LOw Carbon After Life: sustainable use of flooded coal mine voids as a thermal energy source - a baseline activity for minimising post-closure enviromental risks

LOCAL

Research Fund for Coal & Steel

hunosa

D4.4. Benefit cost of heat production /heat and cold reports in different scenarios(Markham site, and Hospital- University sites in Spain). Key parameters and lessons learned

LoCAL WP 4

Partner responsible: HUNOSA

Table of content

1 Background

The use of mine water as geothermal resource is one of the best options to get some economic benefit of this water that in some cases must be pump forever. Barredo Shaft is one of those coal collieries that were built in the center of a city some decades ago. The coal exploitation is close and the colliery is flooded but the water level must be kept at 60 meters below the surface to avoid the flooding of Santiago Colliery. Barredo Colliery is in communication with Figaredo Colliery (also flooded) and there is a gallery between Figaredo and Santiago collieries at this level.

The amount of water pumped in Barredo is 4 Hm3/year. Barredo is not only united to Figaredo; they are also united to San Jose and Santa Barbara collieries, the total water pumped from this four old exploitations, all of them flooded, is 15Hm3/year.

Right now we only use 0,7Hm3/year of this water mainly for giving heating and cooling by the heating pump technology to Mieres Hospital, but the benefit of this business is enough to pay the total cost of pumping in Barredo Shaft, 200.000€/year.

The business model to give geothermal energy with mine water is call “Energy Service”, with this model we are in charge of the whole investment of the installation, the control of the process and the maintenance that is, the client receives energy and do not need to be in charge of the installation. In our case we can offer a certain amount of savings respect to the cost that the client would have in case of use conventional energies or conventional technologies.

2 Model of energy service contract.

The figure 1 presents the model of the energy service contract. In some cases the use or a renewable energy can give some savings compared with the use of conventional energies. The left side of the figure shows the costs of one conventional system that use for example an old technology with a low efficiency. In the other side a new system with a renewable energy (cheaper) or a new technology (more efficient), the energy cost is quite lower, so an important saving can be achieve.

But if the client cannot achieve the necessary investment is when the Energy Services Company (ESC) can develop its business. If the possible saving is enough it can be share between the client and the Energy Services Company. The installation is done by the ESC, with the total investment and during several years this company is in charge of the management of the installation, the client only gets other cheaper energy. It can be established in the contract that once it is finished the installation property passes to the client so the total savings can be receive by him.

This is the model we use for the three geothermal projects we have with the Hospital, University and FAEN building; for example, to the hospital we guarantee 10% of savings respect the use of gas for heating and electricity for cooling.

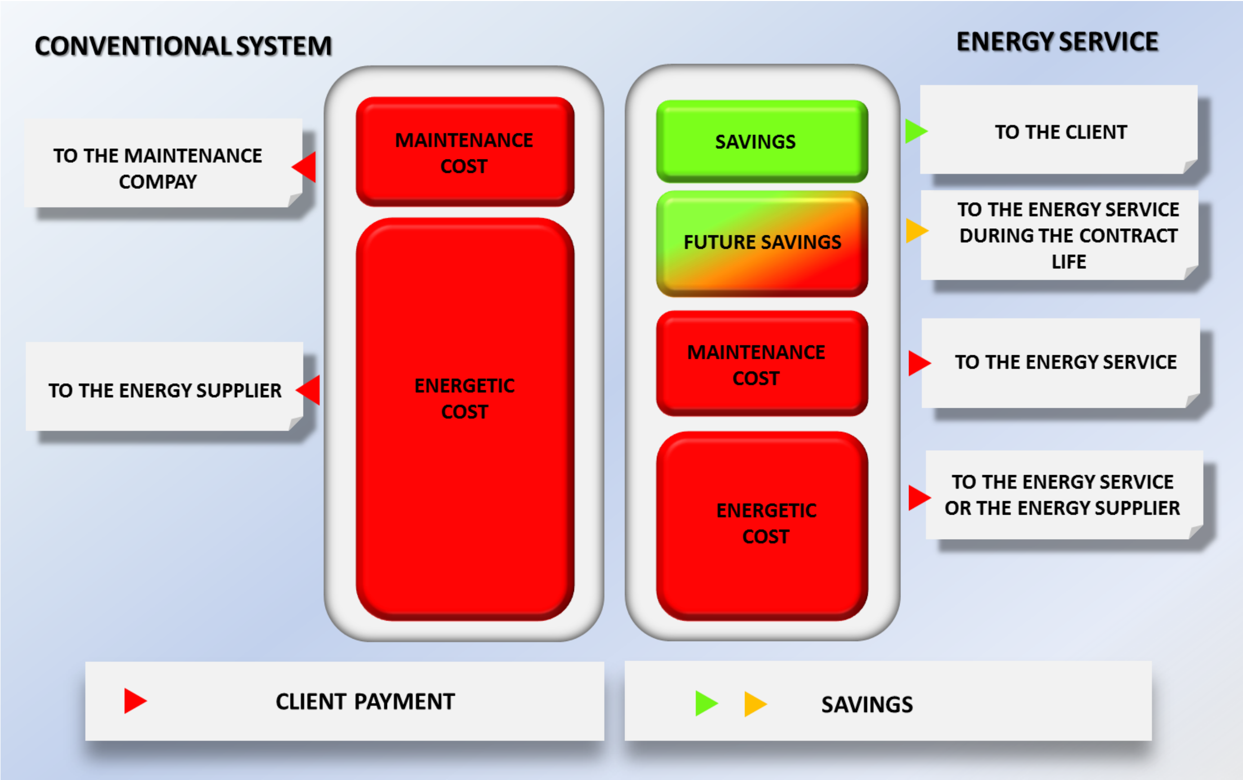

Figure 1: “Model of energy service contract”

2.1 Example of economic model of energy service.

In the table 1 an example of an economic model are shown to explain the concept of Energy Services. The energy consume per year is 7000000kWh, 50% for cooling and 50% for heating.

The price of the natural gas is 0.0457€/kWh and the total cost of heating this conventional energy would be 206.653,75€/year.

The price of electricity is 0.1105€/kWh. The use of refrigeration tower to supply cooling has a EER of 2.1, the total cost for this technology give us a cost or 184.166,67€/year.

The total cost in case of conventional system would be 390.820,41€/year.

We guarantee 10% of savings to the hospital so the cost with geothermal energy must be 351.738,37€.

The hospital must pay electricity to use the heat pumps for geothermal energy, but the COP is 5.6 and the EER is 5.93 (the EER for refrigeration tower was 2.1). The total cost of electricity is now of 134.281,72 €/year.

