GEOTHERMAL ENERGY, THE SUSTAINABLE DEVELOPMENT OF BUCHAREST - TECHNICAL SOLUTION FOR Nzeb

ZEGHICI R.*, POLIZU R.**,
*TUCEB – Building Services Engineering Faculty
** Romanian Geoexchange Society
razvan.zeghici@gmail.com

Abstract - Present article consist a theoretical approach of district heating and cooling application in Bucharest, Romania. Starting from the old Municipality District Heating, this study proves the benefits of a highly efficient system on connected buildings, ending with a case study made for a condominium, in 3rd District of Bucharest. Actual district heating runs at low performances and produces inefficient and expensive power and thermal agent for heating and domestic hot water (DHW).
The specific theoretical case study presented proves high performances of a tri-generation power plant called Geothermal ATES-HP-CHP which can take place to a thermal substation of 3 MW_{th} capacity. Main energy source used is the Geothermal Aquifer underneath Bucharest located at approx. 1500 meters depth which offers proper conditions for massive heat storage between seasons.
This focused application can be extended to the entire Municipality by using the Geothermal Aquifer in a large scale ATES systems network as a smart grid which provides heating, cooling and DHW mostly from RES, according to 20-20-20 targets.

Key words: District heating and cooling, tri-generation, heat pumps, high efficient buildings, Geothermal-ATES.

1. INTRODUCTION

In today's world, Europe is facing rising oil and gas prices, threats to the security of energy supply and energy poverty, as well as the already noticeable consequences of climate change due to massive CO_2 emissions.
Energy efficiency is the quickest, cheapest and most direct way to turn these challenges into real opportunities. With actual technologies, energy savings of up to 50% are already feasible. Improved application of energy efficiency could cut around 30% of greenhouse gas emissions in the EU. However, most EU Member States are still not making use of these enormous opportunities and are lacking clear implementation of energy efficiency *in situ* measures.
Implementation of renewable resources as a technical-financial issue, higher developed in the western countries of the European Union, offers a new perspective of living, best known today as *sustainable development*. This concept is based on the improvement of life standard, generally providing for economic growth without compromising the future generations right to a clean and healthy environment, as established in the United Nations Brundtland Report, dating back as of 1987.
As for the other Member States, the European Union requires that Romania complies with the aims of reducing energy consumption and CO2 emissions, while developing a National Strategy of Improving Energy Performance of Buildings. One of the most important tools is Underground Thermal Energy Storage (UTES). However, it implementation requires high investment costs, overlapping with a strict legal regime.
Taking into account the fact that Romania has to reach the 13,5% of energy savings target until 2016, UTES systems are a valuable help for that to happen, especially in urban areas. However, in spite of legal intricacies, as well as high investment costs, the private sector expresses a high interest in this area.
The complete strategy for the optimization of energy utilization in new or rehabilitated buildings includes new or enhanced building systems for providing heating, cooling, production and distribution of hot water and mechanical ventilation. Also, an important aim is the implementation of intelligent monitoring and adjusting modules.
High efficient buildings are defined as buildings that have a very high energy performance. The source lies, on first place, in the performance of the system producing the energy and only secondary in the isolation envelope of the building. Consequently, it is crucial to highlight the importance of energy producing system in order to have high efficient buildings known as nZEB.

2. TECHNICAL CONCEPT

This concept's innovation is the combination between geothermal energy with the storage of thermal energy in underground aquifers (Aquifer Thermal Energy Storage – ATES) Fig.2.
So called Geothermal ATES – HP – CHP system represents a highly efficient tri-generation power plant which is using the Geothermal Aquifer as RES exploited with HP in a ATES regime and a gas fired turbine that produces combined heat and power. Technical concept is illustrated in Fig.2.

