Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Comparative Analysis of Borehole Heat Exchanger Use in Different Climatic Conditions

Tomasz Śliwa[1], Cristian Gustavo Freidenberger[2]

[1)] Drilling, Oil and Gas Faculty AGH University of Science and Technology, Krakow, Poland

[2)] National Technological University, Bahía Blanca, Argentina

sliwa@agh.edu.pl, cristianfreidenberger@hotmail.com

Keywords: Borehole heat exchangers (BHEs), heat pumps, low enthalpy/temperature geothermal energy, economy of BHE systems, geoenergetics, underground thermal energy storages (UTESs)

ABSTRACT

This paper was made to compare the differences between borehole heat exchangers used for heating and cooling a typical house in Bahía Blanca, Argentina and Krakow, Poland. In Argentina, 57% of electricity comes from thermal power plants, while in Poland this kind of plant produces 90% of the energy. On the other hand, the natural gas is extensively used for heating. Climatic conditions in these places, heating and cooling load of a typical house and soil profile are used to know energetic load for cooling, heating and hot tap water. Economic analysis is also made to assess feasibility of this kind of technology.

1. INTRODUCTION

The comparison of heating and cooling loads for a typical house in Bahía Blanca (Argentina) and Krakow (Poland) is developed in this document. This paper also shows the energy load and its cost including taxes. In the end, it shows the borehole heat exchanger and heat pump requirements for both cities, and presents the payback period of time.

In Poland, 90% of electricity comes from coal. On the other hand, 57% of the electricity in Argentina comes from thermal plants.

Energy from borehole heat exchangers has a great potential to change the way energy is produced to a nature friendly method.

2. CLIMATIC CONDITIONS

An analysis was produced for the maximum and minimum average temperature in Bahía Blanca, Argentina and Krakow, Poland in 2012 (AccuWeather). This analysis allowed for calculating the Heating Degree Days and Cooling Degree Days in both cities.

The comfort range was chosen between 18°C and 22°C for residents in the house. Higher daily average temperatures than the upper limit of the range (22°C) has been considered in heating degree days, the same happened with the lower temperatures in cooling degree days.

It is important to note that in 2012, there were 366 days, because it was a leap year.

Table 1: Heating degree days and cooling degree days compared by city in 2012.

Year 2012	HEATING DEGREE DAYS (18°C)		COOLING DEGREE DAYS (22°C)	
Month	Bahia Blanca	Krakow	Bahia Blanca	Krakow
January	1.0	597.0	107.0	0
February	1.0	708.0	47.0	0
March	24.5	430.0	25.5	0
April	116.5	270.0	1.0	0
May	157.5	138.0	0	0
June	293.5	60.0	0	2.5
July	352.5	24.5	0	17.0
August	239.5	43.5	0	6.5
September	175.5	128.5	0	0
October	96.0	291.0	0	0
November	21.5	372.5	12.0	0
December	7.0	629.5	16.5	0
TOTAL	1,486.0	3,692.5	210.0	26.0

In addition, it is presented a comparison of the monthly and annual average temperature in 2012 for the listed cities (Figure 1). Bahía Blanca has a warm climate while Krakow has lower temperatures than Bahía Blanca. This is indicating that a family living in the Argentinian city will need more energy in summer for cooling than in winter for heating, and the opposite for the Polish city.

Figure 2 shows the different climatic areas in the world which shows that Bahía Blanca is in a subtropical climate zone, while Krakow is in a warm temperature zone.

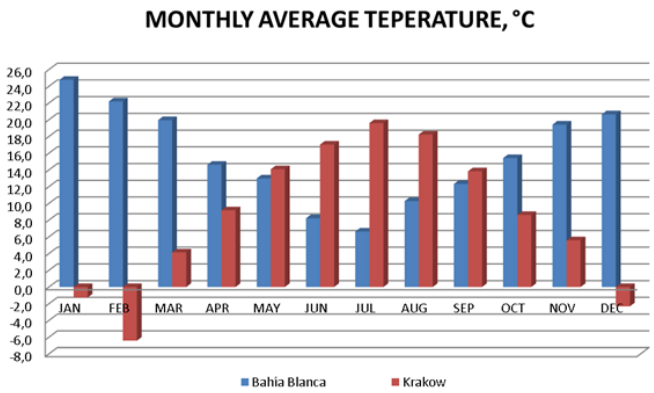

Figure 1: Comparison of monthly average temperature.



Figure 2: World map with climatic zones (White - Ice cap, Light blue - Tundra, Purple - Boreal, Green - Warm temperate, Yellow - Subtropical and Pink - Tropical).

3. THERMAL BALANCE

A thermal balance was made in summer and winter for a typical one story house of 69.6 m^2. This house has adequate thermal insulation.

The following parameters were adopted:

- Wall, k=0.47 $W \cdot m^{-2} \cdot K^{-1}$,
- Metallic roof with polystyrene, k=0.43 $W \cdot m^{-2} \cdot K^{-1}$,
- Metallic door, k=2.07 $W \cdot m^{-2} \cdot K^{-1}$,
- Metallic window with double glazing, k=2.90 $W \cdot m^{-2} \cdot K^{-1}$,
- Concrete floor ceramic coating, k=1.08 $kcal \cdot m^{-1} \cdot K^{-1}$.

On the other hand, it was considered the house was for a four-member family. Thermal requirements for this building, heat degree days and cooling degree days were used all together to know the heating and cooling load needed.

Tables 2, 3 and 4 and the Figures 3 and 4 show comparative information between the cities on heating and cooling load by month. Figures 3 and 4 shows the comparison for monthly heating and cooling load. Tables 2 and 3 shows the calculated heating and cooling peak load for this typical house in both climates.

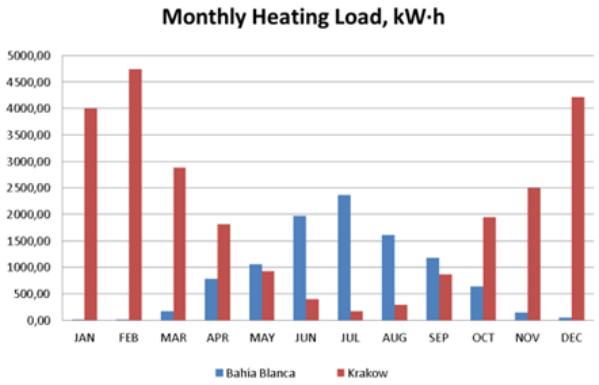

Figure 3: Comparison of monthly heating load.

