumped through plate heat exchangers in the geothermal heating plant to a storage tank from which it is reinjected. The heat is transferred to an intermediate agent (water), which is distributed in a closed loop to the substations, as well as to other current users (a furniture factory and a dairy). Part of the heat-depleted geothermal water is used in a swimming pool (Figure 3).

In scenario 1, the intermediate agent is only used (in the 9 connected substations) to heat the sanitary hot water, the space heating agent being produced in natural-gas-fired boilers. In scenario 2, the intermediate agent is also used to provide the base load (80%) for space heating (Figure 4). As the geothermal water has a wellhead temperature of about 105°C, the intermediate fluid will be heated to 90°C in order to reduce the flow rate and therefore the diameter of the transport pipes, as well as the energy loss in the heat exchangers of the geothermal heating plant. In substations, part of the outlet intermediate agent from the heat exchangers will be mixed in the three-way control valve with the inlet intermediate agent, so that its temperature will not be more than 5°C higher than the outlet temperature of the heated fluid (to reduce the energy loss).

The annual energy sales for the Iosia doublet will be of about 22,276 MWh$_t$ for s.h.w., all from the geothermal source in both scenarios, and about 49,389 MWh$_t$ for space heating, of which only 4,239 MWh_t from natural gas in scenario 2 (the rest from the geothermal resource), and all of it from natural gas in scenario 1.

6. ECONOMIC ASSESSMENT

In accordance with the energy strategy envisaged by the City of Oradea Municipality (set forth in the terms of reference of the tender for establishing an association with a reliable partner to develop and operate the district heating system, including the utilization of the geothermal resource, and the natural gas distribution system), the economic assessment was carried out for this type of a company (hereafter named COGGE - The Company of Oradea for Gas and Geothermal Exploitation), which will include the Municipality of Oradea, the District Heating Section of APATERM, a major investor or consortium, and minor private share holders.

The Municipality of Oradea will be awarded, by the National Agency for Mineral Resources, according to the provisions of the new Mining Law, the License of Exploitation of the Oradea geothermal reservoir. The Municipality will then concede the exploitation to the COGGE, together with the natural gas distribution activity. This way, the operational costs for geothermal production will include only the cost of the electric energy used by pumps and the royalties for the extracted fluid.

The project lifetime for the economic assessment was set at 20 years. A discount rate of 8% was considered acceptable for a company as COGGE, and equal to the expected interest rate on the bank loan for the debt capital investment, which was accepted as 50% of the total capital investment. The capital recovery factor is thus 0.1018 for both scenarios.

The capital investment was evaluated at 2.642 million $US for scenario 1 and 2.823 million $US for scenario 2 (about 30% in hard currency), including costs for natural gas, geothermal water, and intermediate-agent networks, and for the conversion of the existing substations into local heating plants.

The total cost of annual energy consumption (electric, geothermal, and natural gas) was estimated at 87,610 $US for scenario 1, and at 65,615 $US for scenario 2. The total annual operation and maintenance cost was estimated at 367,200 and 335,670 $US for scenarios 1 and 2 respectively.

The annual earnings from the delivered thermal energy (for space heating and sanitary hot water) is in both scenarios about 812,200 $US (for a unit price of 11.5 $US/$MWh_t$). For the conditions mentioned above, and for a 45% total annual tax rate, the net annual earnings (after taxes) are 197,500 and 217,870 $US for scenarios 1 and 2 respectively.

The calculated economic viability indices are:

a) Scenario 1:
- Net Present Value: 528,200 $US;
- Internal Rate of Return: 12.8%;
- Discounted Pay-back Time: 12 years;

b) Scenario 2:
- Net Present Value: 819,270 $US;
- Internal Rate of Return: 15.6%;
- Discounted Pay-back Time: 9 years.

7. CONCLUSIONS

A fourfold increase in production from the Oradea geothermal reservoir is possible without any adverse effects if at least 70% of the extracted geothermal fluid is reinjected.

As natural gas and geothermal water are the least expensive and the least polluting energy sources, the Municipality of Oradea has decided to develop them in the near future.

For a combined natural gas and geothermal district heating system, the best economic performance is obtained in the conditions of scenario 2, in which geothermal energy is used to heat culinary water, and to supply 80% of the nominal space heating demand, the peak load being supplied by gas-fired boilers at each substation. Nevertheless, in this case the annual mean flow rate extracted from the production well is only about half the maximum installed potential. For the entire city, this means that double the number of wells would be required to provide the same annual mean flow rate.

For the City of Oradea, where 12 drilled wells can supply the maximum annual mean flow rate not affecting the reservoir, the best option is to use geothermal energy only for culinary water heating in a larger number of substations, in 5 doublets located in city districts, with space heating of blocks of flats being supplied by natural gas-fired boilers. In this case, the system is also simpler and easier to operate.

