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Cascaded Uses of Geothermal Water in Iosia District, Oradea, Romania

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ABSTRACT

The city of Oradea is situated on top of the best geothermal reservoir in Romania, located in fractured Triassic limestone and dolomite between 2 and 3 km deep with a natural recharge flow rate of about 310 l/s. There are 14 wells already drilled in the Oradea geothermal reservoir and the well head temperatures range between 105°C in the Western part and 70°C in the Eastern part of the city.

The most powerful geothermal well in Romania is located in the Iosia district. It produces up to 50 l/s geothermal water with a well head temperature of 105°C. Two more wells, of which a newer one is not yet used, are located not very far, near the same district. The other one supplies geothermal water to family houses in the neighborhood.

Transgex SA developed a small geothermal district heating system in the block of flats part of Iosia district, part of the heat depleted geothermal water being used in swimming pools near the geothermal heat plant.

In 2012, Transgex SA company installed at the same location and commissioned the first power generation unit in Romania. The installed capacity is only 50 kWe, the main objective being to test the technology.

1. INTRODUCTION

Oradea, the capital city of Bihor County, is located in the Western part of Romania, close to the Hungarian border and has about 200,000 inhabitants. With 14 geothermal wells drilled in its area, Oradea may be considered a geothermal city. But not only the quantity of geothermal water extraction is important, but also the utilization factor, too. Therefore, when it comes to efficiently using the geothermal water we can talk about cascaded uses, where the Lindal diagram is quite useful. Besides the main purpose of geothermal energy utilization in Oradea – hot tap water preparation and district heating – two other important utilizations were added: power generation and recreational bathing.

The TRANSGEX Company owns the wells and has the exploitation license for the Oradea geothermal reservoir, where it also has an agreement with the Municipality for heat supply in certain districts. The main heat producer for the Oradea district heating system is the co-generation power plant located near the City of Oradea, organized as a commercial company owned by the Municipality of Oradea. The cogeneration power plant mainly uses low grade coal and heavy fuel oil (to maintain the flame). Two boilers have been modified to use natural gas, but when the price increased very much these were not used any more. The power plant and the district heating system are very old (more than 40 years), and in very bad shape, with high heat and water losses. The make-up water in the primary network only is about 30 l/s during summer and up to about 100 l/s during winter. A new, gas-fired co-generation power plant has been designed and construction should start soon.

The geothermal energy, from the 14 deep geothermal wells drilled in the Oradea geothermal reservoir covers about 10% of the city heat demand, through different direct-heat applications. Since 2005, a geothermal heat plant has been operating in Iosia District, replacing about 115.000 GJ/year of lignite and natural gas which is used at the existing CHP (Rosca, 2008). In 2012, a 50 kW demonstration ORC power plant was installed near the geothermal heat plant, being the first operational geothermal power generation unit in Romania. Part of the heat depleted geothermal water is used in the near-by swimming pool for health and recreational bathing.

2. THE ORADEA GEOTHERMAL RESERVOIR

The geothermal systems discovered on the Romanian territory are located in porous permeable formations such as Pannonian sandstone, interbedded with clays and shales specific for the Western Plain, and Senonian specific for the Olt Valley. Some geothermal systems are located in carbonate formations of Triassic age in the basement of the Pannonian Basin, and of Malm-Aptian age in the Moesian Platform (Figure 1).

Figure 1: Location of the main Romanian geothermal reservoirs

The Oradea geothermal reservoir was identified in 1963-64 and then geologically and hydrodynamically investigated in 1965-1982 through 12 wells. The Oradea geothermal reservoir comprises two specific aquifers, hydrodynamically connected, the Triassic aquifer Oradea and the Cretaceous aquifer Felix Spa. The reservoir has a natural recharge of 300 ÷ 310 l/s, but a total production of 300 l/s in Oradea and Felix Spa generates pressure draw down in the system, that is prevented by reinjection. In 1986 the Geology Department decided to restrict the total flow rate extracted in the Oradea area at 90 l/s (annual average, without reinjection), compared to a total potential of artesian flow of 140 l/s (Rosca, Antal, Bendea, 2010).