Table 3: Heating peak load by month in both cities.

Month	HEATING PEAK LOAD, kW					
	Bahía Blanca			Krakow		
	Coldest day	HDD	Peak Load	Coldest day	HDD	Peak Load
January	-	-	-	31	31.0	8.65
February	-	-	-	4	38.0	10.60
March	27	4.5	1.26	7	23.5	6.55
April	27	12.5	3.49	9	18.5	5.16
May	30	11.5	3.21	17 & 18	12.5	3.49
June	16	17.0	4.74	2 & 3	6.5	1.81
July	15	16.0	4.46	22	4.5	1.26
August	16	14.0	3.91	28	6.0	1.67
September	27	13.5	3.77	21	11.5	3.21
October	10	10.5	2.93	23	19.5	5.44
November	9	6.0	1.67	14	16.5	4.60
December	-	-	-	9	31.0	8.65

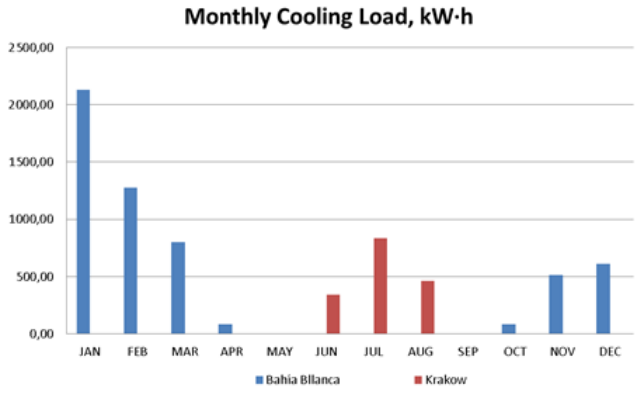

Figure 4: Comparison of monthly cooling load.

Month	COOLING PEAK LOAD, kW					
	Bahía Blanca			Krakow		
	Hottest day	CDD	Peak Load	Hottest day	CDD	Peak Load
January	1 & 5	9.0	4.56	-	-	-
February	7	6.5	4.17	-	-	-
March	4	7.5	4.32	-	-	-
April	-	-	-	-	-	-
May	-	-	-	-	-	-
June	-	-	-	-	-	-
July	-	-	-	6	3.5	5.12
August	-	-	-	6	3.0	5.04
September	-	-	-	-	-	-
October	-	-	-	-	-	-
November	8	5.0	3.93	-	-	-
December	2 & 22	4.0	3.77	-	-	-

Table 4: Cooling peak load by month in both cities.

Table 2: Heating and cooling load by month.

Month	HEATING LOAD, kW·h		COOLING LOAD, kW·h	
	Heat loss		Heat gain	
	0.27893 kW·K^{-1}		0.15838 kW·K^{-1} 55.72/53.65 kW·d^{-1} 0.11463 kW·Δw^{-1}	
	Bahía Blanca	Krakow	Bahía Blanca	Krakow
January	6.69	3,996.51	2,128.86	0
February	6.69	4,739.58	1,274.56	0
March	164.01	2,878.56	801.44	0
April	779.89	1,807.47	82.08	0
May	1,054.36	923.82	0	0
June	1,964.78	401.66	0	338.00
July	2,359.75	164.01	0	831.10
August	1,603.29	291.20	0	462.70
September	1,174.85	860.22	0	0
October	642.65	1,948.05	82.08	0
November	143.93	2,493.63	515.29	0
December	46.86	4,214.07	610.67	0
TOTAL	9,947.76	24,718.78	5,494.99	1,631.80

Peak load is important to model the highest energy needed in a day from the borehole heat exchanger. This higher heating and cooling load was calculated for the hottest and coldest day of each month.

4. COST AND ENERGY DEMAND FOR HEATING AND AIR CONDITIONING

Natural gas is the most popular fuel for heating in Bahía Blanca. Data from Camuzzi, an Argentine operator, shows that it costs 0.169599 ARS·m^{-3} (0.022434 €·m^{-3}) for category R3-1 without taxes (from 1,200 m^3·y^{-1} up to 1,500 m^3·y^{-1}). The real price adding taxes is 0.226245 ARS·m^{-3} (0.029926 €·m^{-3}). Therefore the cost of natural gas is 0.021629 ARS·kW^{-1}·h^{-1} (0.002861 €·kW^{-1}·h^{-1}).

The cost of electricity per kW·h is 0.6156 ARS (0.0814 €) without taxes according to electricity operator EDES S.A (for monthly consumption up to 400 kW·h). Adding taxes, the final price is 0.9215 ARS·kW^{-1}·h^{-1} (0.1219 €·kW^{-1}·h^{-1}).

In Poland, natural gas is also the main heating fuel. The cost is 0.04822 €·kW^{-1}·h^{-1} with taxes included (consumption of 30 MW·h·y^{-1}). Additionally buildings are cooled by air conditioning even while the cooling load is not high. Most of the residential buildings are not cooled. Electricity cost in Krakow is 0.14618 € per kW·h with all taxes included (consumption of 3.5 MW·h·y^{-1})

GAS REQUIREMENT FOR HEATING, m^3 GAS: 9000 cal·m^{-3} 10.46 kW·h·m^{-3} Efficiency: 80%						
Month	Bahía Blanca				Krakow	
	Heating load	Natural gas, m^3	ARS	Euro	Heating load	Euro
January	6.69	0.80	0.18	0.02	3,996.51	192.71
February	6.69	0.80	0.18	0.02	4,739.58	228.54
March	164.01	19,6	4.43	0.59	2,878.56	138.80
April	779.89	93.20	21.09	2.79	1,807.47	87.16
May	1,054.36	126.00	28.51	3.77	923.82	44.55
June	1,964.78	234.80	53.12	7.03	401.66	19.37
July	2,359.75	282.00	63.80	8.44	164.01	7.91
August	1,603.29	191.60	43.35	5.73	291.20	14.04
September	1,174.85	140.40	31.76	4.20	860.22	41.48
October	642.65	76.80	17.38	2.30	1,948.05	93.93
November	143.93	17.20	3.89	0.51	2,493.63	120.24
December	46.86	5.60	1.27	0.17	4,214.07	203.20
TOTAL	9,947.76	1,188.79	268.96	35.58	24,718.78	1,191.94

Table 5: Gas required by month in both cities.

