SZENT ISTVAN UNIVERSITY

Thermal conditions of geothermal heat exchangers in case of heat pump systems

Abstract from Ph.D.theses

Bela Adam

Godollo

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Ph.D. School

Name:	**Technical Sciencies Ph.D. School**
Branch of science:	**Agricultural Engineering Sciencies**
Leader:	**Dr. Istvan Farkas** Professor, DSc. Szent Istvan University, Faculty of Mechanical Engineering Sciences
Head of the program:	**Dr. Laszlo Toth** Professor, DSc. Szent Istvan University, Faculty of Mechanical Engineering Sciences Institute of Process Engineering

…………………………
Approval of school leader

…………………………
Approval of the Head of the program:

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1 INTRODUCTION

1.1 Topicality and importance of the program

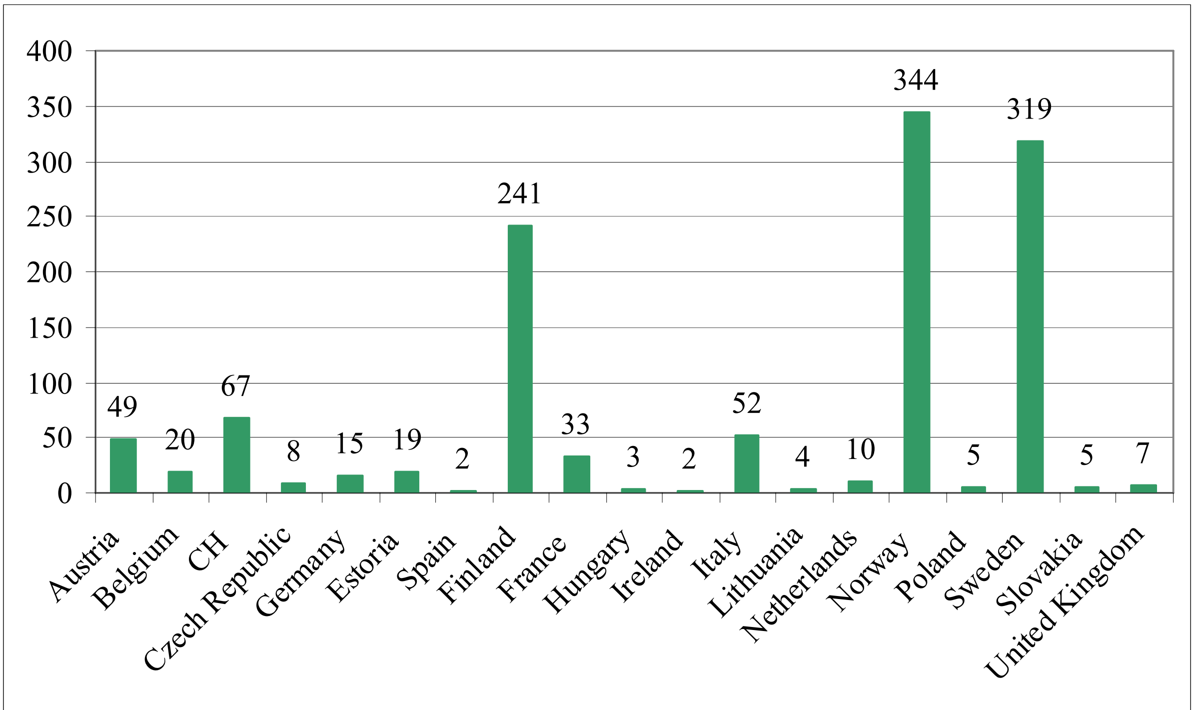
The world arrived at a crossroad in respect of energy consumption. The consumers are forced to thinking not only by prices and reasonability of energy but also by unfavourable climate changes becoming continually obvious.

Among the EU countries Hungary has also prepared its National Renewable Energy Action Plan until the end of 2010, and in October 2011 the National Energy Strategy has been accepted until 2030.