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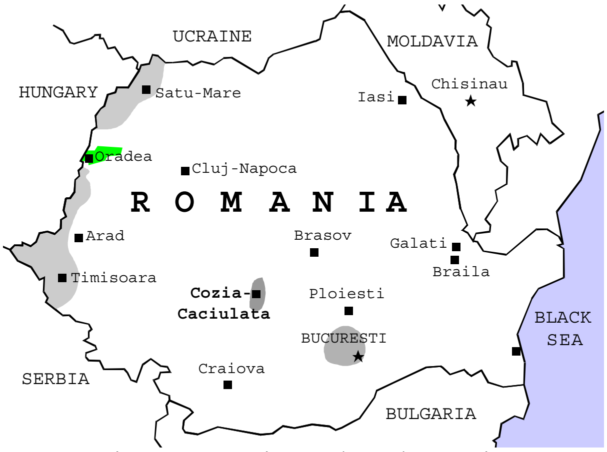

Figure 1: Romanian geothermal reservoirs

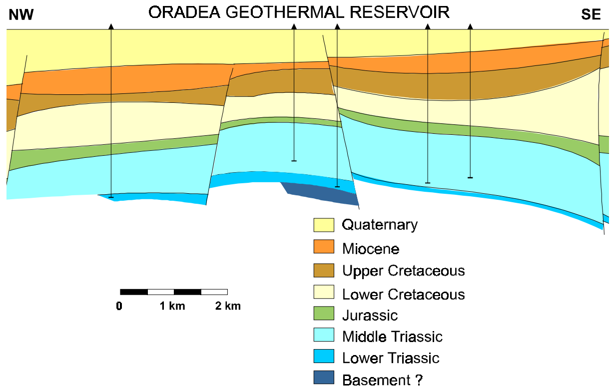

Figure 2: Cross section through the Oradea reservoir

Table 1: General data on the Oradea district heating system (1998)

- Total population 228,500
- Total apartments and family houses 80,000
- Total inhabitants supplied by the district heating system 156,800
- Total apartments and family houses connected to the district heating system 57,000
- Thermal energy delivered by CGPP's .... 2,250,000 MWh_t
  - of which:
    - district heating .... 1,190,000 MWh_t
    - industrial space heating .... 260,000 MWh_t
    - industrial steam for technological processes .... 650,000 MWh_t
    - losses in the secondary network .... 150,000 MWh_t
- Losses in the primary network .... 350,000 MWh_t
- Total electric energy produced .... 1,700,000 MWh_e
- Heat delivered to APATERM substations .... 1,340,000 MWh_t
  - of which:
    - secondary network losses .... 150,000 MWh_t
    - population .... 970,000 MWh_t
    - companies and social cultural institutions .... 220,000 MWh_t
- Geothermal energy annual supply is 65,000 MWh_t, of which 21,000 MWh_t as s.h.w. (distributed through APATERM substations) and 44000 MWh_t for space heating, s.h.w. and process heat (through local networks).
- Annual consumption of a standard apartment is 17 MWh_t, of which 10.5 MWh_t for space heating, and 655 MWh_t for s.h.w.
- Substations operated by APATERM 194
  - of which:
    - 105 with a thermal capacity of .... 1.2÷3 MW_t
    - 36 with a thermal capacity of .... 3÷4.5 MW_t
    - 53 with a thermal capacity of .... 4.5÷10 MW_t
- 103 substations have pumping stations (with pressured vessels) to supply cold and hot water to the upper stories of the blockhouses.
- The installed electric capacity in substations is of 2,400 kW, and in pumping stations is of 3,600 kW
- All secondary networks are in concrete ducts, having a total length of 545 km, the normal operation time has expired for 80% of the pipes, so that these require often repairing.

Table 2: Unit prices of different energy sources, and forecast for the year 2000

1 USD = 9.500 ROL (Oct. 1998)		1998 $US/ton	$US/10^{3}Nm^3	**US/MWh_t$**	ROL/Gcal	2000 $US/ton	$US/10^{3}Nm^3	**US/MWh_t$**	ROL/Gcal
Thermal energy (CGPP)	population			**8.4**	93,000				
	companies			**16.3**	180,000			**17.2**	190,000
Natural gas	population		50.0	**5.3**	58,100				
	companies		75.3	**7.9**	87,500		92	**8.6**	95,000
LPG		338		**26.7**	294,000	480		**38.0**	419,000
Light fuel		268		**20.0**	220,800	300		**25.8**	285,000
Heavy fuel		225		**18.8**	207,500	250		**23.6**	260,000
Wood + coal				**12.0**	132,500			**16.0**	177,000
Geothermal				**6.7**	73,900			**12.0**	132,500
Electric energy	population	**US/ MWh_e$**		**42.5**				**US/ MWh_e$**	ROL/MWh$_e$
	companies			**45.3**				**70.0**	665,000