We negotiated with the hospital a constant payment of 70.856,9€/year in concept of disposal of the installation only for the hospital.

So the different between the guarantee payment and the electricity cost and the disposal concept is the payment in concept of energy supply.

CONCEPT	CONVENTIONAL SYSTEM	GEOTHERMAL SYSTEM
Cooling	184.166,67 €	0,00 €
Heating	206.653,75 €	0,00 €
ELECTRICITY OF HEAT PUMPS	0,00 €	134.281,72 €
PAYMENT OF DISPOSAL	0,00 €	70.856,90 €
PAYMENT OF ENERCY SUPPLY	0,00 €	146.599,75 €
TOTAL PAYMENT	390.820,41 €	351.738,37 €
AHORRO GARANTIZADO	39.082,04 €	10%

DATA	
Cooling (kWh)	3500000
Heating (kWh)	3500000
Electricity price (euros/kWh)	0,1105
Natural gas price (euros/kWh_pcs)	0,0457
Investment (euros)	1200000
Interest rate	0,03
Recovery Period (years)	24
COP (heating)	5,6
EER (cooling)	5,93

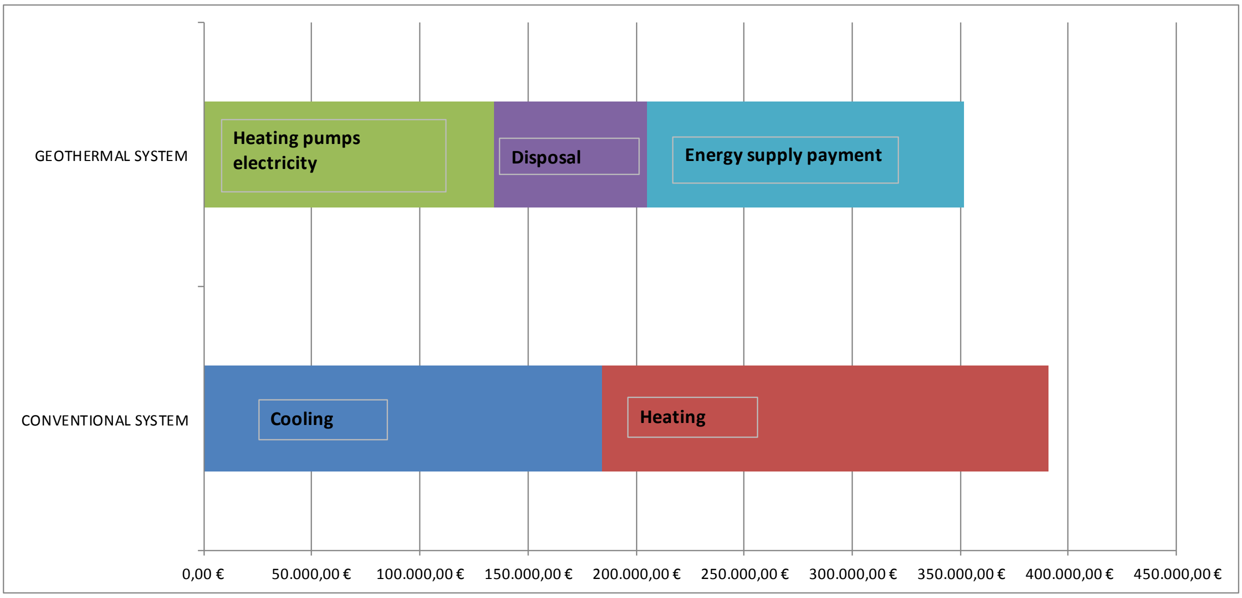

Table 1: Economic model for the hospital

So the savings for the client would be 39.082€/year and our income would be 217.456€/year in this case. The real economic model will be explained ahead with more detail.

3 FAEN Project.

3.1 Description of FAEN Project.

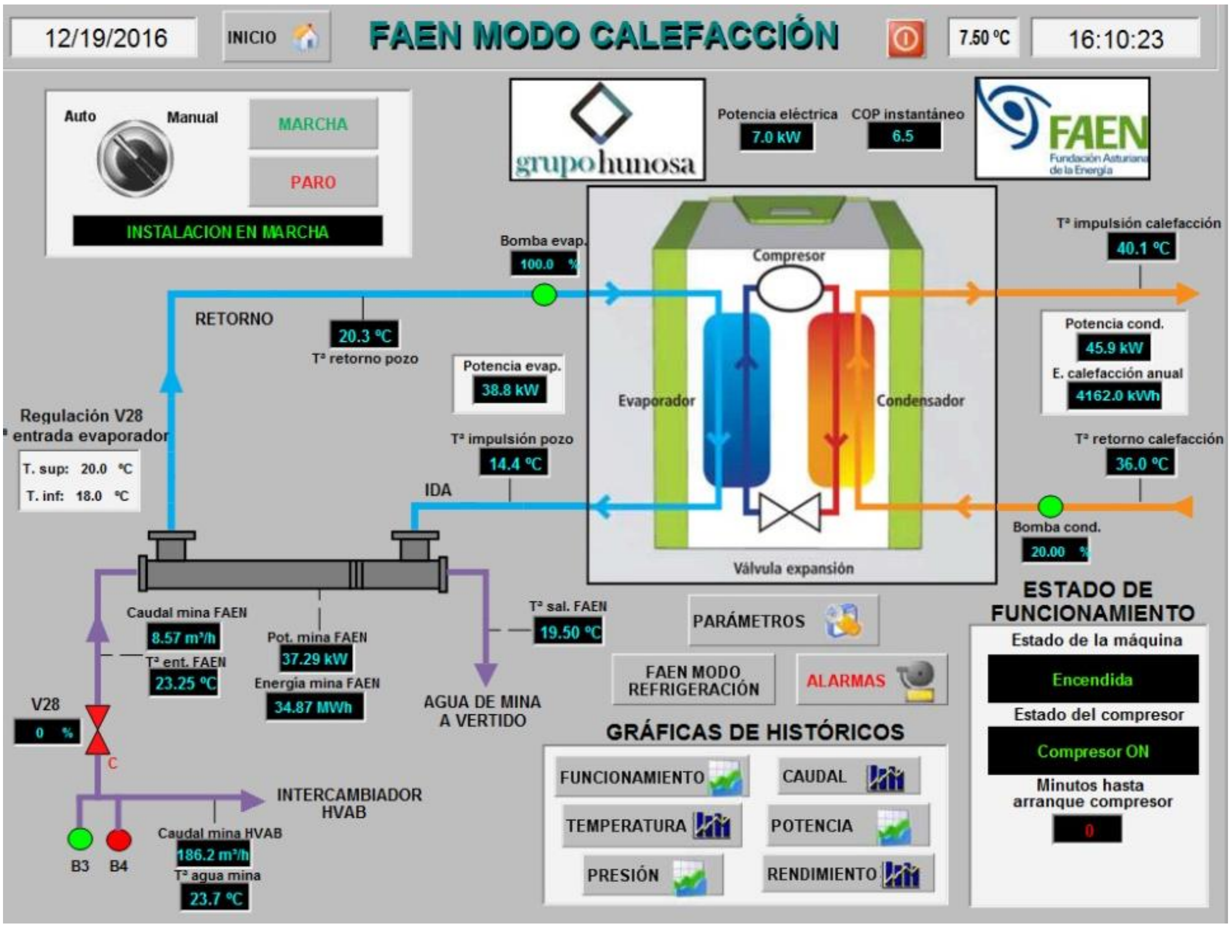

Figure 2: Operation Scheme in Heating Mode in FAEN Project

In the figure 2 it is shown the heating mode operation scheme for the FAEN Project.