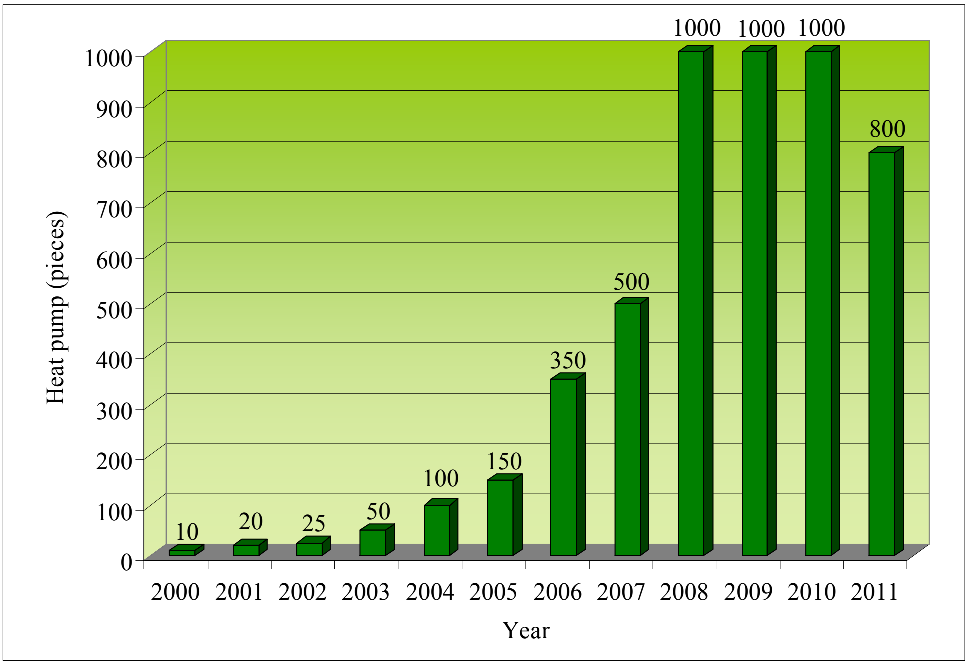
According to the accepted documents the proportionate share of the domestic renewable energy consumption increases from 7.3 % to 14.65 % until 2020.

As to the result of the summary presentation of the “2010 World Geothermal Congress” organized in Bali in April 2010, 69.7 % of the total geothermal energy production capacity of the world bases on the shallow geothermal heat pump capacity (Lund, 2010).

The domestic geothermal heat pump energy production is backward in comparison not only to these data but also to those of the neighbouring countries. It is shown in figures 1 and 2.



1: Heat pump sales/10,000 households, 2010 (Forsen, 2011)



2: "Estimated" heat pump sales statistic in Hungary, 2000-2011 (HHPA - Hungarian Heat Pump Association)

In comparison to EU member countries that are most advanced in the application of heat pump technology, the number of the domestic annual building capacity amounts to 1%.

50 % of this building quantity is made out by the vertical geothermal heat pump systems. The reason for it is due to the relatively favourable domestic geological conditions. These geothermal specialities can ensure achieving heat pump energy production goals of 2020 when applying well-established measurements, modelling, designing and professional completions.

1.2 Targets

The thesis aims at presenting the experiences until now by way of scientific analysis of geothermal potential measurements data started and carried out by me in Hungary, in 2006 on different places on basis of international experiences in order to ensure the general use of the technical-scientific inspection of geothermal heat pump application in the future and so to strengthen the reason for the existence of the domestic geothermal heat utilization. By characterizing the domestic geothermal heat conditions and on basis of my measurements I wish to draw conclusion from the real future utilization possibilities of geothermal heat.

I consider important to scientifically clear measuring and modelling, sizing topics of primary geothermal heat utilization in my essay while taking the different domestic geological conditions into consideration and for the sake of the efficiency of heat pump systems, optimization of the environmental advantages and the economical utilization.

Drafting of recommendations for making catharometries general in Hungary. In this connection to certify the importance of trial holes, geophysical loggings, boreholes and modelling of borehole systems. To present their effect on efficiency and cost-effectiveness of heat pump systems is of stressed importance.

Analysis of employment advantages and disadvantages of vertical geothermal heat exchanger systems (hereinafter abbreviated as BHE) is also of importance for their further expansion. Presentation of solving passive cooling of BHE systems as cost-effective and applicable cooling method means also one of future possibilities.

In case of BHE heat pump systems one of my most important targets is to present BHE field monitoring measurements and to make proposals for application principles of monitoring systems.

