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Exploitation Tests of Borehole Heat Exchangers in the Laboratory of Renewable Energy Sources in Miekinia– Poland

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ABSTRACT

Heat from a shallow geothermal system has been utilized in the AGH-UST Laboratory of Renewable Energy Sources in Miekinia since 2012. The heat is being produced using heat pumps from horizontal and vertical ground sources. For the analyzed system testing and research were performed to determine ground thermal parameters. Thermal coefficients for the analyzed borehole heat exchangers were determined based on the geological profile. During winter season there were made tests of intensive heat extraction from the ground. The results of the research indicated that better thermal properties than expected from geological profile had occurred. Significant influence on the thermal conditions of the ground has the subsurface water. The main aim of the research is determining the possibility of reducing the construction cost of the borehole heat exchanger by reducing its size while maintaining the appropriate parameters.

1. INTRODUCTION

The AGH-UST Laboratory of Renewable Energy Sources and Energy Saving in Miekinia is located 35 km northwest of Cracow. The Laboratory has three heating installations with geothermal heat pumps. These installations have four heat pumps installed. There are two heat pumps with thermal capacity of 10.9 kW. In the condition of B0W35, the temperature of brine inflowing to the evaporator is 0°C and temperature of water outflowing from the condenser is 35°C and the COP, according the European Standard EN 14511 (Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling), is equal to 4.4. These heat pumps work in two installations –one is supplying heat for warming up the ventilation air in air handling units and the second supplies heat for floor heating at the building. In the summer season these installations have the possibility to cooling in the passive way. The third installation with two geothermal heat pumps installed are supplying heat for convection radiators and to produce domestic hot water. These subsystems have also the same type of heat pumps with thermal capacity of 17.03 kW (in the condition of B0W35) and COP according the European Standard EN 14511 equal to 4.4. One of them has borehole heat exchangers as the heat source, the second has a horizontal heat exchanger.

The geothermal heating system is supported by three solar collector installations, one solar installation for each geothermal heating system. The whole installation has many purposes: heating and cooling the object, preparing domestic hot water, didactics and research.

The building, where the heat pumps are installed, is a low energy consuming (930 m^2 area) RES laboratory with a small hostel for 30 beds. The specific heat energy demand for heating is equal 38 kWh/m^2a.

In the heating seasons 2012/2013 and 2013/2014 the performance tests of the ground sources heat pumps installed in AGH-UST Laboratory of Renewable Energy Sources in Miekinia were performed. The tests were performed on two of three installations. It was done on two similar installations, which supply heat for warming the air and heat for underfloor heating.

As mentioned previously these systems use geothermal heat pumps with thermal capacity of 10.9 kW (in the condition of B0W35). The first system which supplies heating for warming the air will be called “air heating” and the second which heats the floor will be called “underfloor heating”.

2. DESCRIPTION OF THE ANALYZED HEATING SYSTEM

In the first system, “air heating”, the geothermal heat source has three borehole heat exchangers (BHE) each at 87 m depth. The three BHE are connected in one system at the manifold and from there the brine flows to the heat pump. The BHE is made from 32-mm diameter polyethylene U-pipes. The manifold is placed in a chamber located under the ground level. From the chamber to the heat pump the brine flows in 50-mm polyethylene pipe. The brine circulating in the BHE is a 40% glycol propylene mixture. The heat from the ground is transported by the brine to heat pump and then the temperature is cooled down and back to the manifold and then to the BHE. The heat pump takes heat from the brine and raise the temperature, using a compressor. The heat is stored in the 500 l buffer tank and then is distributed through the building using the air handling units.

The second system, “underfloor heating”, is very similar. The differences are: the length of the BHE are 80 m in depth and the heat distributing system through the building is underfloor heating. The difference in the length of the BHE results from the other temperature parameters of heat sink. In the project these system have a higher operating temperature of heat sink.

3. GEOLOGY

In Miekinia village there was a quarry of lower Permian porphyry. The porphyry lies directly on upper Carboniferousshale, and partly on “Myslachowice” conglomerates and covered through transgression sediments of lower Triassic. The exploitation of the quarry was ended at 1979.