The heat pump model ECO GEO HP3 25-100 with the following characteristics:

Heat power	kW	25-100
Electrical power	kW	13.3-19
COP		4.49
Temperatures in heating side	ºC	60/20
Temperature increment in heating side	ºC	5
Flow in heating side	l/h	4300/17200

Temperatures in cooling side	ºC	20/-10
Temperature increment in cooling side	ºC	3
Flow in cooling side	l/h	15000

Table 2: Nominal operation conditions for the heating pump

To keep the heating pump in the optimal operation conditions in the heating mode the regulation process works in the following way:

1.- The temperature in the heating side of the heating pump (right part in the figure 2), that is the water that goes to the fan coils of the building, must be kept at 40ºC. To achieve this there is a pump that control the flow that goes through the condenser, the regulation range is 20-100%. If there is a great necessity of heat from the building, this pump reduce the flow to avoid temperature reduction, only whet more heat is transfer from the mine water this pump increases the flow. If the pump is at 20% and there is no heating supplying to the building the system stops the heating pump. The system knows this when the temperature of the water that goes to the building is the same that the one coming from it.
2.- In the cooling side there is also an optimal range of temperature (16-19ºC), the heating pump can work out of this range (from 3ºC to 23ºC) but the COP drops. And if the temperature reaches 23ºC the systems stops the heating pump and gives us an alarm. This temperature would cause a malfunction of the machine, because over this temperature there is no condensation in the heating side. There is a pump to control the flow in this circuit, but it is no used to control the temperature it only supply more energy to the heating pump coming from the heat exchanger.
3.- The temperature control of the cooling side is in charge of the valve V28 (left side of the figure 8). When the temperature of the cooling side gets 20ºC, the flow of the mine water is reduced by this valve, so the heating pump only can get energy from the temperature of the water accumulated in the circuit of the cooling side. Once the temperature reduces the valve opens again.

If the building needs more heat, the difference of temperature in the heating side increases, so the heating pump reduce the flow until 20%, if the temperature keeps the increment, then the pump of the cooling side increases the flow in this side, this creates a reduction in its temperature. This cause an opening in the valve V28 and the heat begin to pass from the mine circuit to the cooling side, the increment of temperature of the cooling side causes an increment in the heating side and the control pump increases the flow so more heat can go to the building.

When the building needs cooling instead of heating the operation is the similar, in this case is the cooling side what is connected to the building and the heating side is connected to the heat exchanger with the mine water. This mode is presented in figure 3.

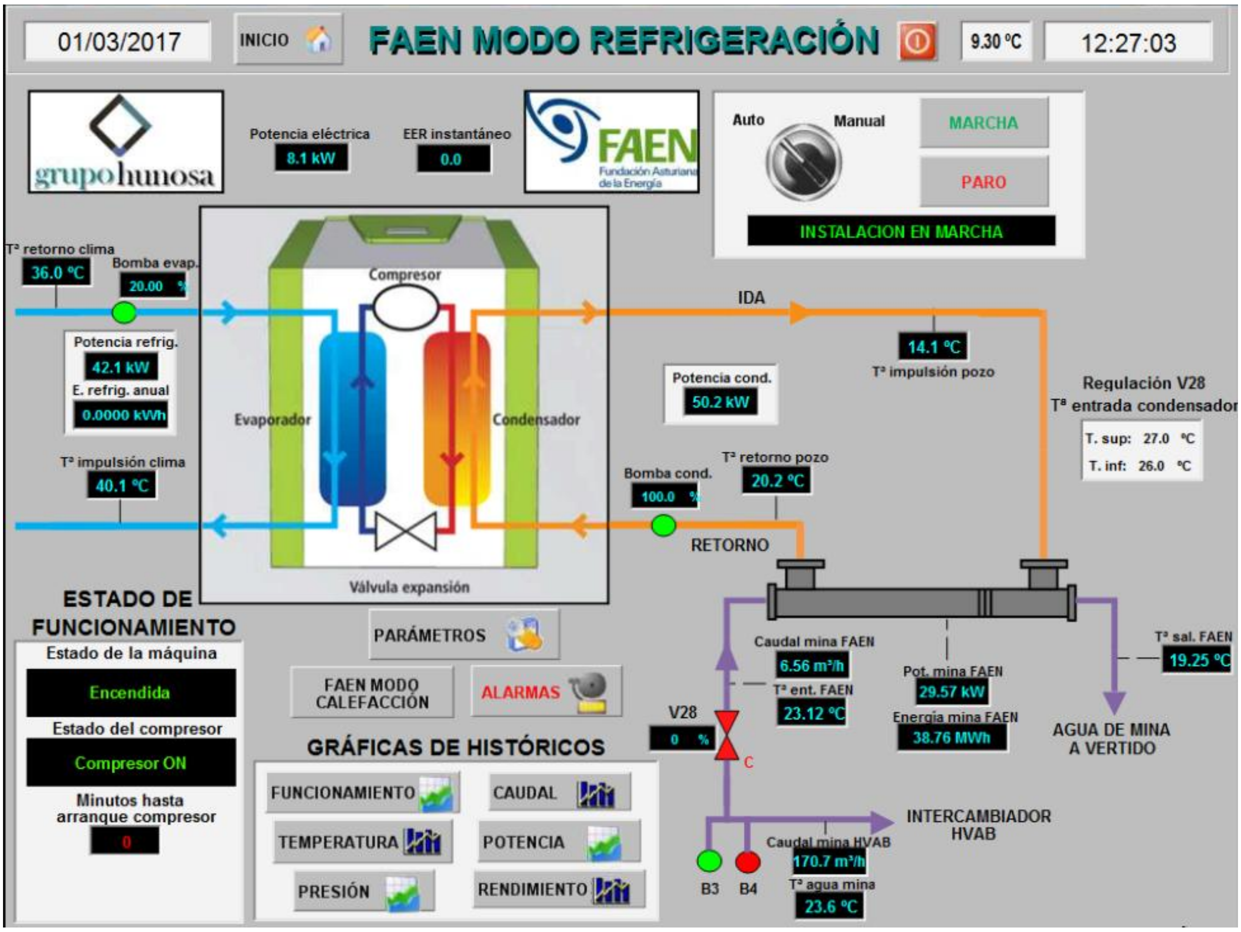

Figure 3: Operation Scheme in Cooling Mode in FAEN Project.