Table 6: Electricity required by month in both cities.

ELECT. REQUIREMENT FOR COOLING, kW-h							
Month	Bahía Blanca				Krakow		
	Cooling load	Electric., kW-h	ARS	Euro	Cooling load	Electric., kW-h	Euro
January	2,128.80	749.60	690.76	91.37	0	0	0
February	1,274.50	448.79	413.56	54.70	0	0	0
March	801.40	282.20	260.05	34.40	0	0	0
April	82.00	28.90	26.63	3.52	0	0	0
May	0	0	0	0	0	0	0
June	0	0	0	0	338.00	119.01	17.40
July	0	0	0	0	831.10	292.64	42.78
August	0	0	0	0	462.70	162.92	23.82
September	0	0	0	0	0	0	0
October	82.00	28.90	26.63	3.52	0	0	0
November	515.20	181.44	167.20	22.12	0	0	0
December	610,6	215,03	198.15	26.21	0	0	0
TOTAL	5,494.90	1,934.85	1,782.90	235.84	1,631.80	574.58	83.99

5. ENERGY DEMAND FOR HOT TAP WATER PURPOSE

Previously it was noted that for this paper a typical four-member family was adopted. In this way, daily and yearly hot tap water load is estimated in following table.

Table 7: Hot tap water demand.

HOT TAP WATER, dm^3			
Artefact	Hot water demand per person daily	Hot water d emand per house daily	Hot water demand per house yearly
Shower	60	240	87,84
Bathroo. Sink	5	20	7320
Washing machine	70 (per week)	40	14,64
Kitchen sink	25	100	36,6
TOTAL	-	400	146,4

Hot tap water is assumed 10°C before the water heater and the temperature rises to 60°C.

The heat needed is:

$$Q = m\, c_w\, \Delta T$$

Where Q, m, c_w, ΔT are heat, yearly water mass, specific heat of water, temperature difference, respectively.

$$Q = 146400 \times 4187 \times (60 - 10)$$

$$Q = 30648.84\ MJ \cdot y^{-1}$$

$$\boldsymbol{Q = 8513.57\ kW \cdot h \cdot y^{-1}}$$

6. COMPARISON OF HEATING, AIR CONDITIONING, HOT TAP WATER AND CLIMATIC CONDITIONS IN BAHIA BLANCA AND KRAKOW

Comparison between these two cities is shown in Table 8.

A big difference of temperature between these cities is an important fact that ca n be seen from the tables.

As a conclusion we can say that the city of Krakow has a higher energy demand for heating in winter, while the city of Bahía Blanca has a larger cooling load in summer. This can be seen by looking at the difference between the temperatures in the table for both cities.

Conversion from ARS to € was done with the price for September 11, 2013.

Natural gas in Krakow is 16 times more expensive, while electricity has almost the same price in both cities. On the other hand, Krakow requires more energy for heating in winter than Bahía Blanca. It is shown that heating and air conditioning energy demand in Krakow is almost 5 times more expensive than in Bahía Blanca.

A simple U-pipe borehole heat exchanger was chosen to develop this research while the borehole diameter for the calculation was assumed to be 150-mm and the shank spacing 89-mm.

Table 8: Cost of heating and cooling a typical house in both cities.

	Bahía Blanca		Krakow	
Yearly average temp., °C	15.6		8.4	
Cost of electricity	0.1218 €·kW^{-1}·h^{-1}		0.14618 €·kW^{-1}·h^{-1}	
Cost of natural gas	0.00286 €·kW^{-1}·h^{-1}		0.04822 €·kW^{-1}·h^{-1}	
Heating	9947.76 kW·h·y^{-1}	35.58 €·y^{-1}	24718.78 kW·h·y^{-1}	1191.94 €·y^{-1}
Hot tap water	8513.57 kW·h·y^{-1}	30.45 €·y^{-1}	8513.57 kW·h·y^{-1}	208.38 €·y^{-1}
Air conditioning	5494.99 kW·h·y^{-1}	235.84 €·y^{-1}	1631.80 kW·h·y^{-1}	83.99 €·y^{-1}
Total energy and cost of heating and air conditioning	23956.32 kW·h·y^{-1}	301.87 €·y^{-1}	34864.15 kW·h·y^{-1}	1484.31 €·y^{-1}
Total unit quantities and cost of heating and air conditioning	344.20 kW·h·y^{-1} m^{-2}	4.34 €·y^{-1} m^{-2}	500.92 kW·h·y^{-1} m^{-2}	21.33 €·y^{-1} ·m^{-2}

7. BOREHOLE HEAT EXCHANGERS

All calculations were made with the computer software Earth Energy Designer (EED 3.16). Total energy was assumed to be delivered from a heat pump operating in cooperation with borehole heat exchanger.

The lithological profile is shown in Tables 9 and 10. Additionally, more important information for borehole heat exchanger calculations is presented in Table 11.

Table 9: Lithological profile in Bahía Blanca.

Top., m	Bott., m	Lithology	Thermal cond., W·m^{-1}·K^{-1}	Vol. spec. heat, MJ·m^{-3}K^{-1}
0	1,6	Silty ground with sand	1.50	2.00
1,6	3	Gravel	1.80	2.40
3	6,5	Sandy silt	1.80	2.20
6,5	33	Sandy silt with clay	1.90	2.40
33	42	Clayed silt	1.70	2.00
42	56	Sandy silt	1.80	2.20
56	62	Sandy silt with clay	1.90	2.40
62	77	Sandy silt	1.80	2.20
77	83	Clayed silt	1.70	2.00
Weighted average			1.87	2.36

Number and distribution of the borehole heat exchangers were selected to maintain the temperature of the heat carrier above 5°C after 25 years of circulation.