1.3 Description of tasks

- International and national literary elaboration of vertical geothermal heat exchanger measurements, focused on the up-to-dateness of the topics.
- Summary of related concepts.
- Systematization and interpretation of the available data of the domestic geothermal TRT (Thermal Response Test) measurements.
- Outline of methodology
- Presentation of geothermal measuring data of the domestic low- and high-production heat pump systems and summary on experiences.
- Inspection of grouting solutions for vertical boreholes.
- Engineering aspects of the efficiency of vertical geothermal heat pump systems.
- Analysis of designing, completion and operative experiences.
- Recommendations for integrating the knowledge base of catharometry into the national education.
- Recommendations for technological development possibilities of geothermal heat utilization.
- Recommendations for determining quality requirements of vertical geothermal heat pump systems.

- Elaboration of the method for database processing according to internationally approved standards. (From data tablet editable map - set up of data bank and later licensing category system - possibility of ranking in 3 categories)

2 MATERIAL AND METHOD

2.1 Connexions applied during measuring and evaluation

2.1.1 Principle of TRT measuring

The most important element of the primary circle of borehole heat exchanger (BHE) system is to define the necessary length, number and distance of the boreholes.

Thus, the BHE field can be optimized by conducting this response test and so the installation and operation of the subsequent heat pump system will not only be cost efficient but also reliable in the long run.

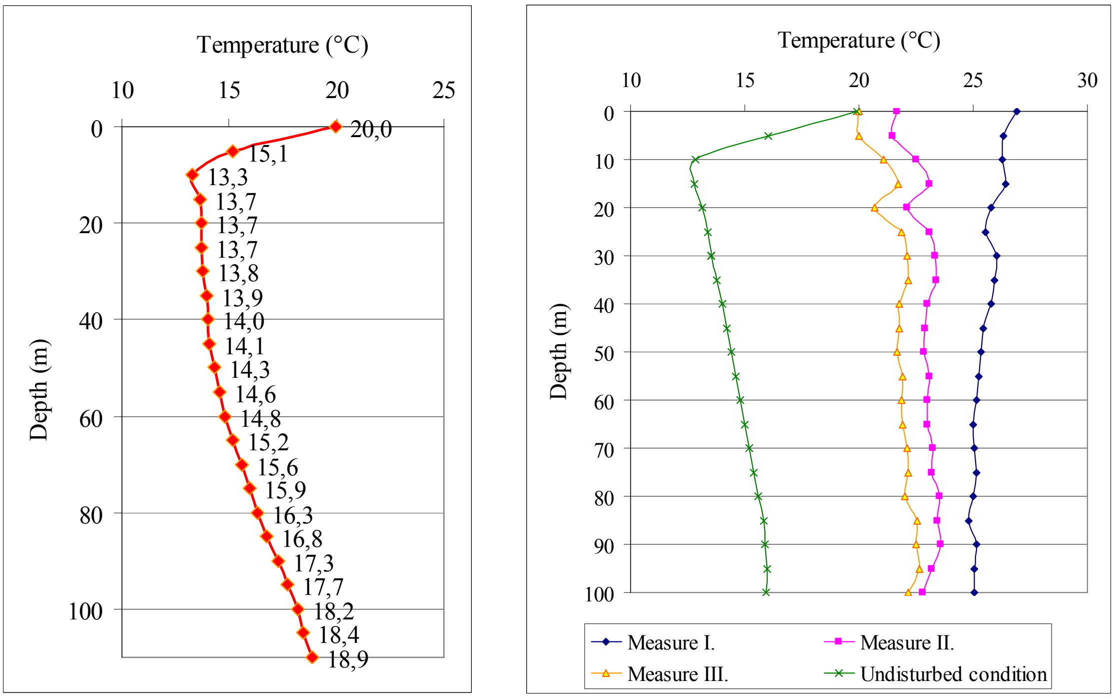
2.1.2 The Geothermal Response Test process

1. drilling of test-borehole and then geophysical logging in it
2. installation of test-BHE pipe
3. BHE grouting (the completion of the borehole heat exchanger is done according to the VDI 4640 guideline)
4. filling the pipe with working fluid
5. Ground-state temperature recording
6. Assembly and commissioning of the testing appliance
7. Borehole airing
8. Starting the test with a minimum duration of 48-72 hours
9. Disassembly of the testing appliance
10. Temperature recovery measuring in the whole BHE length 4 times: immediately after measurement, respectively 1, 2 and 3 hours after the test
11. Determination of the results:
    a. Definition of the borehole thermal resistance (R_b) and the ground thermal conductivity (λ)
    b. Interpretation of the run of the temperature log