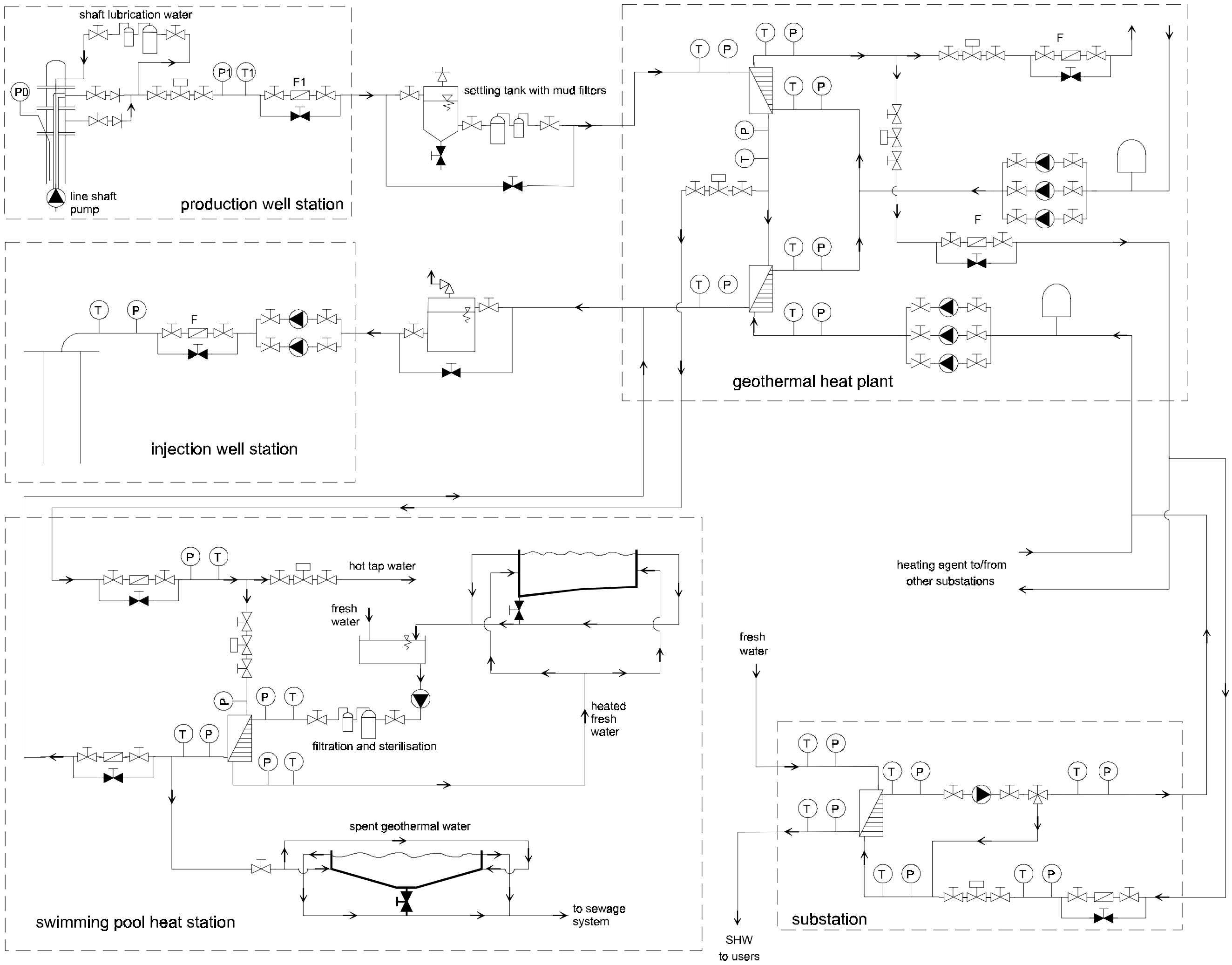

Figure 3: The Iosia doublet layout for scenario 1

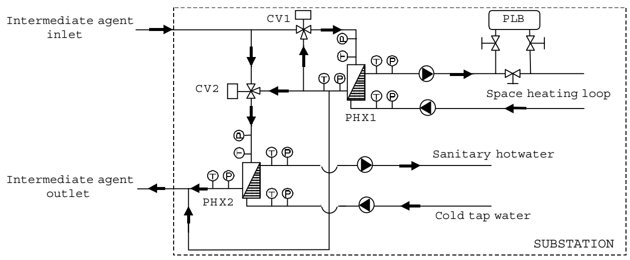

Figure 4: Substation layout for scenario 2