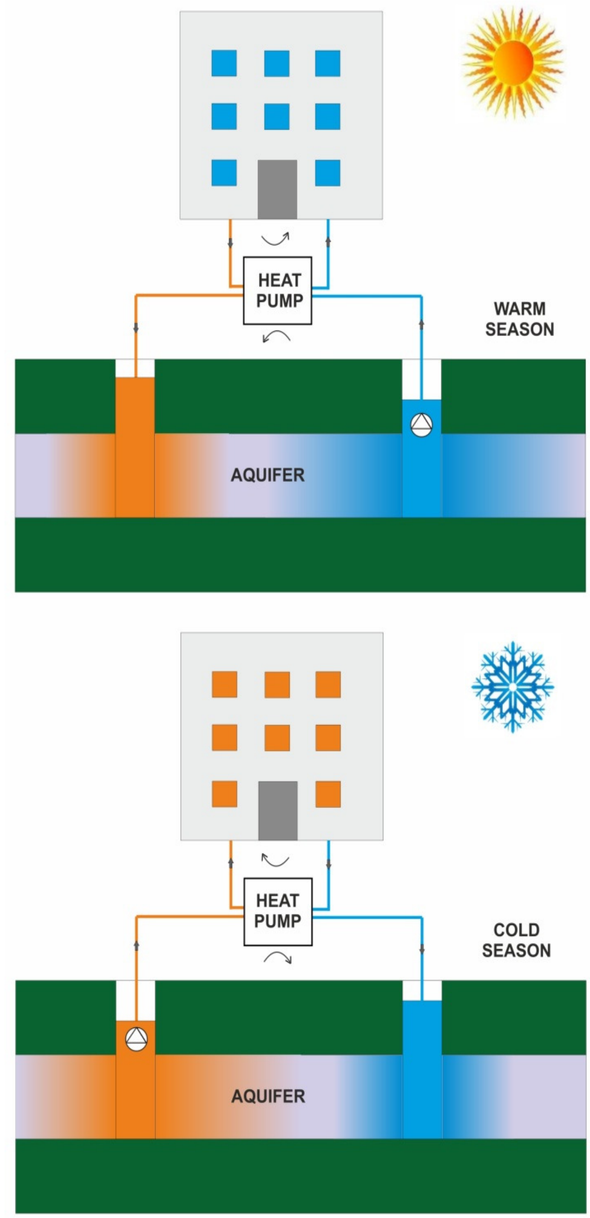

Fig.1. General ATES application

Seasonally stored energy is exploited through a group of geothermal heat pumps in order to comply with the energy demand at building facilities.
The electricity necessary for the functioning of the system while observing the parameters for central heating (55˚C/40˚C) and domestic hot water (60˚C) is produced through cogeneration with a high efficiency gas turbine. The turbo-generator shall function all the time during the year in order to reach a maximum efficiency. As the generator produces some more energy than necessary at highly competitive costs, the surplus can be used for illumination or can be fed into the national grid to district electricity network.
The most important feature of this design is represented by the energy management of the tri-generation unit. In order to maintain a positive energetic balance, energy supply must be perfectly matched with the end user demand

3. LOCATION

The urban beneficiaries of this system may be public buildings, residential and commercial units, currently connected to the centralized low efficiency system, whose acclimatization is achieved with old, unaesthetic equipment.
Thus, this project is highly versatile and can be implemented in any area of Bucharest, while being adapted to the needs of the consumers.
The technical study was drafted for Bucharest, which is the technical, industrial, cultural and financial capital of Romania. Bucharest has a continental-temperate climate, with outside temperatures ranging from -15°C and 40°C, measured in the city center. According to available 2002 statistics, Bucharest has 1,926,334 inhabitants, representing 8.9% of the entire population in Romania. As far as the building structure is concerned, Bucharest has approximately 110,000 residential buildings having almost 800,000 apartments, 500,000 of them still being connected to the centralized heating system.
The state-owned operator of the centralized heating system is RADET and the heating is achieved through the use of central units (for a small number of buildings however), while the acclimatization for dwellings is ensured by heat pumps air-air, split type, individually for each apartment.
Bucharest has an important hydro-geothermal basin made of superior Jurassic and inferior Cretaceous age limestone and dolomite. The geothermal fluid can be exploited over all Bucharest area only by submersible pumping, the hydrostatic level of the aquifer being around -80 meters. As far as hydrodynamics is concerned, the basin can be seen as an integrated system, where the carbonic deposits
are linked through the geologic fissures.
These geothermal deposits can be found at a medium depth that varies between -800 and -1600 meters on SE-NV direction. Another aquifer lies at a higher level, between -90 meters and approximate -200 meters. This aquifer is called the Frătești aquifer and is considered to be the main drinking water source of Bucharest.
Besides Fratesti aquifer, there are other shallow aquifers at around 60 m depth (Colentina and Mostistea).
Due to low values of the geothermal fluid temperature (variations between 35-45˚C in the range of -900m and -1200m), the geothermal energy can be exploited only with the help of water-water pumps, in an open loop.