The geology and litostratygraphic profile, based on the project of geological works, has the following structure (Pelka, Lubon, Szczygiel, 2011):

- From 0 to 8 m depth – embankment of debris porphyry intermixed with clay and other Quaternary sediments,
- From 8 to 12 m – porphyry layer,
- From 12 to 100m –Carboniferous Malinowice layer (from 12 to 40 claystones and siltstones with sandstones inserts and from 40 to 100 cracked sandstones with claystones and siltstones inserts).

The groundwater level is on 40 m depth.

Table1: Coefficient of thermal conductivity and heat capacity for each layers (Sanner, 2011)

Layer	Thermal conductivity [W/m K]	Heat capacity [J/kg K]
Embankment of debris porphyry intermixed with clay	1.2	800
Porphyry	2.6	840
Claystones and siltstones with sandstones inserts	2.2	960
Claystones and siltstones inserts	2.8	1,085

Based on data from Table 1 weighted average thermal conductivity of the layers is 2.5 [W/m K], and the weighted average heat capacity of the layers is 1,017 [J/kg K].

4. DESCRIPTION OF THE TEST METHOD

The heating system in Miekinia is measured for heat production, electricity consumption and energy taken from the heat source. The inlet and outlet temperatures for each of the heating circuits are metered. Everything is archived in the memory of the measuring system DigiEnergy and it is possible to export the data and processing them.

From the collected data, the most interesting ones were selected to analyze which was the data from the heating period, from 1st October to 30th April. In the year 2012/2013 all subsystems operating in Miekinia supplied heat to the building for the total available length of the BHE, based on the heating curve for the heat sink. In the season 2013/2014 the performance of borehole heat exchangers were limited by disabling some loops and setting the constant heating parameter of the heat sink.

5. TESTS

During the first reference season, meaning the 2012/2013 season, the “air heating” heat pump supplied 20,903 kWh of heat while consuming 4,935 kWh of electricity. The seasonal performance factor of the heating system for this period was 4.24. The average temperature of the brine, flowing to the heat pump, was 2.8°C, and outlet temperature was -0.9°C, except that the temperatures varied seasonally depending on the month. During the colder months the heat pump works longer and higher over cooling of the ground. At the end of the heating season, the heat pump operating time was reduced and the temperature of the heat source once again began to grow. On the heating sink the average temperature value in this period was 37°C and the average return temperature was 30°C.

In the comparative season installation with the “air heating” heat pump worked with effective length of BHE equal 87 m and supplied 11,802 kWh of heat while consuming 2,944 kWh of electricity. Such a large reduction of heat demand in this subsystem was due to a milder heating season and changing the settings of air handling units resulted in an increase of efficiency of heat recovery from exhaust air. The average outside temperature during the heating season in the year 2012/2013 amounted about 0.3°C, and in the year 2013/2014 amounted about 3.3°C. The seasonal performance factor of the heat pump for this period was 4.01, with an average temperature of the water supply to the installation at 38.5°C and the return temperature at 32.5°C. The inlet average temperature of brine was 1.4°C and outlet was -2.6°C. The main parameters of the installations are in Table 2.

Table 2: Main parameters of heating systems in heating seasons 2012/2013 and 2013/2014

Time	01.10.2012-30.04.2013		01.10.2013-30.04.2014	
Heating system	Air heating	Underfloor heating	Air heating	Underfloor heating
Consumed electricity [kWh/a]	4,935	4,200	2,944	4,135
Heat production [kWh/a]	20,903	17,331	11,802	15,885
Heat taken from the ground [kWh/a]	16,588	16,113	9,900	14,324
Seasonal Performance Factor SPF [-]	4.24	4.13	4.01	3.84

For the “underfloor heating” the heat production in the season 2012/2013 was 17,331 kWh, and the consumption of electricity was 4,200 kWh. Seasonal performance factor for this heat pump was 4.13. The average temperature at the inlet to the heating power buffer was 33.8°C, and the outlet average temperature was 27.4°C. The inlet average temperature of brine was 2.9°C and outlet was -1.5°C.

During the heating season 2013/2014 heat pump distributing heat by underfloor heating has changed the productivity of energy source during that time. From 1st October to 10th December the heat pump was operating at full available length of the BHE (3 x 80 m), then one of the BHE was disabled and the machine began to work on the effective length of the BHE equal to 160 m (2 x 80 m).