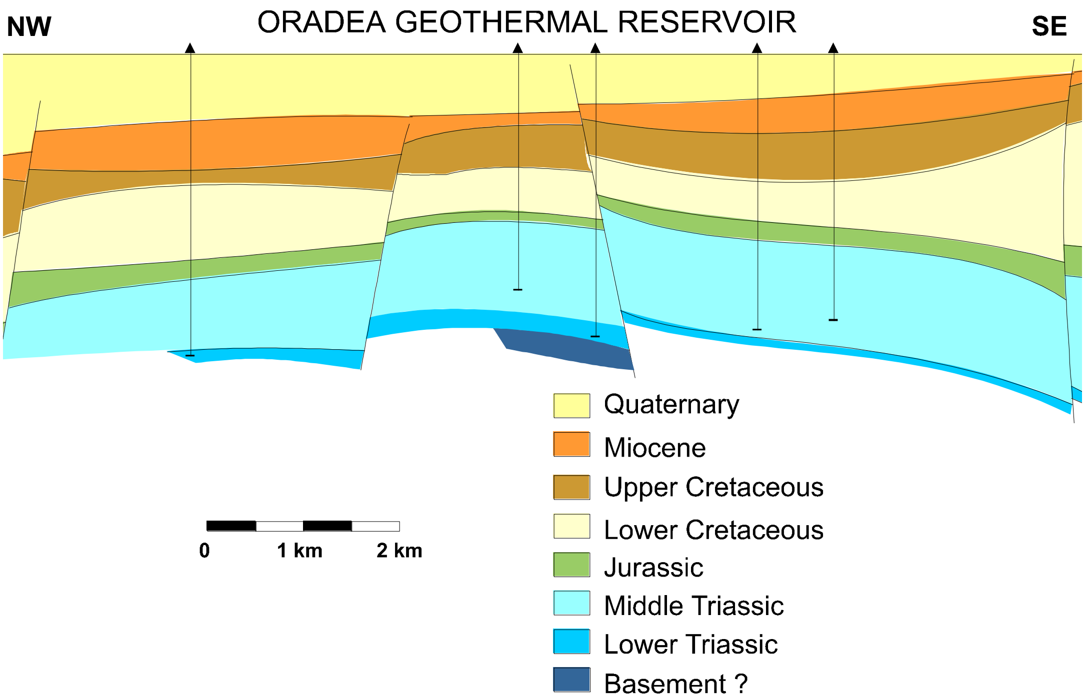

Figure 2: Cross section through the Oradea reservoir

The Oradea aquifer is located in Triassic limestone and dolomites, at depths of 2,200 to 3,400 m (Figure 2). The reservoir covers an area of about 113 km^2 located almost entirely under the City of Oradea, and is exploited by 14 wells, with a total artesian flow rate of 140 l/s and well head temperatures of 70 to 105°C. The water is of calcium-sulphate-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 hydraulically connected blocks. The source of the geothermal fluid is located in the north-eastern part of the reservoir, along preferential pathways represented by the fault system at the boundary .

The terrestrial heat flow is about 90 mW/m^2, and the geothermal gradient 2.6-4.1°C/100 m. Properties such as ionic composition, high radioactivity and the content of rare gases, indicate an active circulation along paths partially in contact with the crystalline basement. The water is about 20,000 years old, the recharge area being in the Western Carpathian Mountains 20-30 km east of Oradea.

Based on all available data (geology, hydrology, well tests and logs, and production history) as well as on the reservoir simulation, the following mean values have been determined for the rock matrix (Rosca, Antics, Karytsas, 2008):

- density: ρ_r = 2,750 kg/m^3;
- effective porosity: Φ = 1.8-2.0%;
- permeability: k_r = 230 mD;
- specific heat capacity: c_r = 1,030 J/kg·K;
- thermal conductivity:
  - λ_r = 3.72 W/m·K for Triassic dolomite;
  - λ_r = 3.00 W/m·K for Triassic limestone;
  - λ_r = 2.79 W/m·K for Lower Cretaceous limestone;
  - λ_r = 3.20 W/m·K for Upper Cretaceous limestone;
- transmissivity: T = 211 D·m.

Currently 13 production wells and one injection well are in operation, with an average flow rate of about 60 l/s. The total installed capacity is about 21.5 MW$_t$ for the approved flow rate of 90 l/s. The current annual heat production is about 430 TJ and the average capacity factor is 63% (Rosca, Bendea, Cucueteanu, 2013).

3. THE CASCADED SYSTEM

The energy source is the geothermal water produced from the wells 4767, 1717, 1731 (Figure 3). The well no. 4767 is located inside a swimming pool facility and is connected through a 250 mm pre-insulated pipe of 180 m to the Geothermal Heat and Power Plant (GHPP). The well can produce 21 l/s in natural discharge and up to 32 l/s in pumping. The geothermal water well head temperature is up to 105°C.

The well no. 1717 is located at 1,560 m south from the GHPP and is connected to it through a 125 mm pre-insulated pipe. The well has an artesian flow rate of 5 l/s and can produce 10 l/s in pumping. The geothermal water well head temperature is up to 106°C.

The 1731 well is located at about 1,450 m west-north-west of the GHPP and is connected through a 150 mm pre-insulated pipe line to it. The artesian production is 8 l/s with a well head temperature of 92°C (no pump is installed in the well, yet).