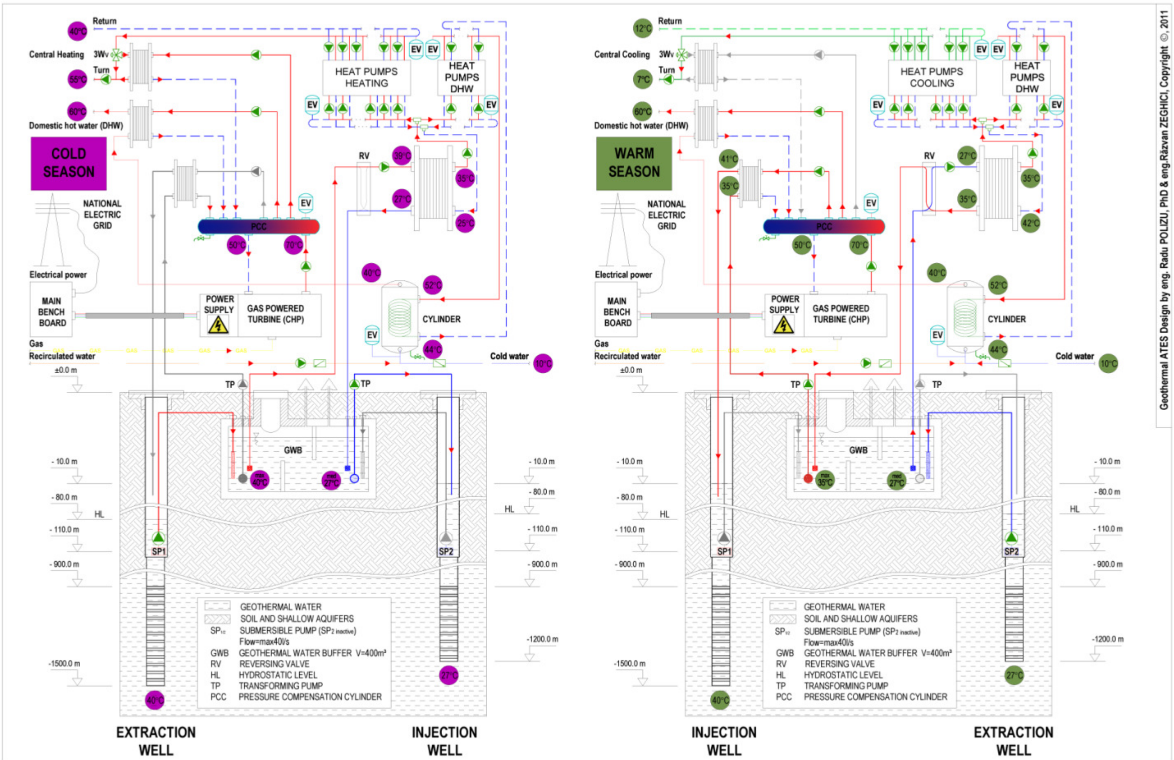

Fig.2 Technical concept of Geothermal ATES-HP-CHP

In the particular case of Bucharest, the surface aquifers do not allow high exploitation flows and Fratesti aquifer cannot be excessive thermally exploited, as it is considered to be the main water source for Bucharest. These impediments come before the 3rd option represented by the geothermal aquifer that lies underneath the Fratesti aquifer. Its water exploitation potential is very high and the only condition regards to the pumps capacities.

The geothermal fluid has a mineralization of 1-2.4 g/l and is chloral-sodium iodine water. The fluid does not contain combustion gases, but it has certain type of associated gases in high quantities, which need to be evacuated.

The location is set in South Eastern part of Bucharest, in 3rd District, more specifically at 5C5/2 thermal substation.

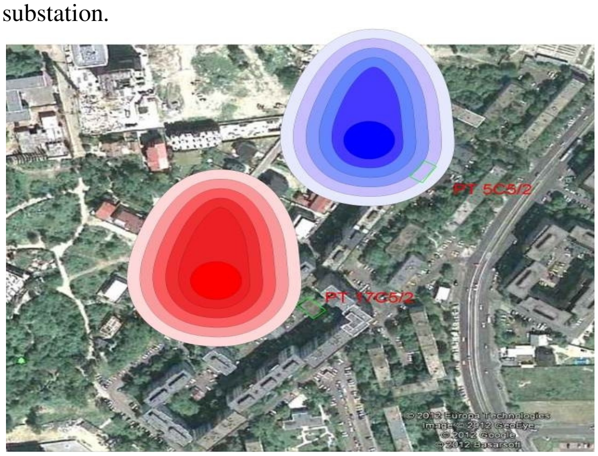

Fig.3 ATES polarization prints

This thermal substation has 2,7 MW capacity and provides the heating and hot domestic water for adjacent buildings. The thermal substation is connected with 13 residential buildings with 4÷10 floors, having approx. 8603 m^2 for 1610 inhabitants and one kinder garden. The thermal unit is owned by the local state-owned heating provider (RADET Bucharest). The secondary thermal agent for heating and domestic hot water is prepared with the use of a cross flow heat exchanger, manually handled.

The geothermal fluid is decanted through an underground storage water tank of 400 cubic meters, build out of concrete, highly hydro-thermal isolated. The storage insures a discontinuous, controlled and efficient functioning of the injection and extraction pumps while allowing a variable control on the secondary circuit according to the hourly consumer demand.

Heating and cooling production is provided by a group of heat pumps build in racks, Fig.4., equipped with variable circulation pumps.

The set exploitation debit of the geothermal liquid is 40 l/s but can be upgraded to more than 100 l/s. The large amount of water extracted and injected during one year may be transposed into a high energetic consumption, reducing significantly the performance of the power plant.

As an extra point, the system provides cold water for cooling during the warm season, as requested under EU regulations. Currently, in Bucharest, the acclimatization during the warm season is achieved through split heat pumps air-air, having a disparate location.

The heat pumps in the project shall ensure the cold water having 7/12°C for a centralized cooling.

Fig.4. Heat pumps build in racks

The use of heat pumps in a cooling mode is necessary for the refill of the geothermal aquifer with hot water. Thus, the thermal transfer balance concept (one of the most important ATES condition) will be achieved. During the operation period, the temperatures of the two wells shall stabilize, increasing the energy performance of the system. Seasonal performance factor (SPF) will be higher than 4.5.
Heating and cooling is possible with 2 stages processes according to Table 1a and 1b respectively.