Decrease of the inlet and outlet temperatures are shown in the Figure 1. Before one of BHEs was disabled, the temperature of geothermal energy source was stabilized on the level 2.3°C at the inlet and -2.0°C at the outlet. When one of BHE was disabled, temperature of energy source decreased to 0.8°C at the inlet and -3.4°C at the outlet and stabilized.

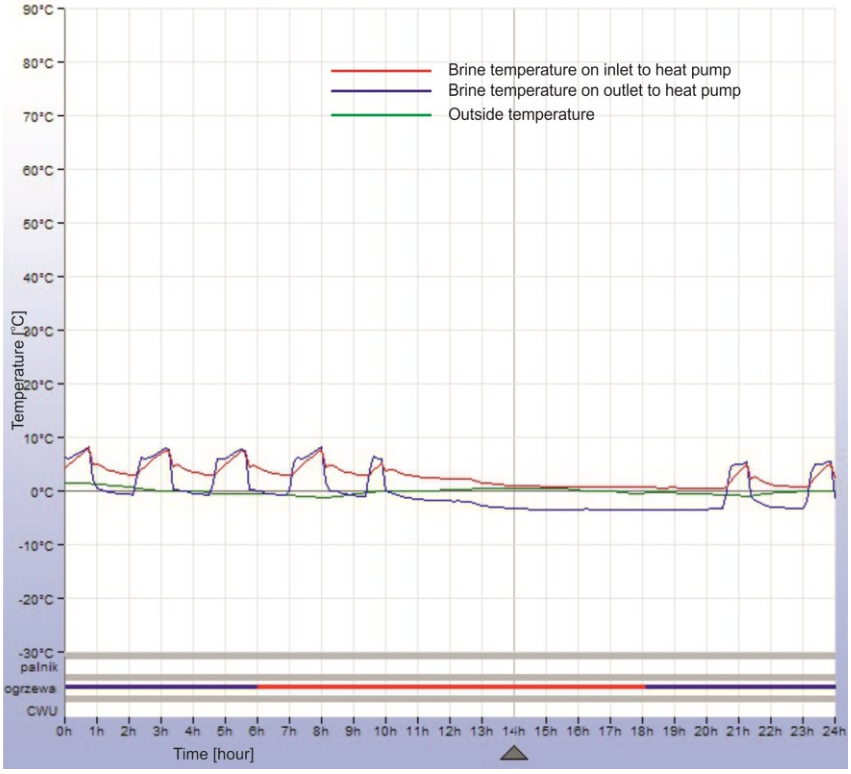

Figure 1: Decrease of inlet and outlet temperature during the closing one loop.

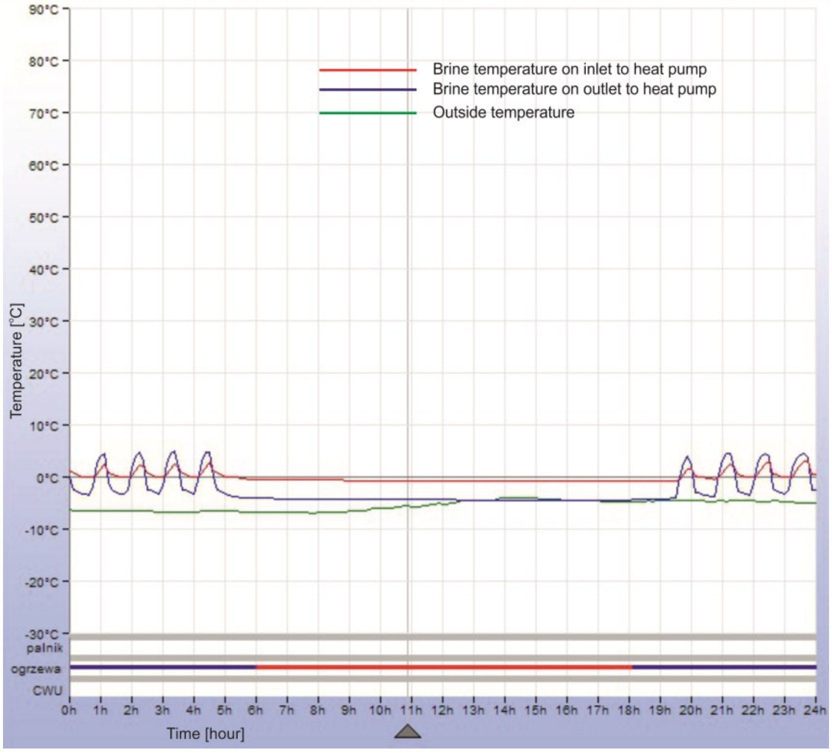

Figure 2: Brine temperatures on the inlet and outlet to "underfloor heating" heat pump on 31th of January, 2014