This control system causes constant variations in the working conditions so there are constant cycles of adjusting them to the necessities of the building. The Figure 4 shows how the COP is changing along one working day. We can see eight working periods and how the COP changes between 5 and 7 (blue line); the first period is in the early morning with the building cool so it is the biggest and with a great necessity of heat so this causes a reduction in the COP because the temperature drops (in this case until 8ºC). The red line is the power taken from the water mine by the cooling side of the heat pump; the system tries to keep it constant in the optimal conditions. And the green line is temperature of the water that goes from the heat exchanger to the cooling side of the heating pump. The changes of this temperature a cause mainly by the mine water flow as was explained before. For these reasons we count the total energy supplied to the building and the electricity used by the installation, mainly by de heat pump. With these values we calculate the invoice to send to the client.

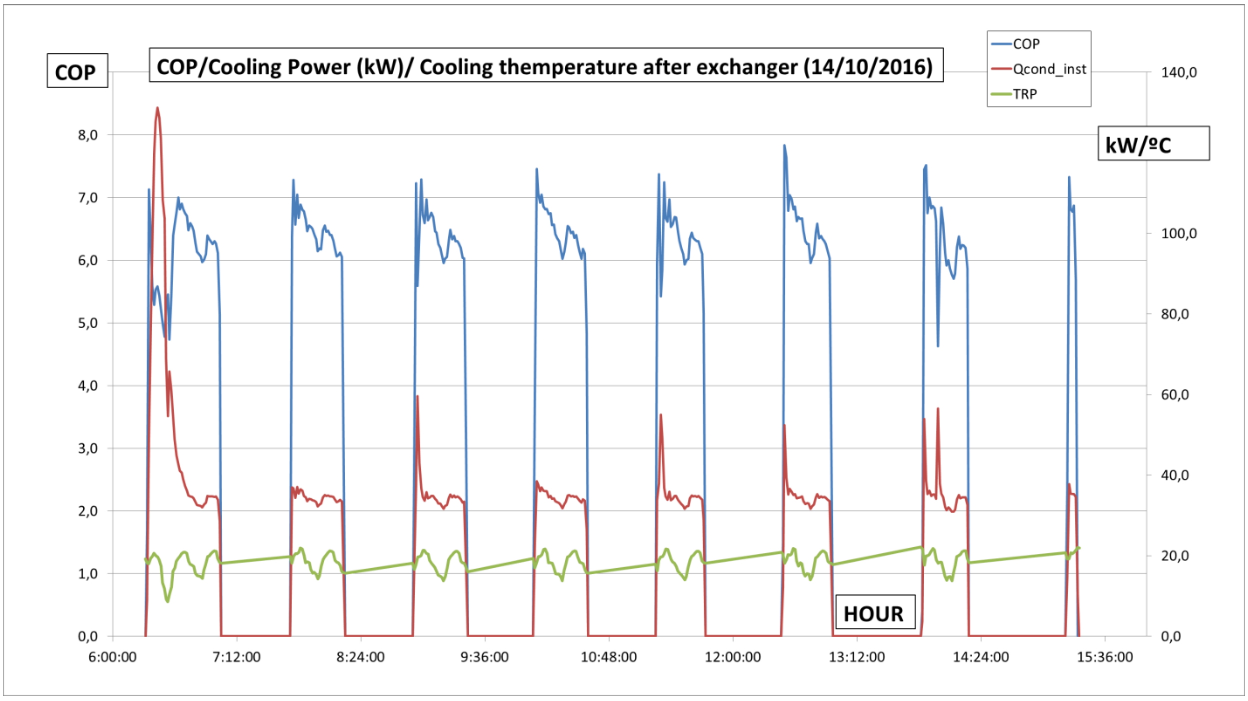

Figure 4: Example of operation conditions for 14/10/2016

3.2 Invoice structure

Every month the invoice sent to the client includes de following concepts:

P1 – Energy supplied to the building; that is kWh of heating or cooling send from the mine water to the building.

P2 – Maintenance: this includes the preventive maintenance to keep all equipment working in ideal conditions.

P3 – Total Guarantee: this service includes the fixing and changing of different elements of the installation to keep is as it is new.

P4 – Workings to build the new geothermal energy system. This includes the renovation of the whole installation, including the project, the purchasing of the new equipment, etc; that is, the total investment of the new system.

The initial map of savings for the client is presented in table 3. The initial period of the contract will be of 8 years. Then in the future the contract can be renewed, and in the year nine for example the savings will be 2.436€ higher because they will not pay the concept P4 (all the money HUNOSA put to renew the system will be recovered), and thet will pay the electricity of the heating pump..The total cost of the installation was 55.591,88€ and the client got a subvention (35.000€) that was used to pay part of it.

Year	1	2	3	4	5	6	7	8	TOTAL
Conventional system	**7.532,56**	**7.636,8**	**7.743,11**	**7.851,56**	**7.962,17**	**8.075,00**	**8.190,09**	**8.307,47**	**63.298,86**
Heating	4.582,04	4.673,68	4.767,16	4.862,50	4.959,75	5.058,95	5.160,13	5.263,33	39327,54
Cooling	629,69	642,28	655,13	668,23	681,6	695,23	709,13	723,32	5.404,61
Recovery (1)	2.320,83	2.320,83	2.320,83	2.320,83	2.320,83	2.320,83	2.320,83	2.320,83	18.566,64
Geothermal system	6.932,08	7.264,08	7.322,83	7.382,75	7.443,88	7.506,23	7.569,82	7.634,69	59.056,36
Savings (2)	600,48	372,72	420,28	468,81	518,29	568,77	620,27	672,78	4242,4

Table 3: Savings for the client.

(1). Recovery. The previous system used by FAEN building was gas for heating and sorption salt system for cooling and it did not work in good conditions. This concept include the cost of using other option instead of geothermal energy, it was the use of heating pump with natural gas.
(2) The savings are 7%. In the year nine the savings will rise to 37%.

The consumption during the first moths was the following.