Table 1a. – First stage process

	Chiller performance			Heating performance	
Condenser	Entering temp (°C)	35.0	Source	Entering temp. (°C)	35.0
	Leaving temp (°C)	41.7		Leaving temp (°C)	26.6
	Flow rate (l/s)	3.78		Flow rate (l/s)	3.78
	Pressure Drop (kPa)	20.3		Pressure Drop (kPa)	21.2
Evaporator	Entering temp (°C)	12.0	Load	Entering temp. (°C)	44.0
	Leaving temp (°C)	7.30		Leaving temp (°C)	53.0
	Flow rate (l/s)	4.30		Flow rate (l/s)	4.30
	Pressure Drop (kPa)	30.3		Pressure Drop (kPa)	24.3
Chiller Capacity (W)		83.6	Heating Capacity (W)		161
Input Watts (W)		21.9	Input Watts (W)		28.2
EER (W/W)		3.80	COP (W/W)		5.70

Table 1b. – Second stage process

	Chiller performance			Heating performance	
Condenser	Entering temp (°C)	35.0	Source	Entering temp. (°C)	30.0
	Leaving temp (°C)	41.7		Leaving temp (°C)	22.5
	Flow rate (l/s)	3.78		Flow rate (l/s)	3.78
	Pressure Drop (kPa)	20.3		Pressure Drop (kPa)	21.7
Evaporator	Entering temp (°C)	12.0	Load	Entering temp. (°C)	44.0
	Leaving temp (°C)	7.3		Leaving temp (°C)	52.1
	Flow rate (l/s)	4.30		Flow rate (l/s)	4.30
	Pressure Drop (kPa)	30.3		Pressure Drop (kPa)	24.4
Chiller Capacity (W)		83.6	Heating Capacity (W)		146
Input Watts (W)		21.9	Input Watts (W)		27.6
EER (W/W)		3.80	COP (W/W)		5.30

In order to avoid this shortcoming and to obtain a high energy performance coefficient, highly efficient natural gas co-generation equipment was added (a micro-turbine). The chosen model is subject to Government Decision no, 219/2007, as highly efficient with low capacity co-generation turbine, Fig.5.
This micro-turbine having a power capacity of 280 KVA will insure a continuous flow of energy for the functioning of the equipment inside the thermal unit, as well as the necessary thermal agent for the increase of the water temperature to the desired level. During the warm season, the excessive heat produced shall be transmitted to the geothermal fluid before the discharge into the warm well. The excessive electricity produced can be provided in the national grid or used for the illumination of a public institution.

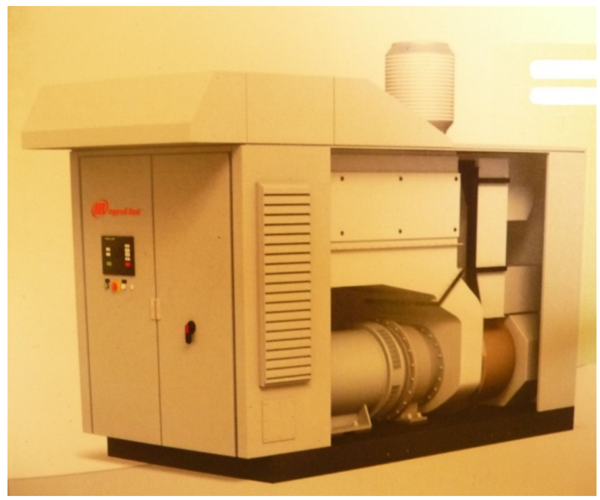

Fig.5. Co-generation turbine

By using a heat recovery unit for preheating the combustion air introduced in the turbine and two heat exchangers for different temperature hot water producing, CHP assures a high performance of 89%. Technical process is illustrated below, in Fig.6.

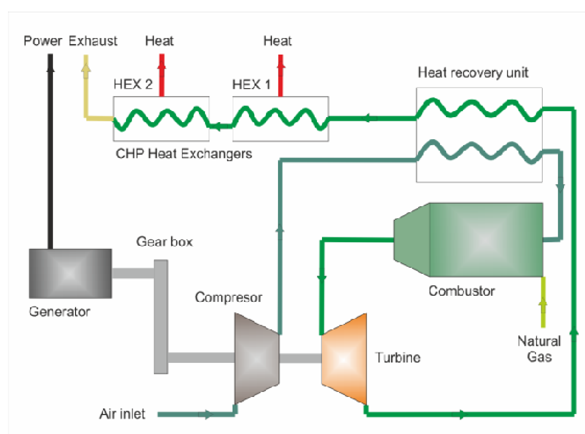

Fig.6. Technical process of CHP

The thermo-electrical unit in the present paper shall have an installed thermal capacity of 2.7 MW and an installed electric capacity of 280 KW. From the analysis of the thermal balance, a surplus of 61% per location shall be generated as compared to the natural gas source, used for the operation of the turbine.

With this performance, the proposed project proves to be more efficient than the classical energy provision system and triggers the connected buildings to be seen as nZE Buildings. Another advantage would be (in case of the dwelling units under the national thermal rehabilitation program) that a proper isolation would definitely allow them to be seen as A category in the efficiency range.

System performances were calculated for one year and the results are illustrated in Fig.7 for the cold season and in Fig.8. respectively for the warm season.

All descriptive graphical representations for energy used in the system were made in terms of primary energy. Variation was set according to local climate conditions and hourly end user demand of heating, cooling and DHW.