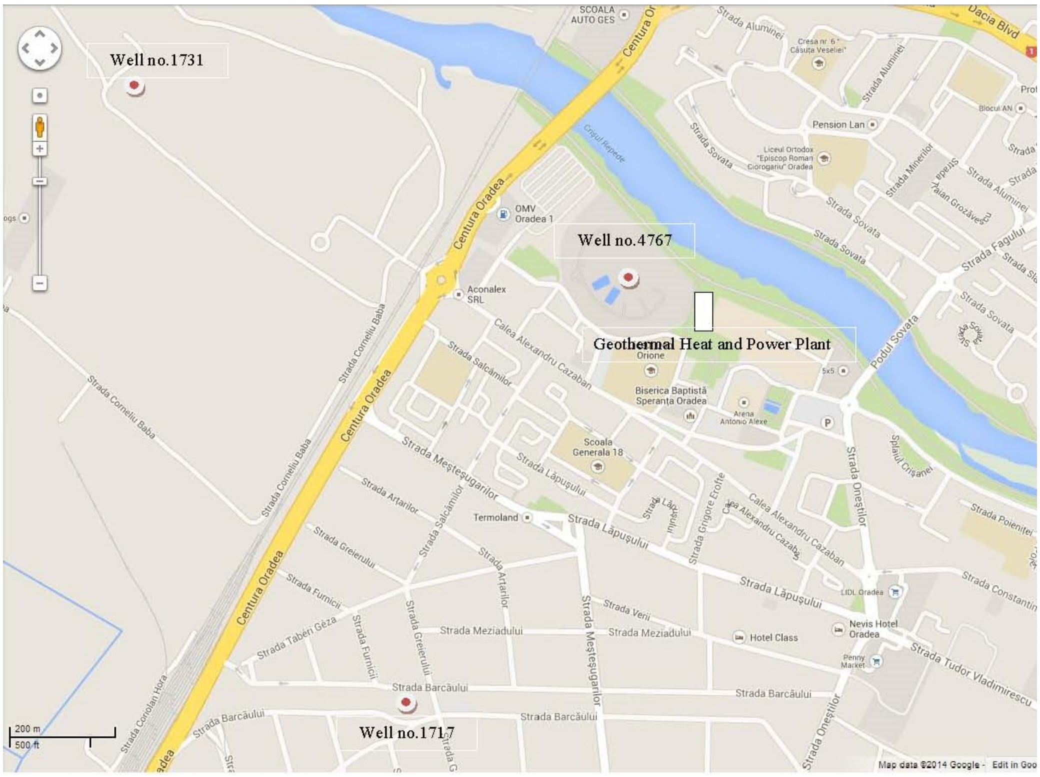

Figure 3: Location of the 3 wells in the Iosia District, Oradea city

The construction of wells 4767 and 1717 is presented in Figure 4 and is a typical design for geothermal wells drilled in fractured rocks in Romania. In the reservoir layer, the wells have a slotted liner. The lithologic column is also shown, in colors, right of the well drawings.