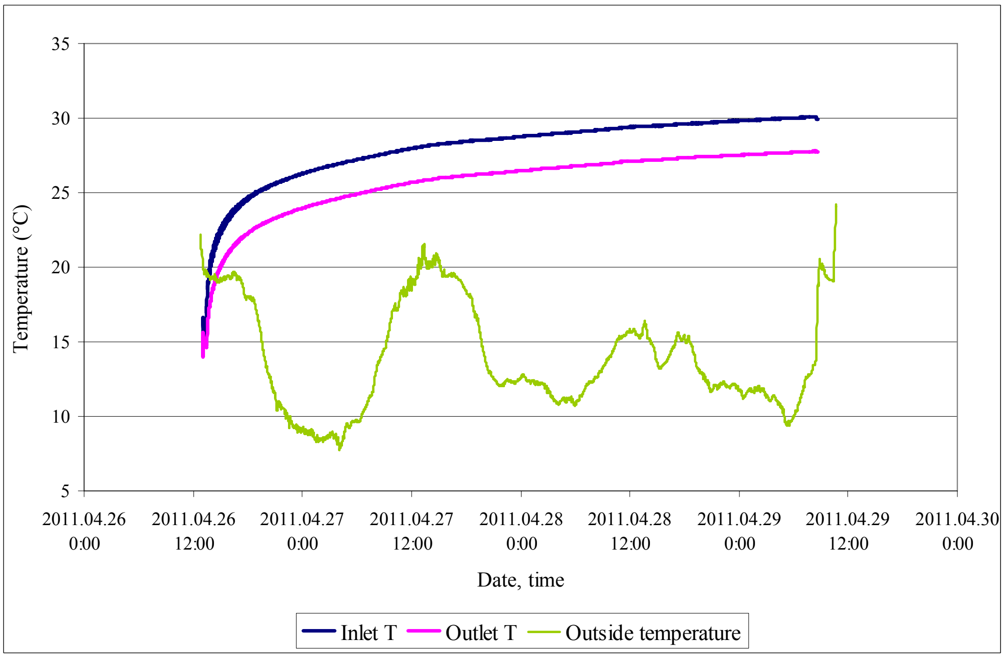
The obtained data from Thermal Response Test are evaluated based on two methods in favour of reliable results: the geological thermal conductivity can be determined with the purpose-developed German GeoLogik TRT Analysis Software and even with the traditional analytical method.

2.2 Collection of measuring data

Before starting Thermal Response Test the undisturbed temperature has to be recorded in the borehole by depth (Figure 3). Following assembly of the testing equipment the fluid shall be circulated without heating in the first 30 minutes and its measured temperature shall be used as input parameter of modelling. During the Thermal Response Test we measure the inlet, the return side and air temperature depending on measuring time (Figure 4).



3: Inspection of cooling following undisturbed temperature and response test along section



4: Delineation of data achieved upon TRT

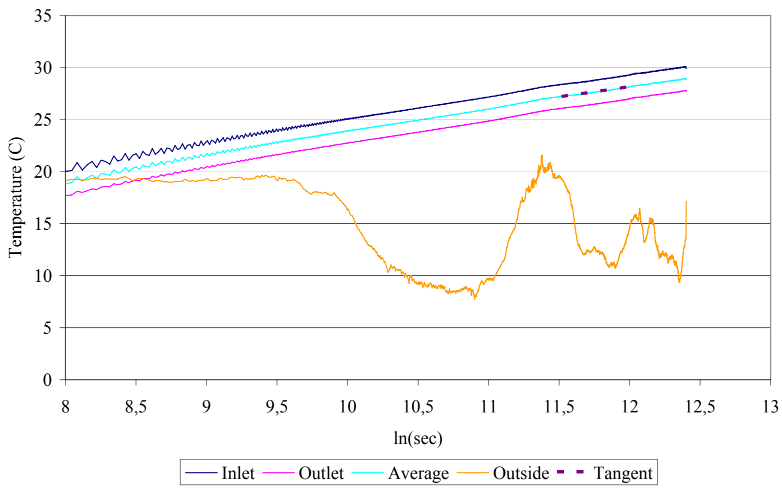
Inspection of re-cooling should be performed following response test. At this point, the heating is stopped and the temperature should be measured along the profile after waiting 1, 2, or 3 hours (figure 3) that allows to infer the character of the regeneration of the subsurface region.