According to Fig.7, 3244 MWh of gas is burned in CHP module to provide 800 MWh electricity for system usage, 1846 MWh hot water for heating and DHW and an excess of 60 MWh electrical energy for feeding into National Electricity Grid or for public spaces illumination. ATES will provide 2653 MWh green energy developed with Heat Pumps to 3453 MWh thermal energy for Heating and DHW. Heat pumps average seasonal performance factor for the heating season is 4.32.

According to Fig.8, 2606 MWh of gas is burned in CHP module to provide 514 MWh electricity for system usage, 1147 MWh hot water for heating and DHW and an excess of 84 MWh electrical energy for feeding into National Electricity Grid or for public spaces illumination. ATES will be fed with 3703 MWh energy from HP and excess heat from CHP. By heat exchange with ATES, Heat Pumps will provide 2827 MWh thermal energy for Cooling and DHW. Heat pumps average seasonal performance factor for the heating season is 5.37.

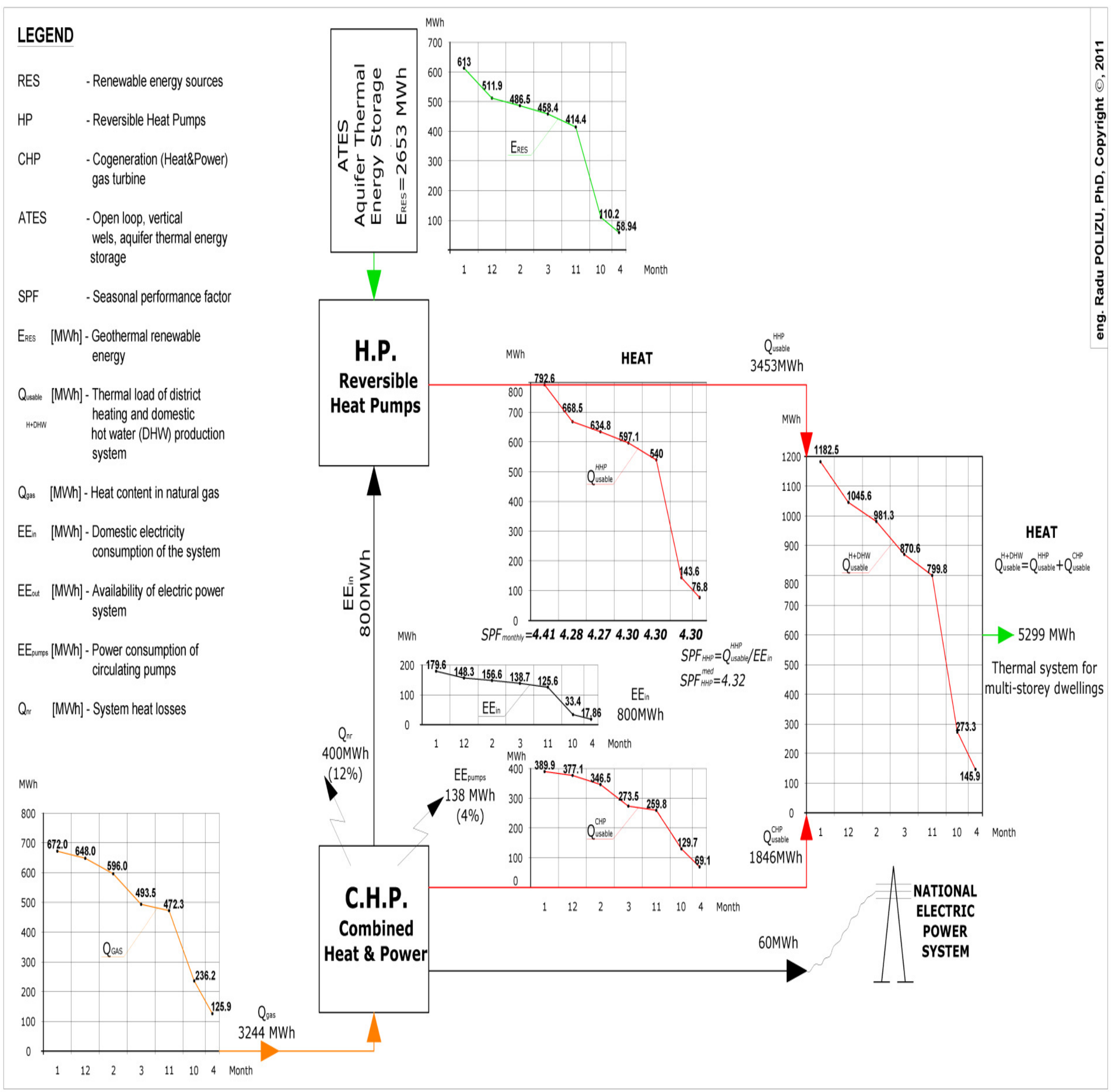

Fig.7. System performances during the cold season (4176 hours/year)