On the 4th of February 2014 the second BHE was disabled. The difference of the brine temperature between the inlet and outlet before the closing the BHE was about 3.6°C. When the second BHE was disabled the difference was about 4.7°C. Because of increase of hydraulic resistance, the flow of brine decreased so that the difference of temperature increased.

The seasonal performance factor of the "underfloor heating" heat pump for the season 2013/2014 was 3.79 with an average temperature of the water supply to the installation at 37°C and the return temperature at 31.3°C. The inlet average temperature of the brine was 1.8°C and outlet was -2.4°C.

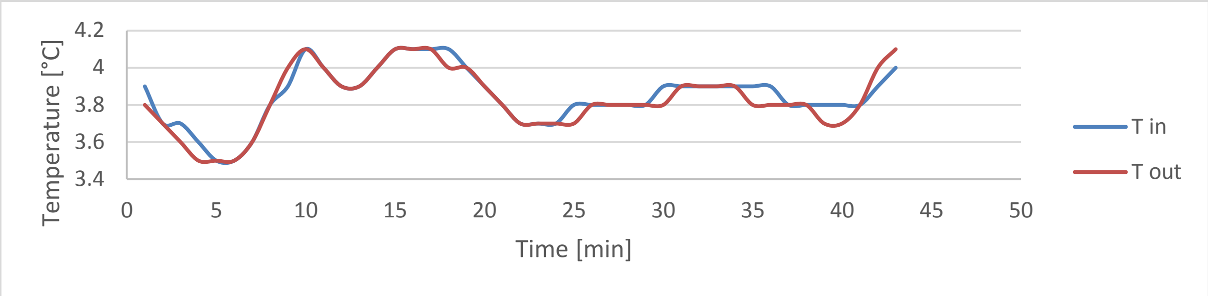

Figure 3: The real temperature of geothermal energy source

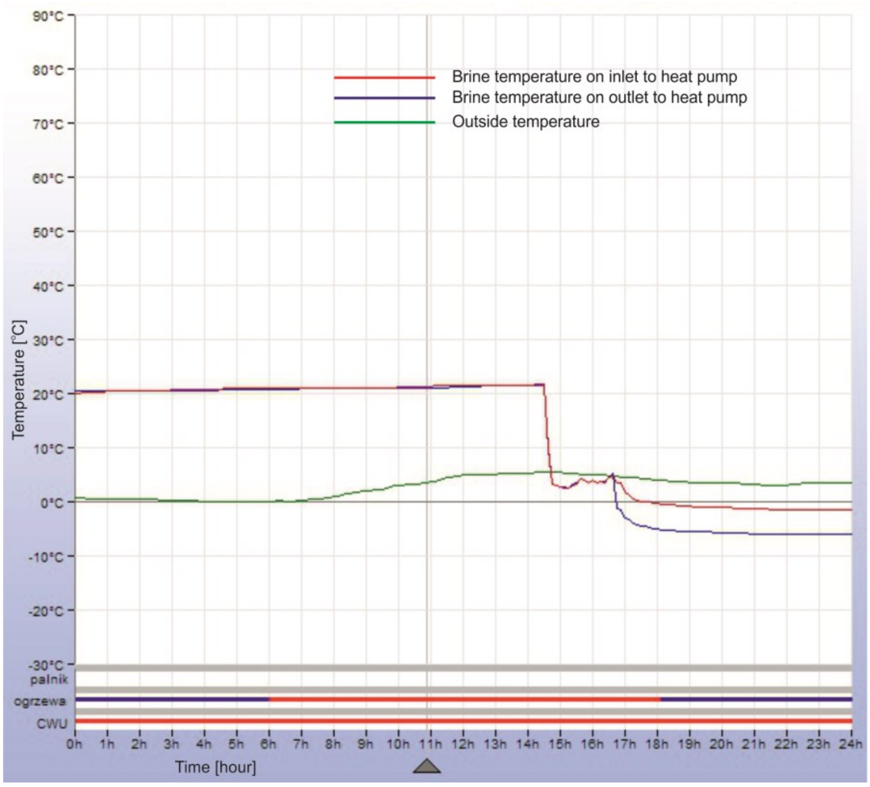

Figure 4: Brine temperatures on the outlet and inlet from the BHE "underfloor heating" heat pump, when only one loop was working