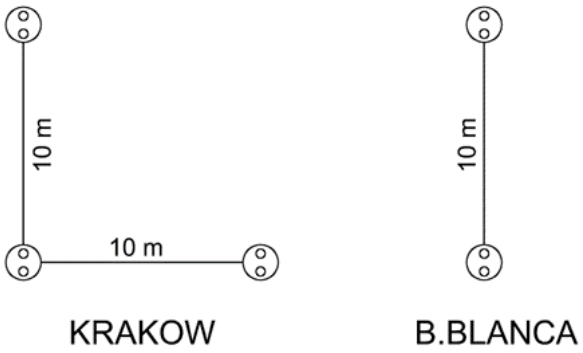

Figure 5: Distribution of BHE.

Table 10: Lithological profile in Krakow.

Top, m	Bott, m	Lithology	Thermal cond., $W \cdot m^{-1} \cdot K^{-1}$	Vol. spec. heat, $MJ \cdot m^{-3} \cdot K^{-1}$
1,8	2,2	Clayed grounq	1.50	2.00
2,2	2,6	Aggredate mud	1.50	2.20
2,6	4	Fine and dusty sand	2.00	2.00
4	6	Fine sand	2.20	2.50
6	15	All-in agregate and gravel	1.80	2.40
15	30	Grey siltstone	2.00	2.30
30	78	Gray shale clay	2.10	2.40
Weighted average			2.04	2.37

Table 11: Data of the analyzed borehole.

CALCULATION DATA	Poland (Krakow)	Argentina (Bahía Blanca)
Thermal conductivity of rocks, $W \cdot m^{-1} \cdot K^{-1}$	2.04	1.87
Bulk heat capac., $J \cdot m^{-3} \cdot K^{-1}$	2.37	2.36
Type of BHE	Single U-pipe	
Distance between BHE, m	10	
Diameter of borehole, m	0.15	
Diameter of BHE pipe, m	0.04	
Thickness of BHE pipe wall, m	0.0037	
Coefficient of thermal conductivity of BHE pipe material, $W \cdot m^{-1} \cdot K^{-1}$	0.42	
Heat carrier	33% glycole	Water

8. IDEAL HEAT PUMP EFFICIENCY

Coefficient of performance shows the efficiency of heat pumps.

$$CPH_H = \emptyset \frac{T_{cond}}{T_{cond} - T_{evap}}$$

$$CPH_C = CPH_H - 1$$

$$CPH_C = \left(\emptyset \frac{T_{cond}}{T_{cond} - T_{evap}} \right) - 1$$

Where CPH_H and CPH_C, ø, T_{cond}, T_{evap} are coefficient of performance, coefficient of efficiency, temperature in compressor, temperature in evaporator, respectively.

8.1 Bahía Blanca Winter

$$T_{evap} = 7.26 - 1.5 - 3 = 2.76\ °C$$

$$T_{cond} = 53 + 3 = 56\ °C$$

$$CPH_{H} = 0.6\ \frac{56 + 273}{56 - 2.76}$$

$$CPH_{H} = 3.71$$

$$\frac{Cost\ energy}{CPH_{C}} = \frac{0.1218\ € \cdot \mathrm{kW}^{-1} \cdot h^{-1}}{3.71}$$

$$\frac{Cost\ energy}{CPH_{C}} = 0.0328\ € \cdot \mathrm{kW}^{-1} \cdot h^{-1}$$

8.2 Bahía Blanca, Summer

$$T_{evap} = 16 - 3 = 13\ °C$$

$$T_{cond} = 30.87 + 1.5 + 3 = 35.37\ °C$$

$$CPH_{C} = 0.6\ \frac{35.37 + 273}{35.37 - 13} - 1$$

$$CPH_{C} = 9.48$$

$$\frac{Cost\ energy}{CPH_{C}} = \frac{0.1218\ € \cdot \mathrm{kW}^{-1} \cdot h^{-1}}{9.48}$$

$$\frac{Cost\ energy}{CPH_{C}} = 0.0128\ € \cdot \mathrm{kW}^{-1} \cdot h^{-1}$$

8.3 Krakow, Winter

$$T_{evap} = -2.76 - 1.5 - 3 = -7.26\ °C$$

$$T_{cond} = 53 + 3 = 56\ °C$$

$$CPH_{H} = 0{,}6\ \frac{56 + 273}{56 - (-7.26)}$$

$$CPH_{H} = 3.12$$

$$\frac{Cost\ energy}{CPH_{C}} = \frac{0.14618\ € \cdot \mathrm{kW}^{-1} \cdot h^{-1}}{3.12}$$

$$\frac{Cost\ energy}{CPH_{C}} = 0.04685\ € \cdot \mathrm{kW}^{-1} \cdot h^{-1}$$

8.4 Krakow, Summer

$$T_{evap} = 16 - 3 = 13\ °C$$

$$T_{cond} = 8.26 + 1.5 + 3 = 12.76\ °C$$

$$CPH_{C} = 0.6\ \frac{12.76 + 273}{12.76 - 13} - 1$$

$$CPH_{C} = -715.4$$

$$\frac{Cost\ energy}{CPH_{C}} = \frac{0.14618\ € \cdot \mathrm{kW}^{-1} \cdot h^{-1}}{715.4}$$

$$\frac{Cost\ energy}{CPH_{C}} = 0.00020\ € \cdot \mathrm{kW}^{-1} \cdot h^{-1}$$

At the end of this paper are the Figures 10 to 13, showing the heat pump temperatures in summer and winter, also to compare both cities.

The home water flow temperature was assumed at 53°C for heating and 16°C for cooling, these temperature levels were largely used for the home temperature conditioning in the studied countries.

9. HEAT PUMP

In the next tables, is a comparison and shown the better heat pump for the typical house in different climatic conditions. The Stiebel Eltron WPC 5, 7, 10 and 13 series heat pumps were chosen to compare. This kind of heat pump works in the heating mode and also in the cooling mode. Furthermore, it is recommended for a home. It has been estimated 3°C for variation inside heat pump condenser or evaporator, for the geothermal heat carrier. On the other hand, the temperature of the heat carrier used to calculate the efficiency is the average temperature between inflow and outflow, given by the Earth Energy Designer program (EED 3.16). The heating capacity, CPH and electricity consumption come from heat pump charts.

Table 12: Chosen heat pump in Bahía Blanca.