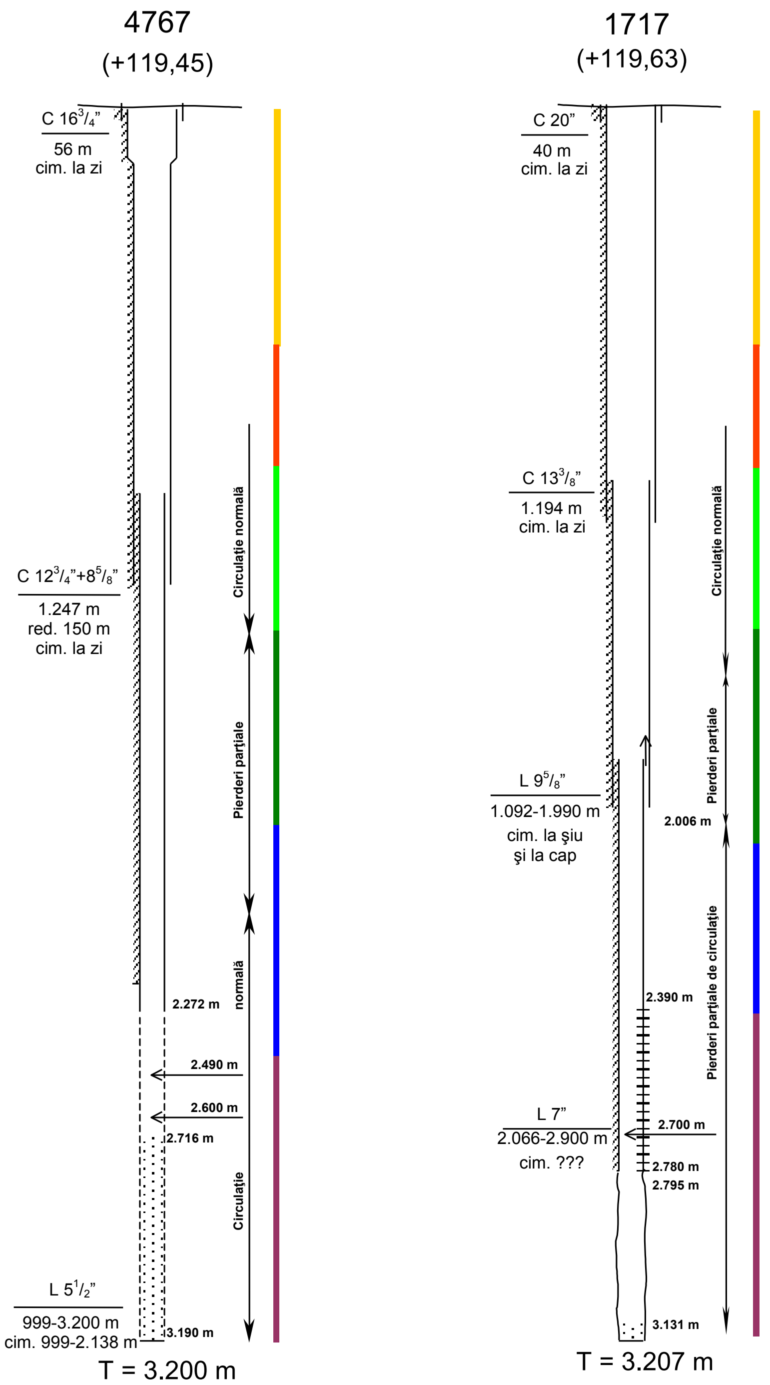

Figure 4: Completion of wells 4767 and 1717

The hydraulic layout of the geothermal cascaded uses system in Iosia district is presented in Figure 5.

The geothermal water from the 3 wells is collected by a manifold located 3 m outside the geothermal heat plant, which supplies it to the heat exchangers inside at a temperature that varies with the flow rate and temperature provided by each of the 3 wells. Just before entering the manifold, a 3-way valve is installed on the pipe coming from 4767 well allowing the geothermal water to supply the geothermal power plant.

The ***geothermal power plant*** is an ORC module, manufactured by ELECTRATHERM, S 4000 model. The geothermal water having a temperature of 105°C and a flow rate of 10 l/s from the 3-way valve is supplied to the evaporator (E) and the pre-heater (PH) , from which it returns with a temperature of 90°C to the manifold outside the geothermal heat plant building. The extracted heat is used to evaporate the working fluid into pressurized vapor which flows through the twin screw expander spinning an electric generator to produce power. The rated electric power at the generator terminal is of 65 kW. The electricity produced by the generator module of S 4000 equipment is supplied to the near-by power transformer by an insulated cable, flush mounted, after the supply of the auxiliary services.