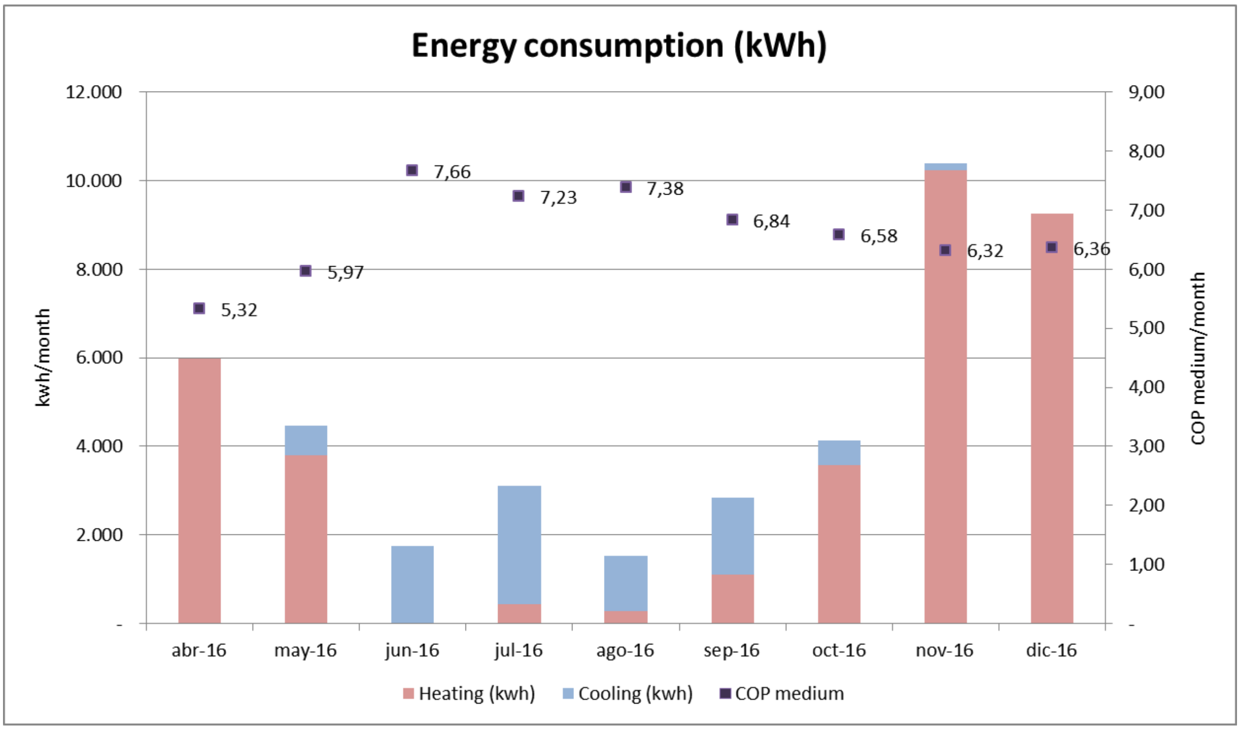

Figure 5: Real values for the first 9 operating months

	Heating supplied	Cooling supplied	Electric energy	Total energy	COP medium
abr-16	5.991,00	-	1.126,00	5.991,00	5,32
may-16	3.790,00	681,00	749,00	4.471,00	5,97
jun-16	-	1.739,00	227,00	1.739,00	7,66
jul-16	441,60	2.657,00	428,40	3.098,60	7,23
ago-16	278,40	1.255,80	207,80	1.534,20	7,38
sep-16	1.109,00	1.728,00	414,90	2.837,00	6,84
oct-16	3.582,00	561,40	629,80	4.143,40	6,58
nov-16	10.239,00	142,00	1.642,00	10.381,00	6,32
dic-16	9.243,00	-	1.453,00	9.243,00	6,36
Total	**34.674,00**	**8.764,20**	**6.877,90**	**43.438,20**	**6,32**

Table 4: Energy supplied to the building FAEN in the first nine operating months.

3.3 Real economic results for FAEN Project.

Incomes (€/year)	
P1- Energy supplied	2.880
P2 - Maintenance	1.165
P3 - Total Guarantee	1.000
P4 - Recovery	4.326
Total Incomes	9.371
Benefit	5.569

Expenses (€/year)	
Electricity	262,89
Electricity of the heating pump	1645,38
Staff	852,54
Equipment	695,67
General	345,66
Total Expenses	3.802

Table 5: Map of incomes/expenses for FAEN project

4 Investigation Center Project.

4.1 IC Project Description.

This was our first business with geothermal technology using mine water and it was designed with these parameters:

Parameter	Value	Units
Heating consumption	586.819	kWh/year
Cooling consumption	745.253	kWh/year
Amount of mine water needed	409.479	m3/year
Heating pumps	2x362	kWh heating power
Distance (Barredo- CI)	250	m

Although the installation is prepared to give heating and cooling right now the University only wants to get heating service. Figure 6 shows the control system during the heating mode.