Heat pump	WPC 5	WPC 7	WPC 10	WPC 13
	Winter - Summer			
Influx temp. heat carrier (water)	7.26 + 1.5 °C 30.87 – 1.5 °C			
Home water flow temperature	53 °C 16 °C			
Heating capacity, kW	**6.70** **8.90**	**9.00** 11.90	**12.00** 14.80	**16.20** 21.20
CPH	3.50 6.70	3.60 7.00	3.50 6.60	3.80 7.20
Electricity consump., kW	1.90 1.32	2.50 1.70	3.40 2.20	4.26 2.90
Peak heat needed by typical house, kW	**4.70** **4.50**			

Table 13: Chosen heat pump in Krakow.

Heat pump	WPC 5	WPC 7	WPC 10	WPC 13
	Winter - Summer			
Influx temp. heat carrier	- 2.76+ 1.5 °C 8.26 – 1.5 °C			
Home water flow temperature	53 °C 16 °C			
Heating capacity, kW	5.20 6.80	7.10 9.00	9.40 12.00	**12.70** **16.30**
CPH	2.8 5.00	3.10 5.10	2.60 5.00	3.00 5.30
Electricity consump., kW	1.90 1.36	2.3 1.8	3.60 2.40	4.23 3.10
Peak heat needed by typical house, kW	**10.60** **5.04**			

program (EED 3.16), are shown in Figures 6 to 9 at the end of the paper.

10. PAYBACK PERIOD

To assess if a geothermal system for heating and cooling is achievable, it is important to recognize the different economic resources implicated. Also it is necessary to make a comparison between traditional fuels and this clean method. Payback period is the time involved to recover all the investment made at the start of the project. It is and acceptable payback period for up to 10 years for houses.

$$SPBP = \frac{I_{HP} - I_{gas\ boiler} - I_{AC}}{C_{H\ trad} + C_{C\ trad} - C_{HP}}$$

Where SPBT, I_{HP}, $I_{gas\ boiler}$, I_{AC} $C_{H\ trad}$, $C_{C\ trad}$, C_{HP} are simple payback time, heat pump and borehole investment, gas boiler investment, air conditioner investment, traditional heating cost, traditional cooling cost, heat pump heating and cooling cost, respectively.

10.1 Bahía Blanca

$$SPBP = \frac{3290\ € - 1200\ € - 1200\ €}{66.03\ + 335.84 - 13879.36}$$

$$SPBP = -0.07\ years$$

The SPBT has a negative number in Bahía Blanca, so it is not economically returnable for heating and cooling with this system. The reason for this is the low price of gas in Argentina (Freidenberger and Śliwa 2014).

10.2 Krakow

$$SPBP = \frac{7420\ € - 1500\ € - 1200\ €}{11300.7 + 83.99 - 8382.73}$$

$$SPBP = 2.9\ years$$

11. CONCLUSIONS

1. Houses in Poland need more energy in winter than in summer. Moreover in Argentina it has almost the same heating or cooling load.

2. Energy needed in Krakow is latger than in Bahía Blanca.

3. The borehole heat exchange for heating and cooling is economically possible in Krakow, but in Bahía Blanca running this kind of system is more expensive than traditional systems. Natural gas in Argentina is cheaper than electricity, maybe it will be better to use a gas compressor heat pump.

4. In Bahía Blanca, the rock mass does not cool down quickly, like in Krakow. The moderate climate of Argentina make this system works ideally because the rock mass has a constant temperature over the years.

5. Payback time in Krakow has a really optimistic period.

ACKNOWLEDGEMENTS

The paper was carried out under the Statutory Research at the Faculty of Drilling, Oil and Gas, AGH University of Science and Technology, financed from the funds of the Polish Ministry of Science and Higher Education.

NOMENCLATURE

- Δw Humidity difference
- € Euro
- ARS Argentine Peso
- CDD Cooling degree day
- HDD Heating degree day

REFERENCES

AccuWeather webpage. Available in http://www.accuweather.com. Accessed August 2013.

Banco de la nación Argentina. Available in http://www.bna.com.ar/bp/bp_cotizaciones.asp?op=m. Accessed September 2013.

Camuzzi Gas Pampeana. Available in http://www.camuzzigas.com/includes/tarifas/18.pdf. Accessed September 2013.

Cardoso, R. R., Hamza, V. M., and Alfaro, C.: Geothermal Resource Base for South America. A Continental Perspective. Available in http://www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/1618.pdf. Accessed August 2013.

EDES S.A. Available in http://www.infoedes.com/descargas/2013/Anexo%20II%20(Expdte%20Oceba%202429-3828)_%20Cuadro%20tarifario%20vigente%20a%20partir%20del%201%20de%20Agosto%20del%202013%20sin%20subsidio.pdf. Accessed September 2013.

Europe's energy portal. Available in http://www.energy.eu. Accessed September 2013.

Volantino, V. L., Bilbao, P. A., Azqueta, P. E., Bittner, P. U., Englebert, A., and Schopflocher, M.: Ahorros mediante aislamiento térmico en la construcción, Instituto Nacional de Tecnología Industrial. Available in http://www.inti.gob.ar/construcciones/pdf/ahorros_aislamiento_termico.pdf. Accessed August 2013.

IRAM 11601 - 11603 – 11604, Instituto Argentino de Normalización y Certificación. Accessed August 2013.

Carrica, J. C., and Albouy, E. R.: Universidad Nacional del Sur, Bahía Blanca. Available in http://insugeo.org.ar/libros/cg_13/24_carrica.htm. Accessed September 2013.

Peel, M. C.1 , Finlayson, B. L.2, and McMahon, T. A.1: Updated world map of the Köppen-Geiger climate classification, 1Department of Civil and Environmental Engineering, The University of Melbourne, Victoria, Australia, 2School of Anthropology, Geography and Environmental Studies, The University of Melbourne, Victoria, Australia. Accessed August 2013.

Ministerio de Economía y Finanzas Públicas de la República Argentina. Available in http://www.mecon.gov.ar/peconomica/informe/notas_tecnicas/22%20NOTA%20TECNICA%20Nivel%20de%20Actividad%20%20inf%2070.pdf. Accessed September 2013.

NASA Surface meteorology and Solar Energy. Available in https://eosweb.larc.nasa.gov/sse/RETScreen/. Accessed August 2013.