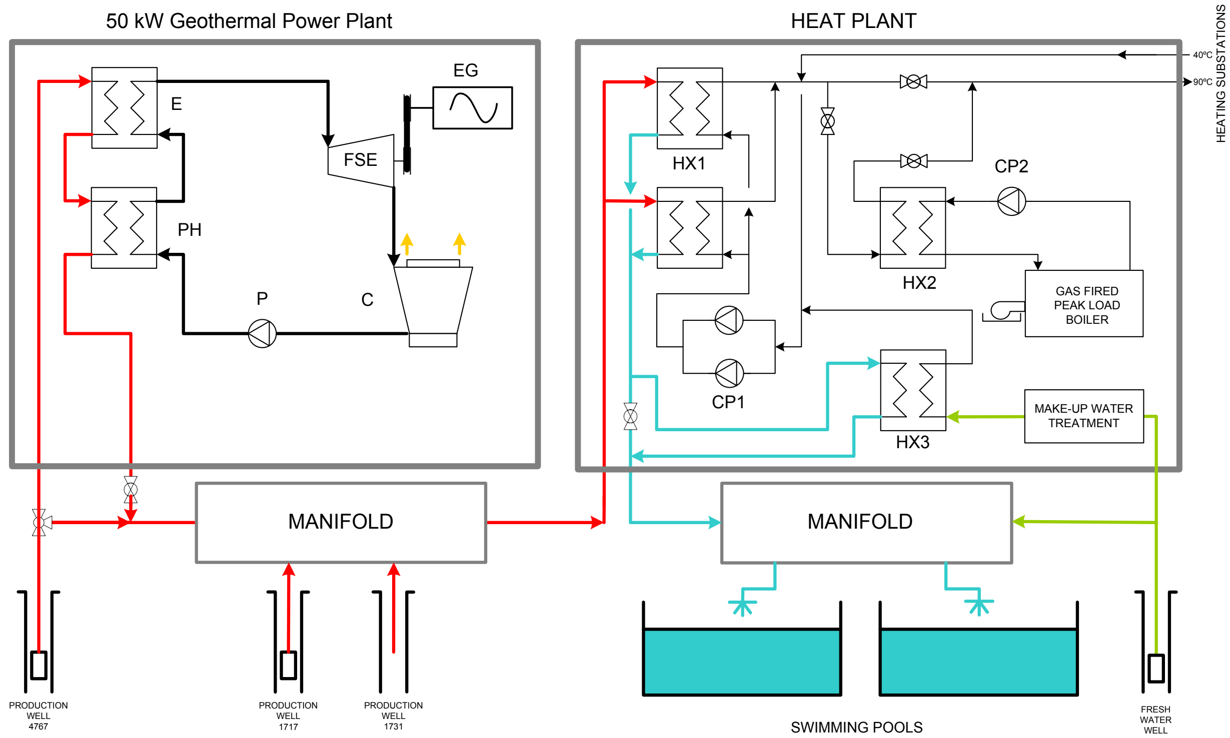

Figure 5: Geothermal water cascaded uses system in Iosia District, Oradea

The low pressure vapor from the twin screw expander is cooled and liquefied through a GUNTNER air-cooled condenser, ETP/N 11283/1 model, having the capacity of 650.8 kW, and then, to repeat the cycle, it is pumped back into the pre-heater and evaporator plate heat exchangers. The equipment belonging to the power generation unit near the geothermal heat plant is shown in Figure 6.

The unit is provided with both electrical and thermal energy metering devices.

The organic fluid is pentafluoropropane (HFC 245 fa) and it is non-flammable, non-toxic and, once released in the atmosphere, it does not affect the ozone layer; its contribution to the global warming is minimal.

Figure 6: Geothermal power plant, near the geothermal heat plant building and power transformer

Regarding the ElectraTherm S 4000 equipment, the manufacturer provided with the following data (Table 1):

Table 1 ElectraTherm S4000 operating parameters

Electrical output	Hot source			Cold source	
Power [kW]	T [°C]	Capacity [kW]	Flow [l/s]	T [°C]	Capacity [kW]
30 - 50	88 - 116	430 - 715	9.5 - 11	10 - 21	400 - 665

The ***geothermal heat plant*** supplies heating agent to the following consumers:

- District heating substations HS 512; HS 513 and HS 514;
- Sport Arena;
- Youth House;
- Don Orione High School;
- Orthodox Church;
- “5x5” Sport Facility

The heat depleted geothermal water is mainly used in the near-by swimming pool facility and also, when needed, to preheat (in HX3, Figure 5) the make-up water produced from a fresh water well. This well can be used to decrease the geothermal water temperature for the swimming pool, as well.

The geothermal heat plant consists of a battery of 3 heat exchangers (HX1), having a rated thermal power of 6.5 MW_{th} each, two of them being in-use and one in stand-by. All year round, the geothermal heat plant supplies the consumers with primary heating agent for preparation of domestic hot water. Therefore, the return of the primary heating agent that comes from the consumers (heating substations and individual consumers) has a temperature of about 40°C and is heated in HX1 up to 90°C by the geothermal water of about 105°C. The inside of the geothermal heat plant is presented in Figure 7.

Figure 7: Geothermal heat plant (HX1 and peak load boilers)

In winter time, when also space heating is needed, the primary heating agent supply temperature is usually 90°C, at a flow rate higher than in summer time. When the daily average outdoor temperature decreases below -10°C, it is needed to start the natural gas fired peak load boilers for increasing the primary heating agent supply temperature up to 110°C in HX2. There are 2 peak load boilers of 1310 kW each, having a rated operating temperature of 115°C and a maximum allowed temperature of 145°C. The water capacity of one boiler is 3800 liters.

The temperature range for different loops of Iosia district heating system are shown in Table 2.

Table 2 Temperature range for Iosia district heating system

District heating	Primary network		Secondary network		
	Supply temperature	Return temperature	Space heating supply temperature	Space heating return temperature	Domestic hot water
Substations	80 - 110°C	40 - 70°C	80 - 85°C	60 - 65°C	55 - 65°C

The ***geothermal swimming pools*** are located between the geothermal heat and power plant and the production well 4767 (Figure 8). There are 2 large rectangular pools (of 900 m^3 each) in which the geothermal water is mixed with fresh water in order to decrease the temperature, and there are 6 round pools filled only with heat depleted geothermal water.

Figure 8: Geothermal swimming pools (heath and recreational bathing)

4. CURRENT OPERATION OF THE CASCADED SYSTEM

The heat supply to Iosia-Nord district – both for district heating and sanitary hot water – is continuously monitored (see Figure 9) but data is not recorded. One heat meter is installed on the primary network in the geothermal heat plant and all consumers have their own heat meters that are read every month for invoicing.