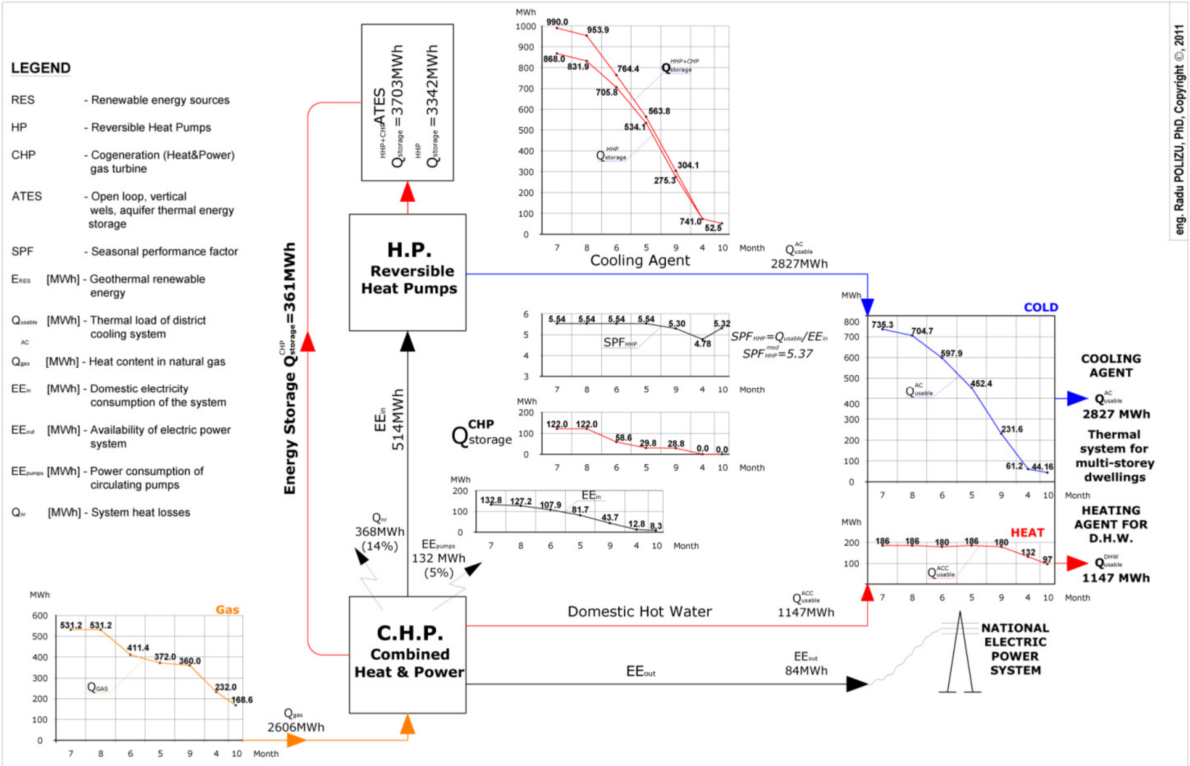

Fig.8. System performances during the warm season (4584 hours/year)