Stiebel Eltron heat pump charts. Available in http://www.sollaris.cz/media/download/manualy/wpc_5-13_de_05-06.pdf. Accessed September 2013.

Freidenberger C.G., and Śliwa T. (2014): Residential Price of Natural Gas in Argentina, AGH DRILLING, OIL, GAS - submitted to the editor. Available in http://journals.bg.agh.edu.pl/DRILLING/index-en.php. Accessed September 2013.

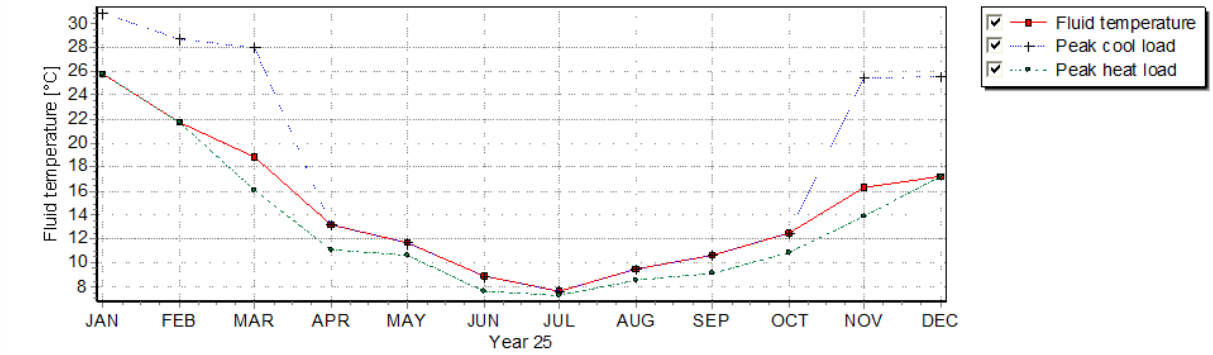

Fig 6: Distribution of average temperature of heat carrier in 25th year of borehole operation in Bahía Blanca.

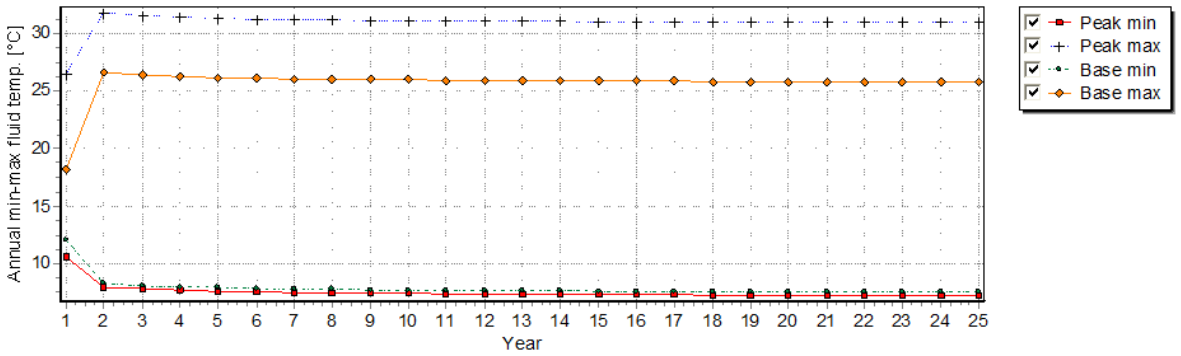

Fig 7: Distribution of max. and min. temperature over 25 years of borehole operation in B. Blanca.

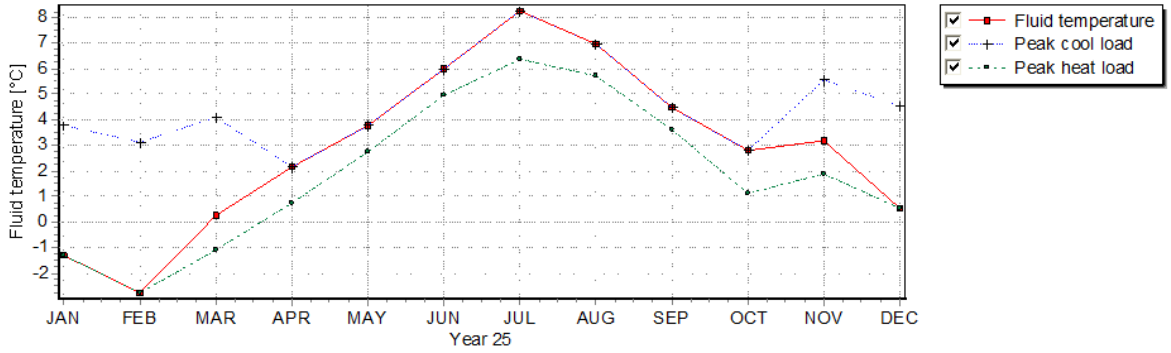

Fig 8: Distribution of average temperature of heat carrier in 25th year of borehole operation in Krakow.

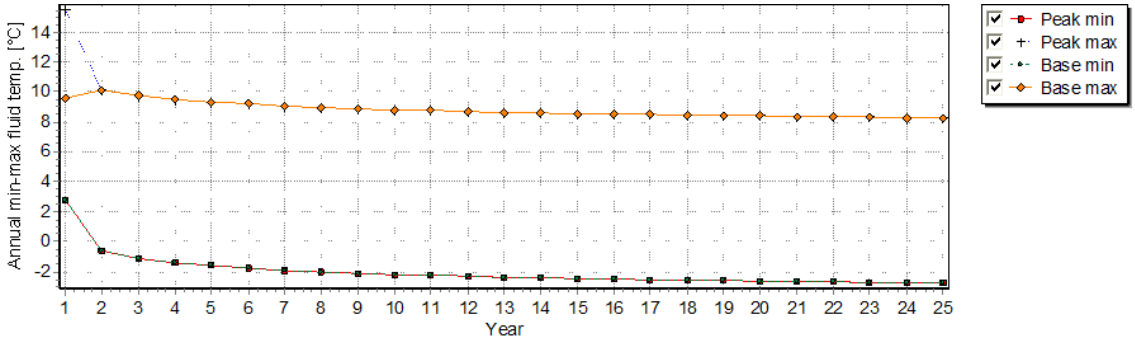

Fig 9: Distribution of max. and min. temperature over 25 years of borehole operation in Krakow.