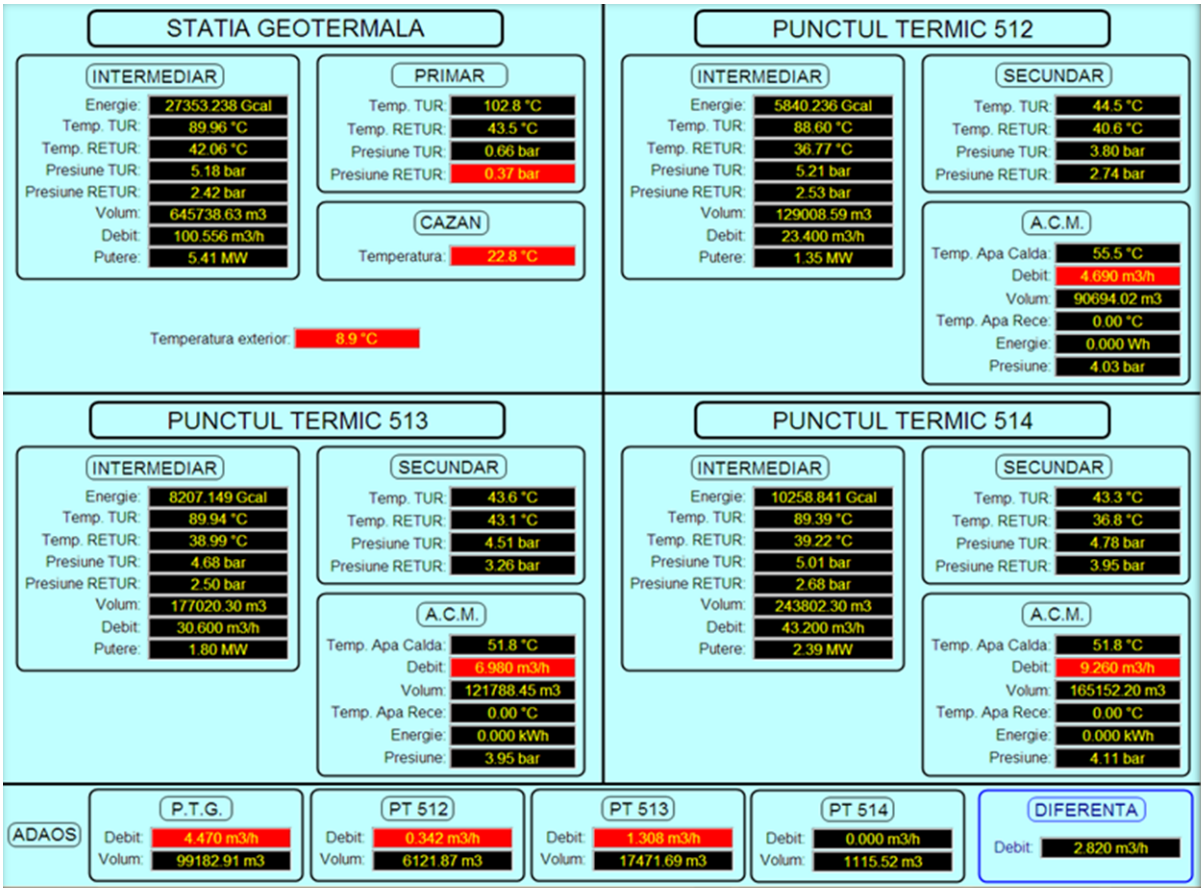

Figure 9: Monitored parameters of Iosia district heating

In order to meet the demand, the heat delivered to the primary network can be controlled either by modifying the flow rate of the primary agent (by means of 4 circulation pumps) and by modifying the supply temperature (for each flow rate stage).

Table 2 summarizes the ***annual thermal energy consumption*** of all heat consumers in 2012, 2013 and the first half of 2014.

Table 2 Annual total heat consumption

Heat consumers	Units	Year 2012	Year 2013	Year 2014 January-June
512	GJ/year	22937	25257	11790
513	GJ/ year	32860	35532	16853
514	GJ/year	43210	47275	22552
Sport Arena	GJ/year	2750	2776	859
Youth House	GJ/ year	297	418	282
Don Orione High School	GJ/year	1366	1277	691
Orthodox Church	GJ/year	90	109	67
“5x5” Sport Facility	GJ/ year	104	95	47
Total heat consumption	**GJ/year**	**103614**	**112739**	**53141**

The ***electric energy production*** varies basically with the outdoor air temperature that influences the condensing temperature. In Figure 10 are shown the daily average electric energy production for each month of 2013. All year round, the ORC unit ran with a relatively constant geothermal water flow rate of 10 l/s, generating 399.2 MWh gross and 327.5 MWh net electricity. It is obvious that in the summer months the electricity production is lower due to higher air temperature.