2.3 Analysis, evaluation of measuring data

Several ways of Thermal Response evaluation are known. **I made it with Kelvin line source method ("line source").** The so-called equivalent thermal conductivity (λ) is obtained by solving the differential equation of the heat transport with the equation as follows:

$$T_f(t) - T_0 = \frac{q_c}{4\pi\lambda}\left(\ln\left(\frac{4\alpha t}{r_b^{\,2}}\right) - \gamma\right) + q_c \times R_b = \frac{q_c}{4\pi\lambda}\ln(t) + q_c\left[R_b + \frac{1}{4\pi\lambda}\left(\ln\left(\frac{4\alpha}{r_b^{\,2}}\right) - \gamma\right)\right] \quad (1)$$

Where:
T_f: fluid temperature
T_o: undisturbed ground temperature
λ: thermal conductivity [W/m * K]
γ: constant
α: heat diffusivity [m^2/s]
t: start of inspection [s]
q: heating power [W]
r_b: radius [m]
R_b: thermal borehole resistance [m * K/W]



5: Semilog diagram: x=lnt, y=T(°C)

The solution is an equation that allows calculating the thermal conductivity (λ) of space surrounding the borehole from the appropriate measuring results. The calculation refers to the "equivalent" thermal conductivity of the borehole surrounding that can be calculated from the tangent of the logarithmic average temperature of the inlet and outlet fluid. It means, if we examine the inlet and returning temperature recorded upon response test depending on natural logarithm of time, and then the slope of the tangent can be determined (figure 5).

Thus the temperature change can be calculated depending on the time passed and the distance from the source (distance from the borehole). The equivalent thermal conductivity (λ) can be calculated on basis of parameters measured during response test (T0= undisturbed subsurface temperature, i.e. the fluid temperature circulated without heating at the beginning of the test; the temperature of the inlet and returning fluid; quotient of the constant output and length of boring):

$$T_f(t) = T_0 + \Delta T(r_b, t) + \frac{Q}{L} \cdot R_b = T_0 + \frac{Q}{L \cdot 4 \cdot \pi \cdot \lambda} \cdot \left(\ln\left(\frac{4\kappa t}{r^2}\right) - \theta \right) + \frac{Q}{L} \cdot R_b \quad (2)$$

The equivalent thermal conductivity value (λ) determined with the above method reflects also the conductive heat conduction existing in rock formations and convective heat conduction generated by groundwater.

Heat transmission between probe tube and borehole wall depends on the location of pipes, the characteristics of refrigerant and grouting material. These effects can be characterized by the thermal resistance of the borehole that is marked as R_b. Thermal resistance of the borehole can be determined with the formula as follows:

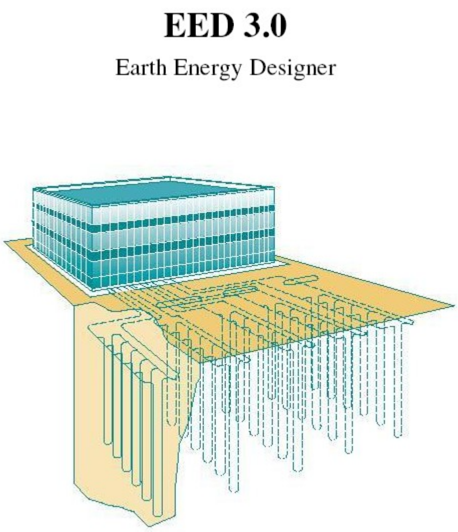
$$R_b = \frac{H}{Q}(T_f - T_0) - \frac{1}{4\pi\lambda}\left\{ \ln(t) + \ln\left(\frac{4\alpha}{r^2}\right) - 0{,}5772 \right\} \qquad (3)$$