Table2: SPF change after disabling the another loop

Total length BHE	3 x80m (240m)	2x80m (160m)	1x80m (80m)
Time	01.10.2013-10.12.2013	11.12.2013- 04.02.2014	05.02.2014 – 30.04.2014
Heat production [kWh]	5441.9	6053.0	4190.4
Consumed electricity [kWh]	1311.4	1653.7	1169.4
Seasonal performance factor[-]	4.15	3.66	3.58

In Table 3 the change in SPF is shown. The SPF decreases when another loops was disabling. When total the length of the BHE was used by the heat pump the SPF was 4.15. So the high SPF value is related to, among others, an initial period of exploitation of the BHE and the high temperature of energy source at that time. In the last period of time when only one loop was working the SPF was 3.58.

On the 18th of December, 2013 a test of the energy source were made for "air heating" pump heating. At 9.00 am the heat pump was started to extracting heat from the ground. The heat pump was using only one of three loops in BHE (1/3 of the total length at 87 m. During the first hour of operation the temperature on the outlet from BHE decreased from 4°C to –0.6°C (temperature changes shown in Figure 5). When the temperature of the heat sink reached the set temperature the heat pump was stopped. The circulating pump of the energy source was still working and then the temperature of the brine was observed. The temperature on the outlet from the BHE was increased from -0.6°C (temperature measured in the moment of stop the heat pump) to 3.5°C after about 50 minutes of work from the circulation pump.

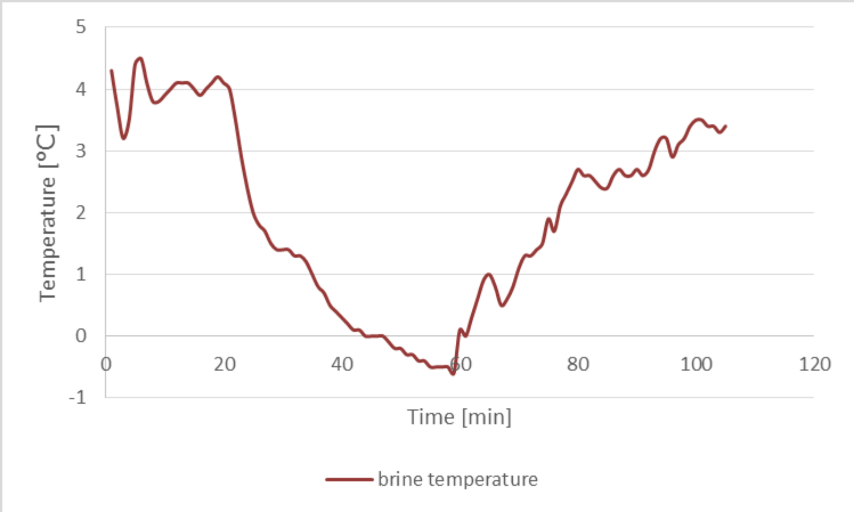

Figure 5: Brine temperature during heat exploitation and during rest time.

In next step the temperature of the brine in another loop (unexploited during this heating season) was verified and it was about 6.3°C. The unexploited loop is located at a distance of 7 m from the exploited loop. The fluctuation of this temperature is shown at Figure 6.