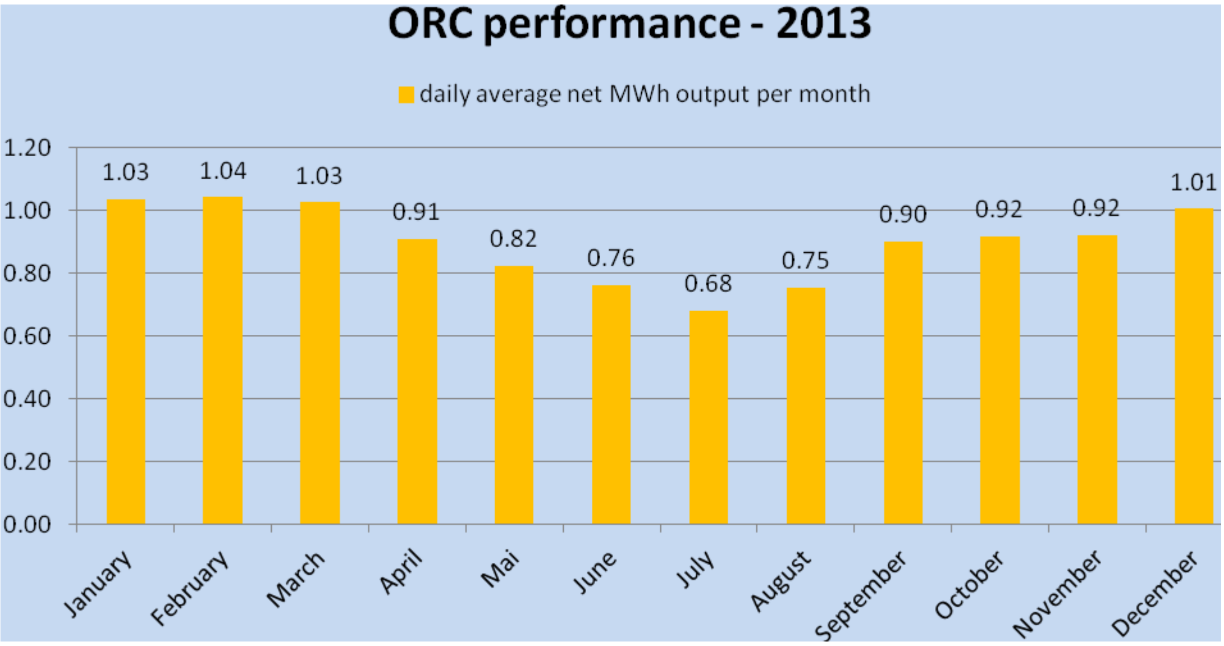

Figure 10: The 50kW ORC unit performance per 2013

The highest gross and net system efficiency achieved in 2013 by the power plant was 9.48%, and 7.64% respectively, while the lowest gross and net system efficiency was 5.98%, and 3.95% respectively. The maximum performance was achieved during the coldest day of the year, whereas the minimum was noticed during the hottest day of the year, being clearly observed the dependence of the air cooled binary-cycle power plant performance on the ambient temperatures.

	Maximum [%]	Minimum [%]	Efficiency drop [%]
Gross efficiency	9.48	5.98	36.9
Net efficiency	7.64	3.95	48.3
Efficiency drop [%]	19.4	33.9	

When the air temperature is high not only the gross efficiency is decreasing (due to higher condensig temperature of the organic working fluid), but also the net efficiency decreases very much due to the highe electric energy consumption of the fans on the condenser (Figure 11).