Where:
H: length of borehole
Q: heat quantity input/output
T_0: ground temperature at rest
T_f: average rock temperature
r: boring diameter
α: thermal diffusion
λ: average heat conduction factor (W/mK)
Erf Gaussian error function
L: length of cylinder

2.4 Potential definition by modelling

Modelling can be performed by EED (Earth Energy Designer) Program following the evaluation of the geothermal response test results; the adoption of this program is general in Europe in case of similar projects (figure 6). G-function values received from numerical simulation are involved in EED program. Calculation of refrigerant is made according to monthly heating/cooling load. Database of the program involves both the key soil parameters (thermal conductivity and specific heat) and the characteristics of pipe materials or heat carrying agents. Borehole resistance shall also be calculated by the program on basis of borehole geometry, grouting material, pipe material and testing tube arrangement geometry. Arrangement of BHE field is optional from the available 798 alternatives of the database.

Application of the program enables determination of the length of geothermal heat exchanger, the difference between boreholes, the borehole depth and arrangement as well as the temperature of the heat carrying agent circulated in the geothermal heat exchanger, and, fitting them to each other. In addition to basic dimensioning, the calculation of the necessary borehole length is also possible on basis of data input, it means to optimize the response test system.



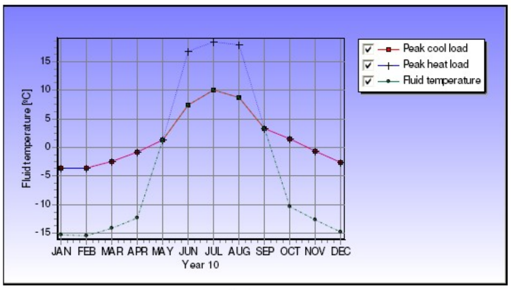
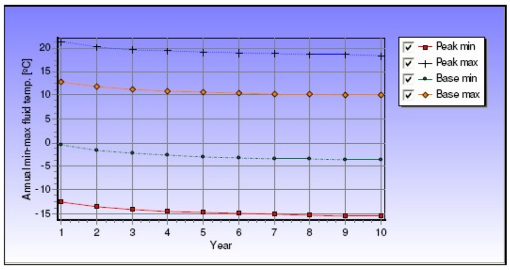


Figure 5.2: Fluid temperature chart.

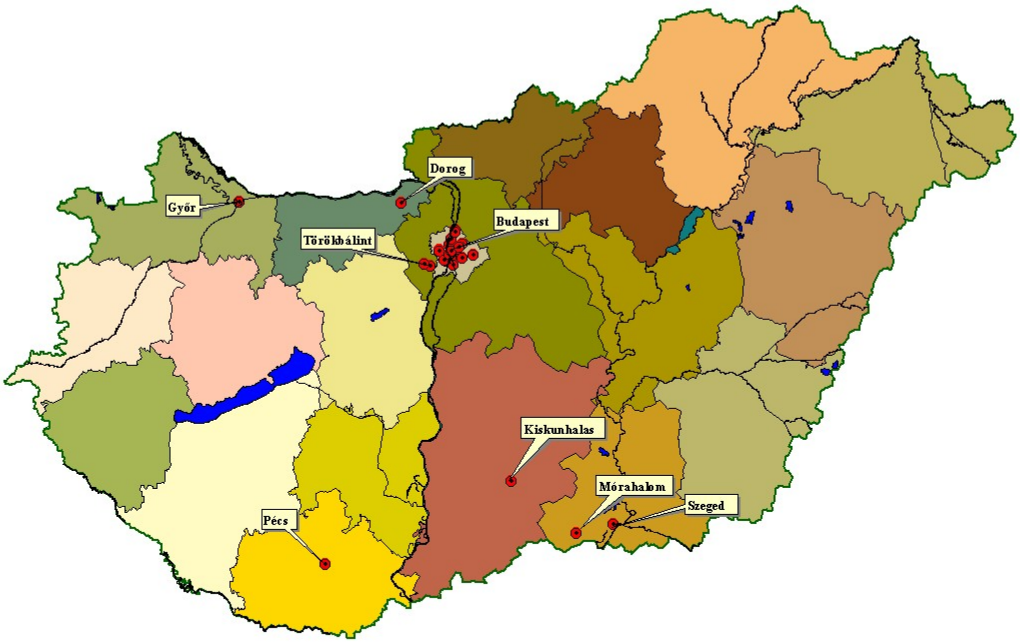


6: Displaying the temperature of heat carrying fluid in EED software in the period simulated

3 RESULTS

3.1 Places of measuring

When collecting data of the thermal conductivity of geothermal heat exchangers and borehole resistance measurements started in 2006 in Hungary I aimed to provide a good base for a domestic scientific thesis based on the appropriate number of data. I can summarize and evaluate this database founded on 27 measurements (figure 7).