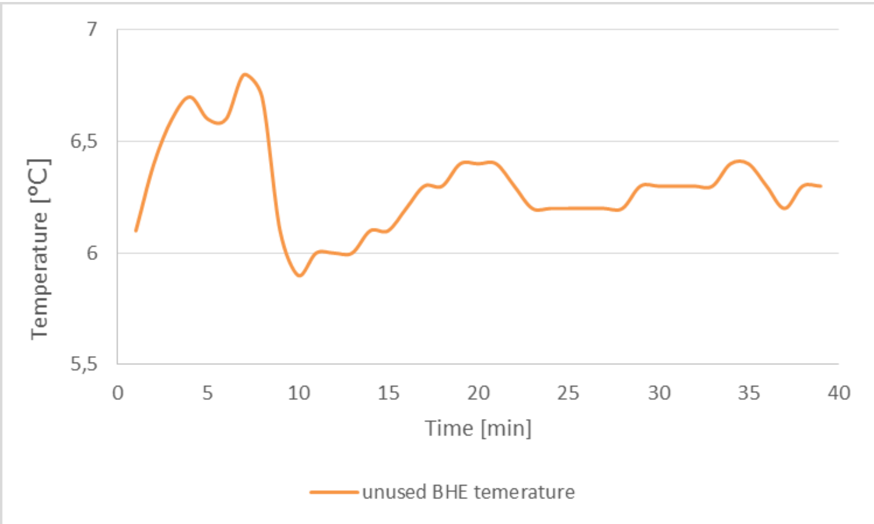

Figure 6: Unexploited BHE temperature

Table 4: Thermal power from the ground and the average temperatures of the brine for the "air heating" heat pump

Period	01.10.2012-30.04.2013	01.10.2013-30.04.2014
Thermal power of BHE [W/m]	34	92
Average inlet brine temperature [°C]	2.8	1.4
Average outlet brine temperature [°C]	-0.9	-2.6

Comparing the two graphs (Figure 6 and Figure 7) it can be deduced that the temperature of the brine in the exploited loop of the BHE is lower than the temperature of the brine in the unexploited loop of the BHE by about 5°C. So the slight difference is due to the close proximity of both loops.

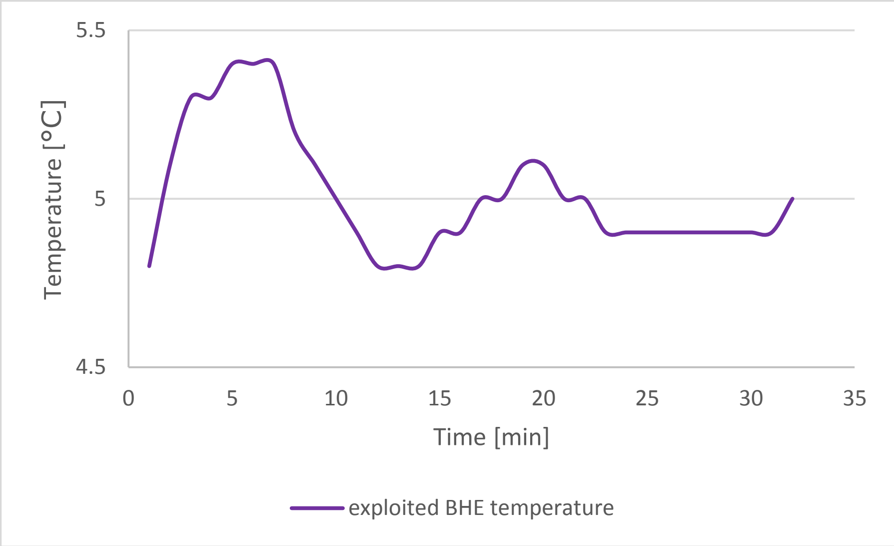

Figure 7: Temperature of exploitation BHE after a two hour brake

Table 5: Thermal power from the ground and the average temperatures of the brine for "the underfloor heating" heat pump

Period	01.10.2012-30.04.2013	01.10.2013-10.12.2014	11.12.2013-04.02.2014	05.02.2013 – 30.04.2014
Thermal power of BHE [W/m]	39	38	50	97
Average inlet brine temperature [°C]	3	4.7	1.1	-2.9
Average outlet brine temperature [°C]	-1.2	0.2	-2.9	-4.6

Depending on the dispositional length of the BHE, the unitary thermal power from the ground was changed.

6. SUMMARY

Two heating systems with geothermal heat pumps was examined during two heating seasons. Exploitation tests performed in Miekinia RES Laboratory showed the temperature of brine dependent on the BHEs length. During exploitation the temperature in each situation was stabilized, but the level of it depends on the total length of BHE. The temperature of the brine was decreased if the total length of BHEs was decreased. It had a inconsiderable impact on the seasonal performance factor (Table 3). For the "air heating" heat pump in the second analyzed season less heat was produced than in first analyze season. In the coming seasons successive tests will be done.

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6. REFFERENCES

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