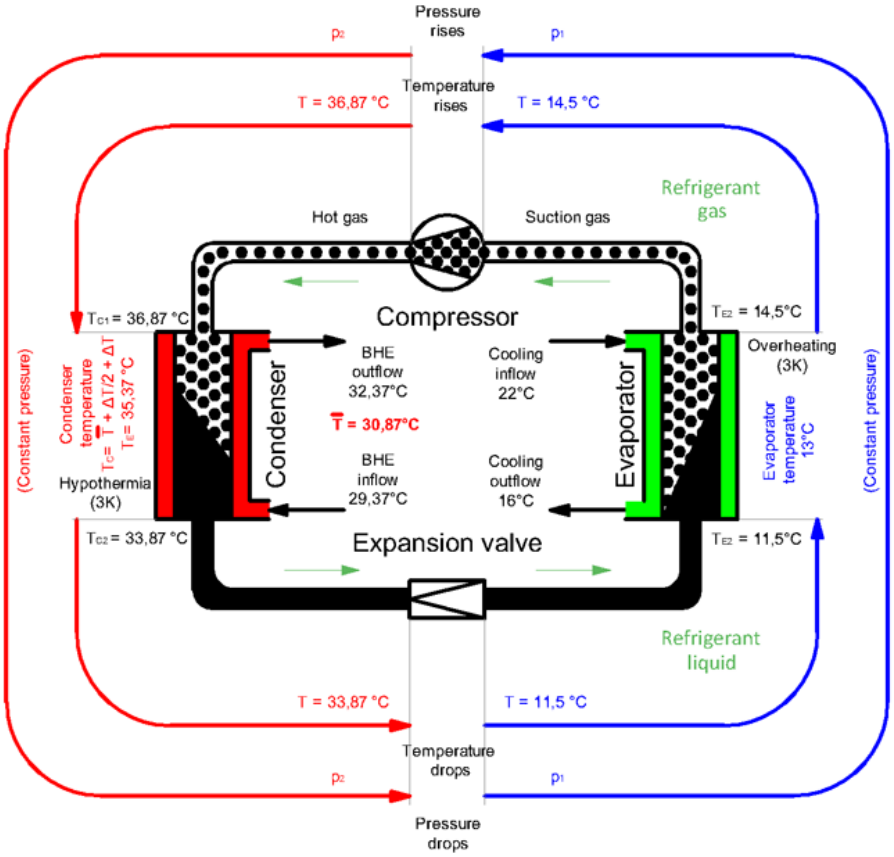

Figure 10: Heat pump temperatures in summer in Bahía Blanca.

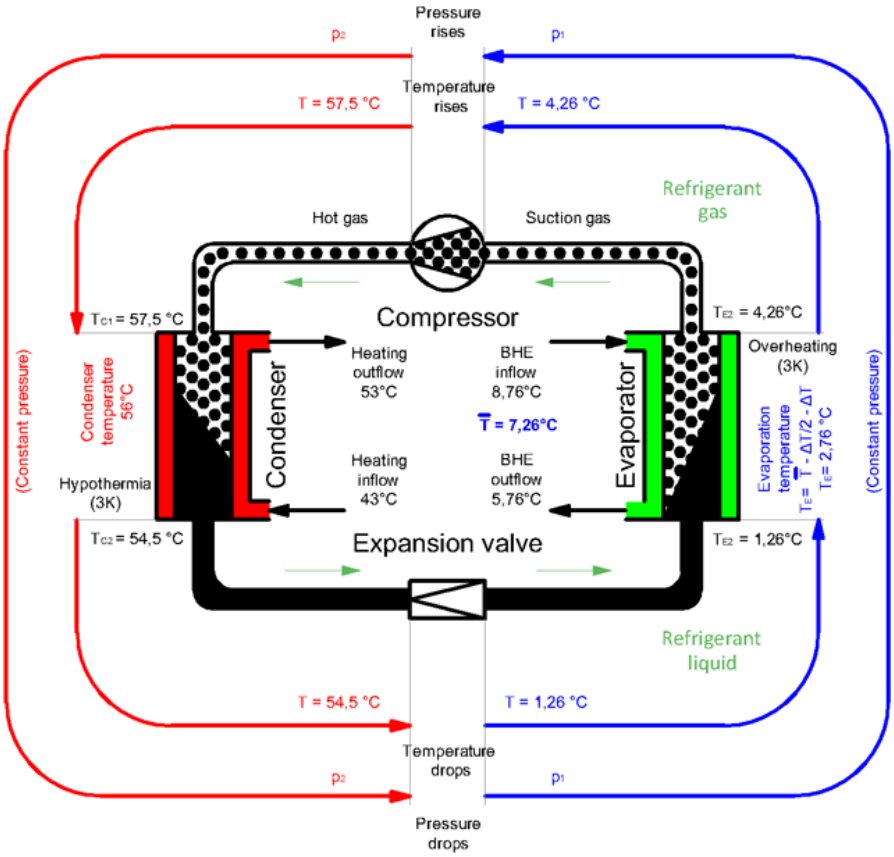

Figure 11: Heat pump temperatures in winter in Bahía Blanca.