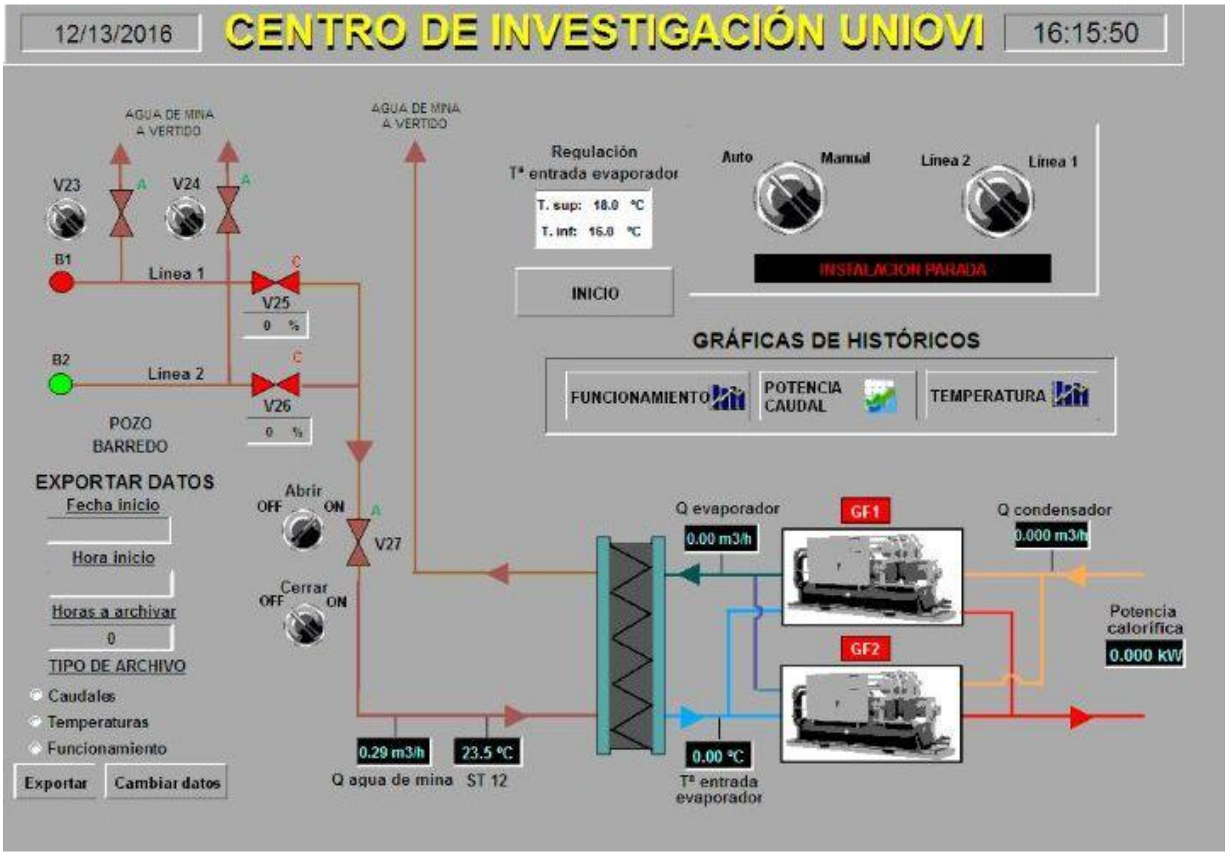

Figure 6: Scheme in heating mode for University Center

In this case the mine water goes from the shaft to the building through a 200mm diameter pipe, the water pass throw a plate heat exchanger an then goes to the same pouring point with the rest of the mine water. The different of level between Barredo Shaft and the Installation is 10m so there is no need of pumping. The temperature in the cooling side must be below 18ºC, so the regulation system use the mine water flow to keep this temperature between 16-18ºC. When the building requires more heat, there is a reduction in the temperature of the cooling side, so the valve V26 opens and more mine water passes to the exchanger.

4.2 Business plan.

The structure of the contract is very similar to the previous one. In this case the duration of the contract is 5 years (after that the contract will have an extension. The total cost of the installation build by HUNOSA (62.142,24€) only includes the equipment to carry on the water from the shaft to the heating pumps (piping, valves, heat exchangers, etc). At the beginning the idea was to guarantee to the university savings up to 10% on a 10 years contract. Finally the university decided to reduce the contract to 5 year, so there will not be savings the first 5 years and for the following extensions of the contract the savings will be of 12%.

Table 6 contains the expected incomes per year from the University for the four typical concepts. 2014 is not a complete year, the contract begun in august.

ANUALIDAD	P1 17.01-421B-221.01	P2 17.01-421B-213	P3 17.01-421B-213	P4 17.01-421B-203	IMPORTE TOTAL
2014	10.000,00€	2.255,00€	1.100,00€	5.187,98€	18.542,98 €
2015	30.000,00€	6.765,00€	3.300,00€	15.563,93€	55.628,93 €
2016	30.000,00€	6.765,00€	3.300,00€	15.563,93€	55.628,93 €
2017	30.000,00€	6.765,00€	3.300,00€	15.563,93€	55.628,93 €
2018	30.000,00€	6.765,00€	3.300,00€	15.563,93€	55.628,93 €
2019	20.000,00€	4.510,00€	2.200,00€	10.375,95€	37.085,95 €
	150.000,00€	**33.825,00€**	**16.500,00€**	**77.819,65€**	**278.144,65€**

Table 6: Incomes per year.

The costs of the project for HUNOSA reach 19.913€/year (see table 7); that makes benefit of 35715€/year during the first five years, then the benefit will be 20152€/year.

Electricity (pumping the mine water)	11.120€/year
Maintenance (staff)	5.446,07
Equipment	329,05
General costs	3.346,08
Total	**19.913**

Table 7: Costs for Investigation Center Project

4.3 Real economic results.

Due to the economic crisis the university has decided to use only heating and no cooling in summer. This means less income for HUNOSA. In table 8 is presented a summary of the real economic results of the business.

Investigation Center Consumption			
	HEATING		
DATE	Energy supply (MWh)	Electricity (MWh)	SPF
november 2014	18,79	4,6	4,12
dicember 2014	31,57	8,4	3,77
yanuary 2105	57,64	15,7	3,68
february 2105	59,20	17,2	3,45
march 2015	55,51	10,3	5,39
april 2015	11,47	2,9	4,00
november 2015	25,50	10,1	2,53
dicember 2015	29,07	7,3	3,96
yanuary 2106	34,06	8,5	3,99
february 2106	38,29	8,7	4,38
march 2016	35,47	10,1	3,51
april 2016	33,71	9,2	3,66
october 2016	35,54	9,8	3,63
november 2016			
dicember 2016			

	2014/2015	2015/2016	2016/2017
Incomes	30.346,29	25.412,29	21.180,88
P1	5634,96	5429,77	0
P2	6522,94	5590,90	5590,9
P3	3181,80	1528,88	2727,24
P4	15006,59	12862,74	12862,74
Expenses	17.517,42	9.466,05	4.764,81
Energy	8134,62	6931,49	4149,15
Staff	2752,38	1986,34	0,00
Subcontractors	5037,92	0,00	0,00
General expenses	1592,49	548,23	615,66

Table 8: Real economic results in Investigation Center Project

Notice that the season 2016/2017 is incomplete.

5 HOSPITAL Project.

The installation was designed to supply 3.3MW of heating and 3.7MW of cooling to the hospital. The total energy consumption of the hospital is 7GWh per year. The figure 7 is a basic scheme where the main elements are the following:

1.- The heat exchanger (in the left side of the figure), in blue is represented the circuit of the mine water. It is a small part so the maintenance caused by the iron is quite simple. The mine water goes very quickly along the pipes in the exchanger so the risk of iron precipitation is low.

2.- The circle circuit of clean water that transport the heat between the exchanger in Barredo Shaft and the hospital is 2010m length, the two pipes a 400mm made of PVP.