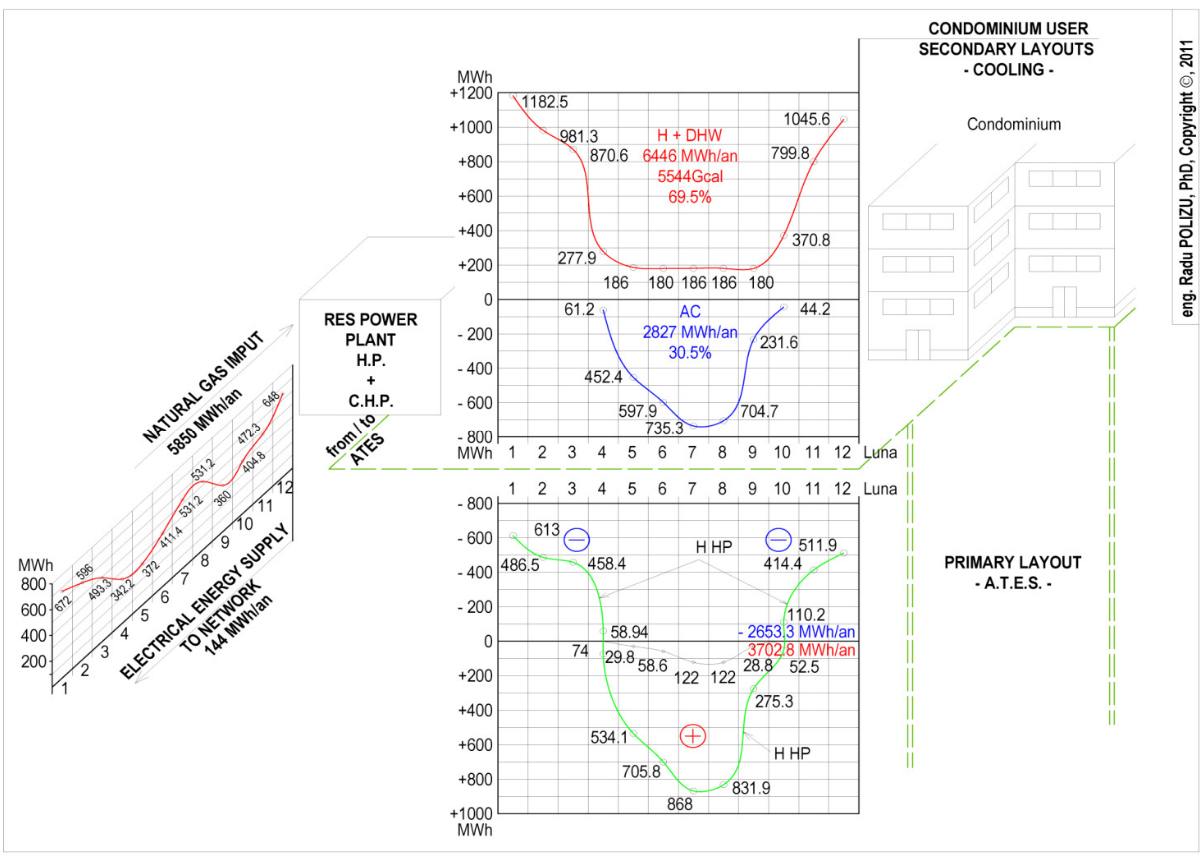

Fig.9. Energy performance of the power plant

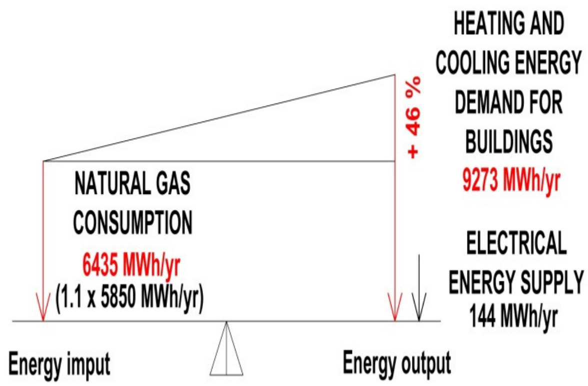

Fig.10. Primary energy balance of the power plant

Primary energy conversion of urban heating/cooling:

$$f_{system} = \frac{6435}{9273 + 144} = 0.68 \qquad (1)$$

Energy performance of the power plant is determined below as:

$$SPF_{yr} = \frac{6446 + 2827 + 144}{5850} = \frac{9417}{5850} = 1.61 \qquad (2)$$

4. FOLLOWED RESULTS

■ **Installing of 2,7 MW_{th}** capacity for supplying condominium with 6446 MWh thermal energy for heating and 2827 MWh thermal energy for cooling. The entire power demand for heat pumps and circulation pumps is covered by **high efficiency co-generation** with **280 kW_{el}** capacity.

■ **Efficient District Heating and Cooling** demonstration according to European Directives 2004/8/CE and 2006/32/CE regarding high efficiency cogeneration and energy efficiency to final user. In 2012 both Directive will be gathered into a new Directive with specific corrections as:

- Centralized production of minimum 50% thermal energy form renewable sources and co-generation (**present project assures 77%**)
- Primary Energy Factor for District Heating and Cooling must be less than 0,8 (**present project assures 0.68**)

■ Over **61%** available energy produced on site in addition to energy bought in the system. It means that all buildings connected to the Tri-generation Power Plant will be **nZEB** (nearly Zero Energy Buildings), fulfilling purposes of EPBD Recast 2010/31/EC regarding new or refurbished buildings in the community.

■ Demonstrative **usage of a smart grid** of central heating and cooling distribution and power supply for auctioning and self-adjusting system according to variable demand of the condominium buildings.

■ Certification of a system with a **high potential of multiplication**.

■ Demonstrating a **positive economic effect** by delivering energy at a supportable cost for the final user, lower than subsidized cost, engaged by local energy suppliers produced with conventional energy sources (fossil fuels).

5. INVESTMENT FEASIBILITY

The investment was designed with a return rate over a period of 10 years, in the full observance of EU standards. The gas price is an important component in the investment structure, as gas is one of the energy sources for the thermal unit. The official information published on the website of the Eurostat (http://epp.eurostat.ec.europa.eu) marks an important increase in the gas prices (44% in the next 10 years).

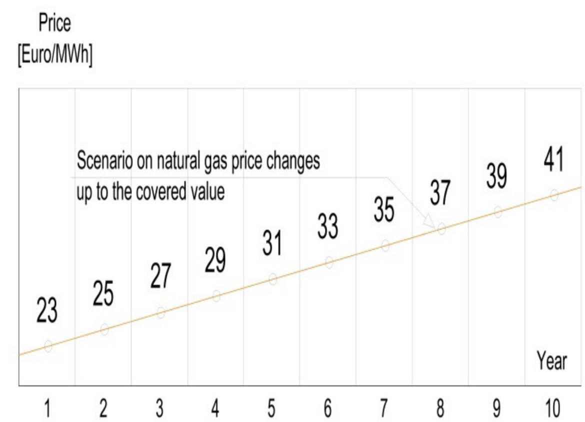

Fig.11. Variation of the natural gas price in Romania

The total investment cost is of 5,100,000 EUR, where 1,600,000 EUR are unsupportable by EU aids from the program related to the increase of energy performance through the use of renewable energy sources. If this investment shall obtain private financing from credit institutions, one can assume the payment of a 5% fixed interest per year or the annual payment of a fixed amount of 510,000 EUR per year.

The operation and maintenance expenses could be foreseen at around 300,000 EUR for the first 10 years.