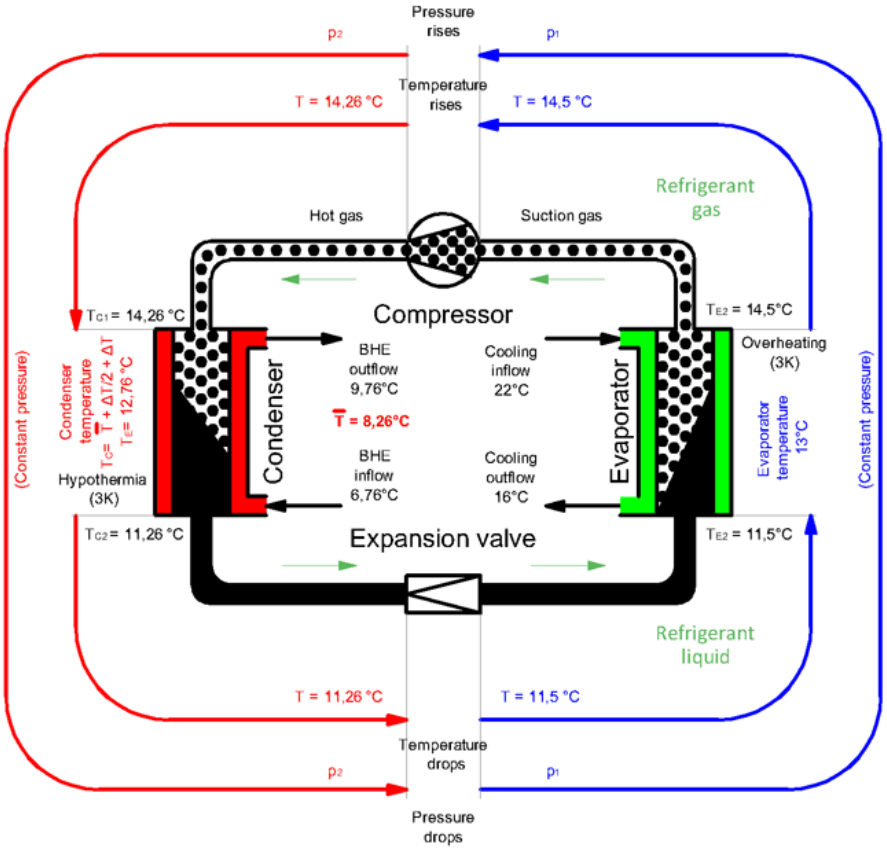

Figure 12: Heat pump temperatures in summer in Krakow.

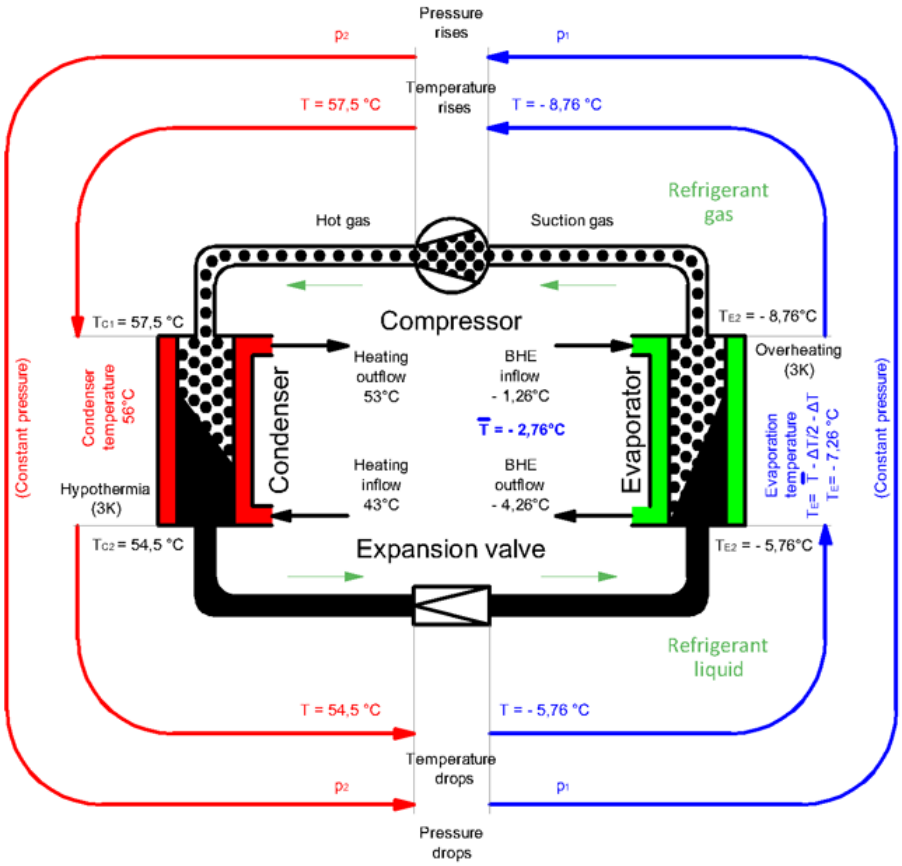

Figure 13: Heat pump temperatures in winter in Krakow.

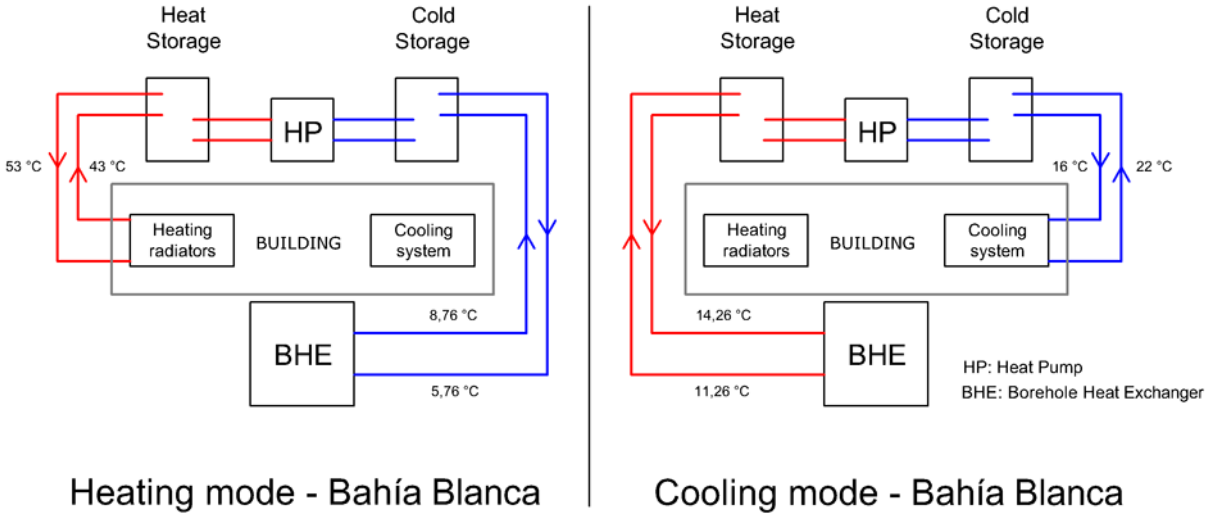

Figure 14: Borehole heat exchanger configuration in Bahía Blanca.