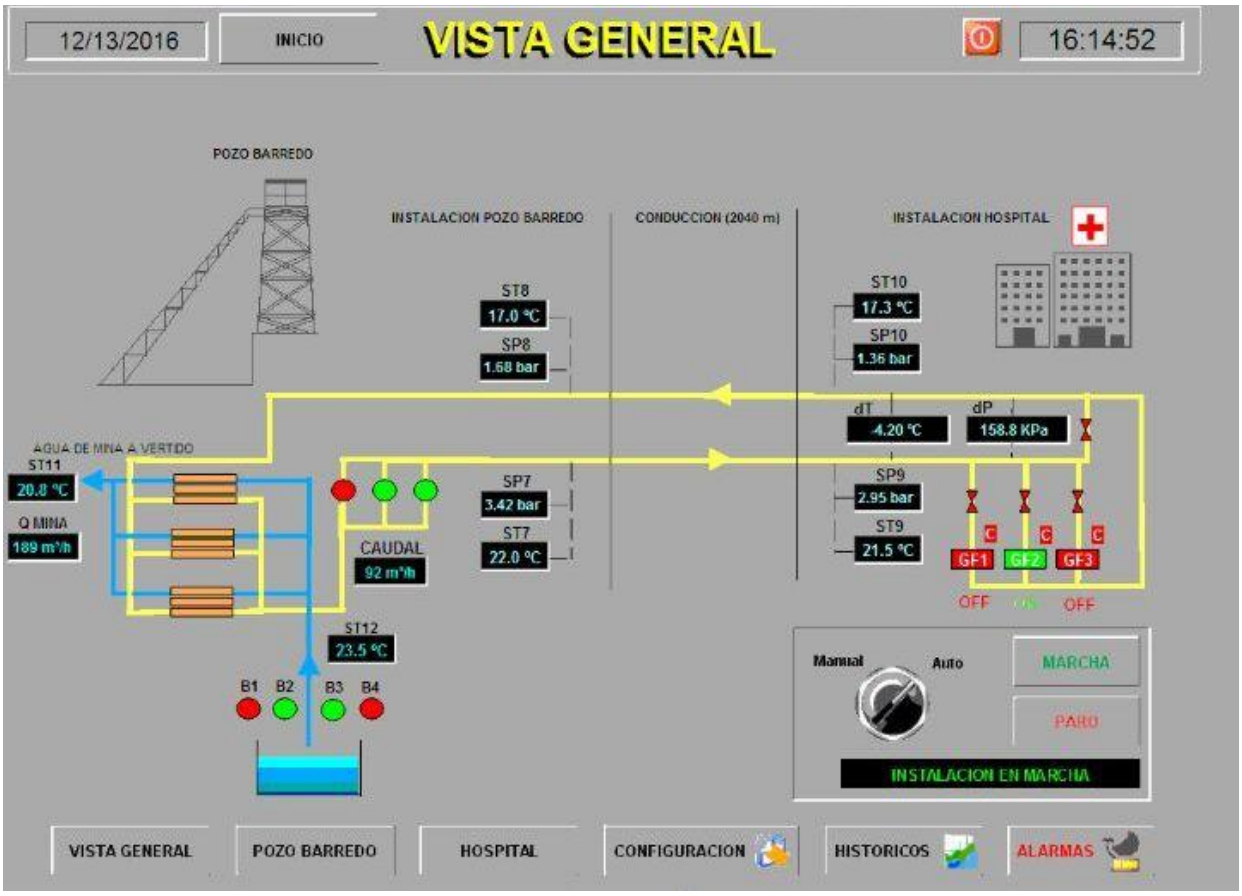

Figure 7: geothermal scheme of the hospital project

3.-The flow of water in the circle circuit is kept by three pumps of 55kW and 200m3/h. The number of the pumps in operation is related to the necessity of the hospital.

4.- Three heating pumps are in charge of extract the heat coming from the mine and transfer it to the hospital circuit. Two of them are equal (B1152) and they will work transferring the heat and the third one (B652) will work in "compensation", that is transferring the heat between different areas of the hospital (when cooling and heating are necessary at the same time). In the following tables different working points of the heating pumps are shown.

Table 9 shows the estimated energy needed by the hospital each month, the heat pump B652 will give heating and cooling at the same time when the hospital will need both at the same time, we can see in the last column that this will happen in every moth (areas like surgery and CAT equipment need constant cooling).

Month	*Energy (kWh)*	*Heating (kWh)*	*Cooling (kWh)*	*Energy without balance*	*Energy with balance*
January	492.900	423.530	69.370	354.160	69.370
February	507.560	415.540	92.020	323.520	92.020
March	484.330	315.520	168.810	146.710	168.810
April	476.660	269.390	207.270	62.120	207.270
May	486.240	173.880	312.360	138.480	173.880
June	521.340	71.370	449.970	378.600	71.370
July	565.440	37.200	528.240	491.040	37.200
August	600.000	27.220	572.780	545.560	27.220
September	581.800	78.510	503.290	424.780	78.510
October	469.630	124.680	344.950	220.270	124.680
November	459.010	354.030	104.980	249.050	104.980
December	475.110	429.140	45.970	383.170	45.970
Total	***6.120.020***	***2.720.010***	***3.400.010***	***3.717.460***	***1.201.280***

Table 9: Estimated monthly consumption for the hospital.

When the hospital needs more heating than cooling or the opposite the difference will be given by the heating pump B1152 (fifth column) and this energy will pass from the water mine to the hospital in winter and from the hospital to the water mine in summer.

5.1 Business plan

In this case the model of contract only have two concepts, disposal of the system in exclusive for the hospital (57.911 €/year), and energy supply under the guarantee of 25% respect the cost of conventional energy (natural gas for heating with a 86% of efficiency and refrigeration tower and heat pumps with an ERR of 2,1 for cooling). The final savings of the hospital under these conditions will reach 10%. The contract will last 24 years and the initial cost of the installation for HUNOSA was 1.314.648€.

The hospital only had 24.000€ of expenses to adapt the initial installation for geothermal energy. In this initial plan the idea was use heating pumps to produce cooling and send the waste heat to the refrigeration tower. Actually this alternative is operative, so when any fault causes the loss of the geothermal energy the hospital can take cooling from the refrigeration tower and the heating from natural gas.

Table 10 contains the savings for the hospital during the first eight years. The prices will increase according the inflation rate. As the conventional energy usually increases it prices more than the inflation rate the savings will increase in time.