Based on the utilization of geothermal energy another income source (approx... 30%) could be represented by the sale of white and blue certificates received for the energy efficiency and energy provided by co-generation. This program is currently financed by the EU and is regulated by Directive no. 32/2006. At present, it is implemented only in the UK, but as of 2013 it shall be extended in the rest of the Europe.

Considering this, the price for a Gcal and for a MWh shall have a medium increase of 3.4% per year, meaning 61.2 EUR/Gcal and, respectively, 52.7 EUR/MWh after the first 9 years. The energy delivered by the national provider RADET is established by law at a level of 72,4 EUR/Gcal for the final consumer. Until now, this price was subsidized by the local authorities to 40 EUR/Gcal for all Bucharest inhabitants, further subsidies being granted to special social cases.

The total revenues for this period (10 years) is of 6,132,000 EUR and includes the income resulting from the sale of thermal energy for heating, domestic hot water and cold water for acclimatization, where the EU aids for renewable energy sources use is added. Thus, considering the total investment costs (investment costs – 4,000,000 EUR, natural gas cost – 1,876,900 EUR and maintenance and exploitation costs – 298,700 EUR) the profit rate is at 456,000 EUR (8%). The implementation costs of this system, including installations in the private housing units are covered by Gcal price and nonrefundable aids from the EU.

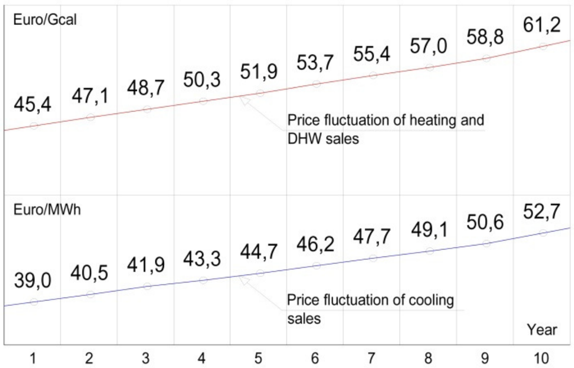

Fig.12. Prices for heating and cooling at end user

5. CONCLUSIONS

The technical feasibility study offers a method of transforming a significant amount of the actual buildings stock in high efficient buildings. Efficient District Heating and Cooling can be provided by using a high rate of local natural resources instead of burning large quantities of fossil fuel in an inefficient way. New technologies are followed by smart metering which provides a precise control and accounting of the energy used.

Thermal substations can be transformed into high efficient tri-generation power plants which are producing heating and cooling at affordable prices for the citizens. This study case can be easily adapted to any other application which has an important potential of heat storage in aquifers upper than 2000 meters depth.

The cogeneration equipment will be soon produced in Romania, this fact adding a plus for the project's efficiency parameters.

The advantages for the final consumers are also very important and are reflected in lower prices per Gcal and rising comfort in actual residential buildings by providing central cooling during warm season.

This investment program is aimed at Energy Service Companies (ESCO), which are the first market players that are able to get involved in implementing, monitoring and financing energy matters.

The implementation of this pilot project shall also be an opportunity for Romanian Research and Education Institutes.

As a further step in the development of the proposed project, a global implementation at the level of the entire Bucharest is also to be considered. However, this will only be possible after the research results on thermal pollution of aquifers and chemical modifications of geothermal water will be available.

This concept was built according to Romanian and European methodology on EPB and cost effective measures (2010/31/EC, EU Regulation No 244/2012, EED Proposal)

6. REFERENCES

1. Geotrainet - 2011, Geotrainet training manual for designers of shallow geothermal systems
2. Geotrainet – 2011, Geotrainet training manual for drillers of shallow geothermal systems
3. MARES project – 2011, Managed Aquifer Recharge and Storage study tour - The Netherlands
4. Polizu R. – "Differences between ground source heat pump (GSHP) systems and underground thermal energy storage (UTES) systems"
5. Seibt P. Kabus F. - "Aquifer thermal energy storage – projects implemented in Germany"
6. Kabus F., Wolfgramm M. - "Aquifer thermal energy storage in Neubrandenburg -Monitoring throughout three years of regular operation"
7. TNO – 1990, Hydrochemistry and energy storage in aquifers
8. European geothermal Energy Council, Geothermal district heating
9. Roșca M. – 1999, Geotermalism și centrale geotermale
10. Shaw-Yang Yang, Kuang-Yi Li – 2010, "Modelling transient temperature distribution for injecting hot water through a well to an aquifer thermal energy storage system"
11. EPBD Directive recast – 2010, Directive 2010/31/EU of the European parliament and of the council on the energy performance of buildings
12. Energy Efficiency Watch Project-2009, Promoting Energy Efficiency in Europe
13. Augustine C. Tester A. Anderson B. – 2006, A comparison of geothermal with oil and gas well drilling costs
14. Fistung D., Miroiu R., Popescu T., Agenda 21 Pentru regiunea 8, București-Ilfov - un posibil model de dezvoltare regională durabilă
15. Energy Resources Conservation Board-2009, Simulation of Geothermal Flow in Deep Sedimentary Basins in Alberta
16. www.decc.gov.uk, Department of Energy and climate change - Renewable heat incentives (RHI) scheme