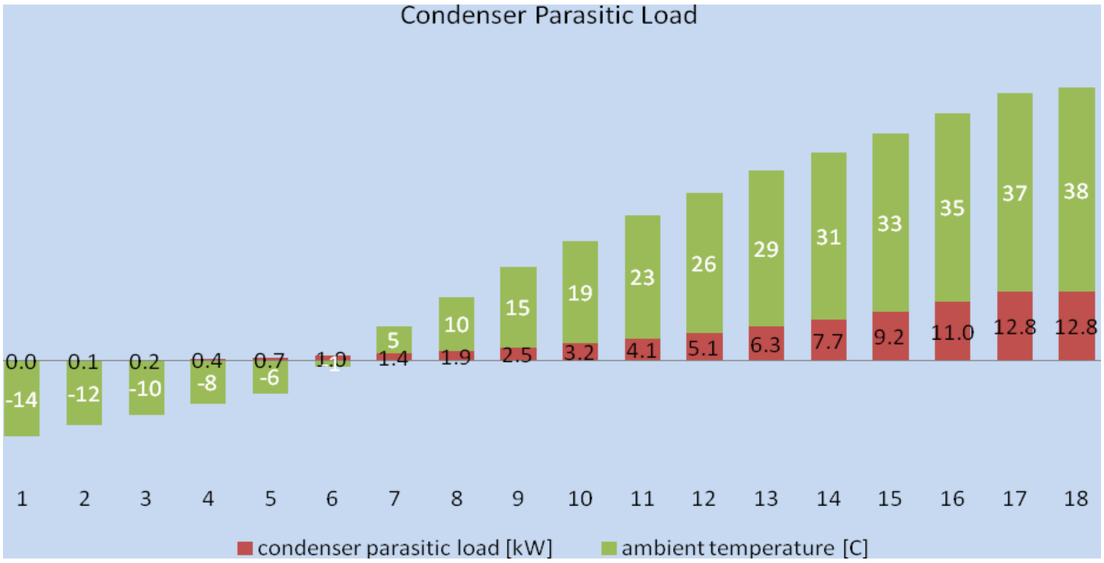

Figure 11: Air Cooled Condenser Consumption vs Ambient Temperature

Table 3 shows the electric energy produced in representative winter month (February 2013), when the heat demand for space heating was quite high, as the outdoor air temperature was low.

Table 3 – Energy Efficiency of the ElectraTherm Geothermal Power Plant

DATE	PRODUCED ELECTRICITY		CONSUMED HEAT	EFFICIENCY	
	GROSS kWh	NET kWh	MWh	GROSS	NET
01.02.2013	1179	1016	13.6	8.65	7.46
02.02.2013	1172	996	13.6	8.60	7.31
03.02.2013	1190	1055	14.3	8.30	7.36
04.02.2013	1130	1026	13.6	8.29	7.53
05.02.2013	1172	1042	14.1	8.31	7.39
06.02.2013	1193	1013	14.3	8.32	7.06
07.02.2013	1187	1043	14.1	8.42	7.40
08.02.2013	1178	1078	14.1	8.35	7.64
09.02.2013	1182	1088	14.6	8.11	7.46
10.02.2013	1172	1076	14.1	8.31	7.63
11.02.2013	1189	1092	14.6	8.16	7.49
12.02.2013	1179	1051	14.1	8.36	7.45
13.02.2013	1082	923	12.9	8.38	7.15
14.02.2013	1283	1053	14.1	9.10	7.47
15.02.2013	1353	1068	14.3	9.44	7.45
16.02.2013	1352	1080	14.3	9.43	7.53
17.02.2013	1344	1096	14.3	9.37	7.64
18.02.2013	1348	1104	14.6	9.25	7.57
19.02.2013	1351	1084	14.3	9.42	7.56
20.02.2013	1330	1063	14.1	9.43	7.54
21.02.2013	1356	1095	14.3	9.46	7.64
22.02.2013	1344	1075	14.3	9.37	7.50
23.02.2013	1337	1031	14.1	9.48	7.31
24.02.2013	1204	983	13.9	8.69	7.09
25.02.2013	1157	971	13.6	8.49	7.13
26.02.2013	1018	982	13.6	7.47	7.21
27.02.2013	1026	1010	13.4	7.67	7.55
28.02.2013	1014	997	13.6	7.44	7.32

5. CONCLUSIONS

The main target of Transgex S.A. company is to develop the utilization of the Oradea geothermal reservoir up to its maximum potential. The cascaded system in Iosia District, Oradea is a good example of increasing the energy utilization factor from the available flow rate of the geothermal water.

The geothermal district heating system with peak load boilers offers the possibility for supplying space heating for a larger number of consumers, as the geothermal energy covers 75% of the rated heat demand (calculated for a daily average outdoor temperature of -15°C). For most winters, the heat supplied by the boilers during the peak load periods is very low. For Iosia District, in 2013-2014 heating season the peak load boilers were not used at all.

The geothermal power generation unit uses a small quantity of thermal energy from the geothermal water and produces electricity which increases the economic efficiency of the entire system (although Transgex S.A. company does not receive the green certificates as they should).

Transgex S.A. company is not charging the Municipality for the heat depleted geothermal water delivered to the swimming pools, but this decreases their cost for the disposal of the used flow rate, as there is no reinjection yet in the Iosia District.

The Municipality of Oradea, in collaboration with Transgex S.A. company, plans to further develop the utilization of the geothermal water in the Iosia District for:

- Supplying primary heating agent to two more sub-stations (510, 511);
- Create a modern health spa facility on the current location of the swimming pools, including a laboratory for research and development of skin-care products from the solids dissolved in the geothermal water;
- Supplying with geothermal water a spirulina production unit.

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