CONVENTIONAL SYSTEM	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Heating costs (€/year)	172.197	179.085	186.248	193.698	201.446	209.504	217.884	226.600
Cooling costs (€/year)	209.910	218.307	227.039	236.120	245.565	255.388	265.603	276.227
Total expenses for conventional system	382.107	397.391	413.287	429.819	447.011	464.892	483.487	502.827
GEOTHERMAL SYSTEM	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**
Electricity costs (€/year)	137.309	142.801	148.513	154.454	160.632	167.057	173.740	180.689
Disposal cost for HUNOSA (€/year)	57.911	59.388	60.902	62.455	64.048	65.681	67.356	69.074
Energy supply cost for HUNOSA (€/year)	149.271	155.242	161.452	167.910	174.627	181.612	188.876	196.431
Total expenses for geothermal system	344.492	357.432	370.868	384.819	399.306	414.350	429.972	446.194
Real savings	*10%*	*10%*	*10%*	*10%*	*11%*	*11%*	*11%*	*11%*

Table 10: Economic model for the hospital

This economic model was calculated for 6.120.020 kWh of consumption per year; the real necessity of the hospital change in time with the climate conditions, for example in 2016 the final supply of energy was more than 7.000.000kWh

HUNOSA is also in charge of the maintenance of the all equipment in the hospital, the payment for this service is 79.845€ per year, so the total income for HUNOSA is 287.027€/year.

Expenses in mine water pumping from Barredo Shaft	***30.538,02***
Electricicy	15.386,27
Maintenance Staff	12.917,12
Equipment	780,44
General Expenses	1.454,19
Expenses in pumping between the hospital and Barredo Shaft	***26.962,89***
Electricicy	10.262,28
Maintenance Staff	3.700,00
Equipment	11.716,66
General Expenses	1.283,95
Maintenance expenses in hospital installation	***72.587,00***
Maintenance Staff	30.900,00
Official technice service for machinery	16.000,00
Guard service	6.933,00
Auxiliary services	3.333,00
Materials	8.267,00
Official audtis	800,00
Correctivo (16 h/mes)	4.754,00
Legionella Prevention	1.600,00
Total expenses	130.087,91

Table 11: Cost for hospital project

Table 11 contains the cost structure for HUNOSA with a total of 130.087€/year that gives a benefit of 156.940€/year.

5.2 Real results

Year	2015	2016
Heating supply (kWh)	5.144.670	5.640.700
Cooling supply (kWh)	2.812.720	2.597.300
Electricity (kWh)	1.046.860	1.037.540
COP medium	7.6	7.9
Income (€)	290.322,2	314.020,17
Expenses (€)	68.892,67	74.013,15

Table 12: real values for hospital project in 2015 and 2016

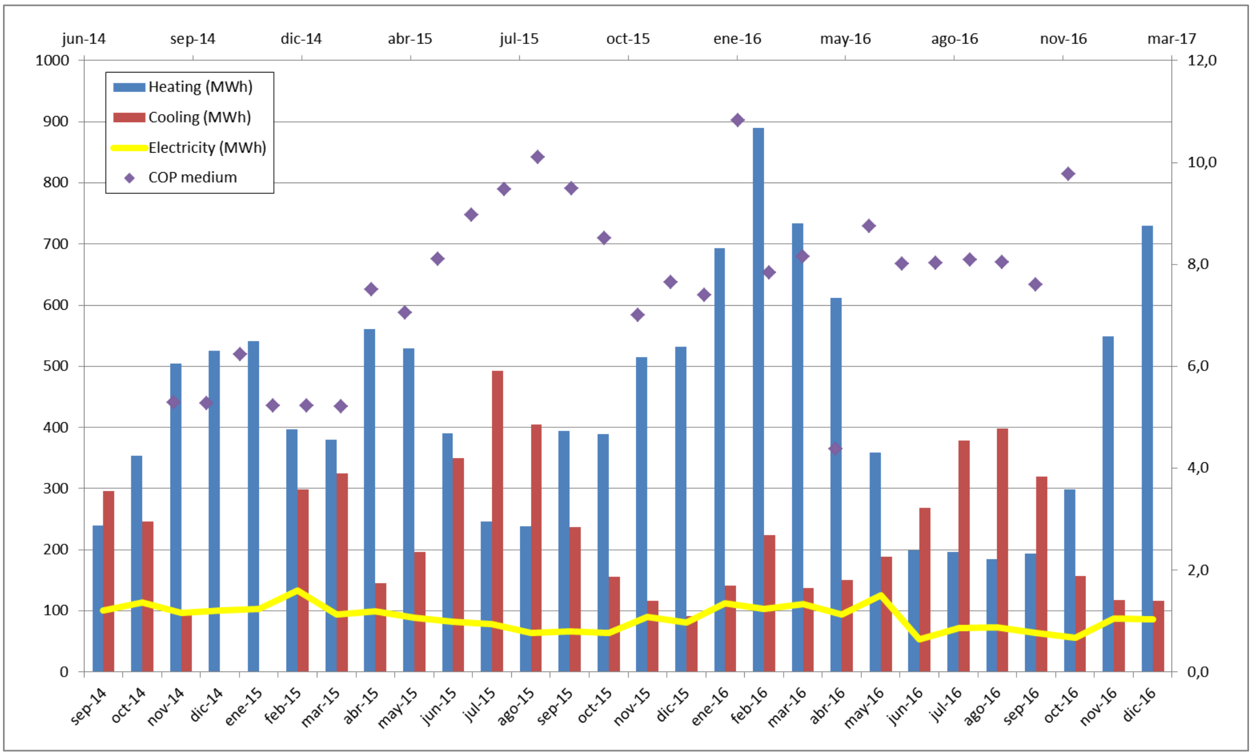

Figure 8: monthly values of energy supplied to the hospital in 2015 and 2016

6 Conclusions.

The hospital project is a great project that has very good economic results. It costs five years to get the confidence different public administrations about the use of the mine water as geothermal energy resource and to negotiate the contract with the company that manages the hospital. In the future when mining activity is closed and the level of water in Barredo Shaft is higher (actually the level is kept at 60m to protect Santiago Colliery from flooding) the operative costs will be lower (less electricity to pump the water out of the shaft). Another important point of this technology is the low operative costs of the heating pumps.

The other two projects are very small but they demonstrate the viability of geothermal energy for lower consumption if it is close to the source.

The electric cost is important of course (43% in hospital project of 49% in case of FAEN project) that is quite important to maintain the COP in optimal conditions.

HUNOSA is working right now in two districts heating with geothermal energy, one in Mieres with Barredo Mine Water too and the second in Langreo with the mine water of Fondon Shaft. They will be give heat to new residential buildings.

The economic results are achieved thanks to the good temperature of the water (23/24ºC) although sometimes in summer it can cause the breakdown of the heating pumps because they are designed to work with temperatures up to 17ºC. To increase the possibilities of the mine water we are trying to develop designs of heating pumps to work with the temperatures of our mines. And at the same time in the market there are heating pumps that gives water at 80ºC instead of 50ºC, this will help to look for projects to supply geothermal energy to old residential buildings where the traditional heating system works with this temperature.