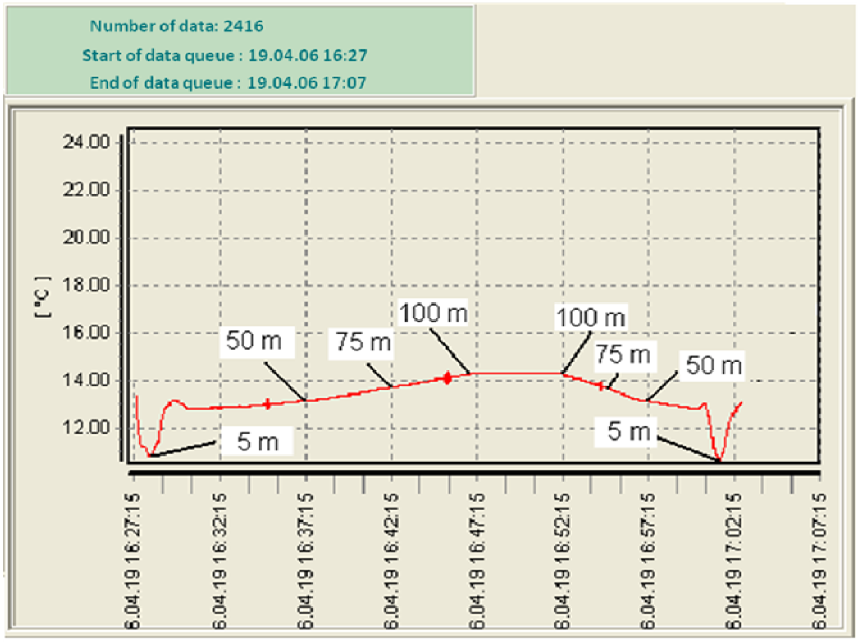
7: Locations of our TRT measurements

3.1.1 Heat pump system for Raiffeisen Bank - The first measurement (2006)

Budapest XV., Kesmark Street 14-13 - a corner plot on triangle-shaped area: the investment has been made neighbouring to the centre of the bank that was built earlier; in addition to the floor area of the building there was only a limited free area available.

When making boreholes, geophysical logging has also been carried out to clarify the geological structure of the area. The area consists of Neogene formations. On the investigated area the 8.0 m thick Holocene and Pleistocene formations are followed downward by Upper-Pannon layers. Holocene consists of thin topsoil. Holocene is followed by clayey, sandy, sabulous formations from Pleistocene period in the successive layers. Pleistocene is followed by rhyolitic tuff, clay, sand and aleurite formations from Upper-Pannon period.

We investigated reconstruction of so-called in situ state after boring on April 18, 2006 (figure 8) with temperature registration that amounted to 10.7-14.3°C depending on depth, and then we performed TRT measuring for both double and simple loop.



8: Raiffeisen Bank: normal state recording

In period from 18th to 23rd of April, 2006 we alternately carried out response test in double boreholes located 5 m from each other. We repeated the test for both double and simple loop. Testing time lasted 60 hours.

Table 1: Data of EED sizing – Raiffeisen Bank, Budapest, Késmárk street

Geothermal heat output in heating hours	450 kW
Geothermal heat output in heating hours	818 kW
Number of geothermal heat exchangers	81 pcs
Depth of boreholes	100 m
Total borehole length	8100 m
Borehole type	32 mm double borehole
Distance of boreholes	5 m
Thermal conductivity (on basis of response test)	2.61 W/mK

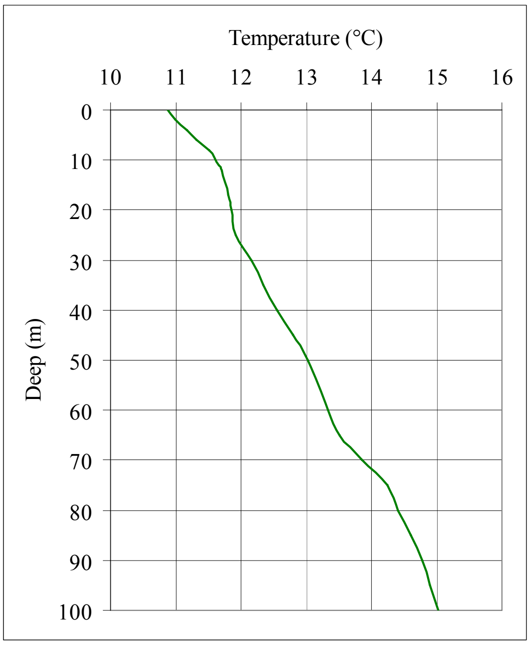
Water flows and the open-looped line arrangement provided for leading away the all-time high 818kW in cooling. Considering the more than 10kW cooling thermal load per one borehole, we made Geowatt AG, Switzerland check the data and Dr. Rybach confirmed the results of measuring and modelling.

3.1.2 Telenor House - heat pump system

Telenor house is located in Torokbalint, in Egett-valley. Aimed at thorough mapping of the geological structure and hydrogeological conditions a boring test of 100 m has been applied in 2007. After boring we made geophysical logging and following this geophysical logging a simple geothermal heat exchanger of 100 m has been built in the borehole where we performed response test. During the boring test we traversed clayey, sandy formations of

Pleistocene period under the thin Holocene topsoil. Formations from Pleistocene period were followed by sabulous, sandy, clayey layers from Miocene period in the successive layers. Boring test stopped in 100 m deep in the formation from Miocene period.

During measuring we recorded the temperature of the ongoing and returning section and the mass flow of the circulated fluid. Before starting with boring test we recorded the steady state (figure 9). The measured temperature values varied along the 100 m section between 11.99 – 13.97 ˚C.



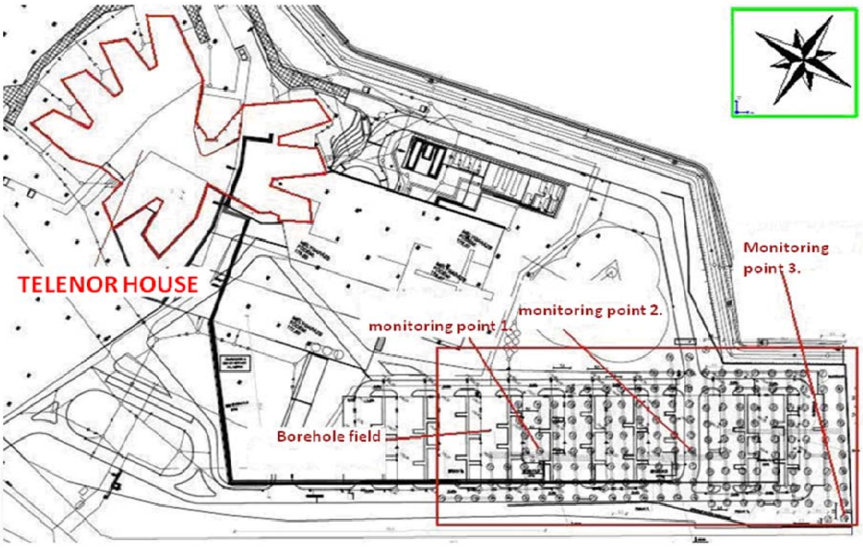
9: Torokbalint, normal state recording

Absorbable geothermal heat output: In case of 100 m simple borehole: 5.91 kW (with glycol); the thermal conductivity amounted to 2.80 W/mK on basis of evaluation. Determination of final numbers of boreholes, making use of the response test results, has been made by the EED sizing software developed for this special purpose and the following data were taken into consideration:

Table 2: Data of EED sizing – Telenor House, Torokbalint

Geothermal heat output in heating hours	860 kW
Geothermal heat output in heating hours	960 kW
Number of geothermal heat exchangers	180 pcs
Depth of boreholes	100 m
Total borehole length	18 000 m
Borehole type	400 mm simple borehole
Distance of boreholes	7 m
Thermal conductivity (on basis of response test)	2.80 W/mK

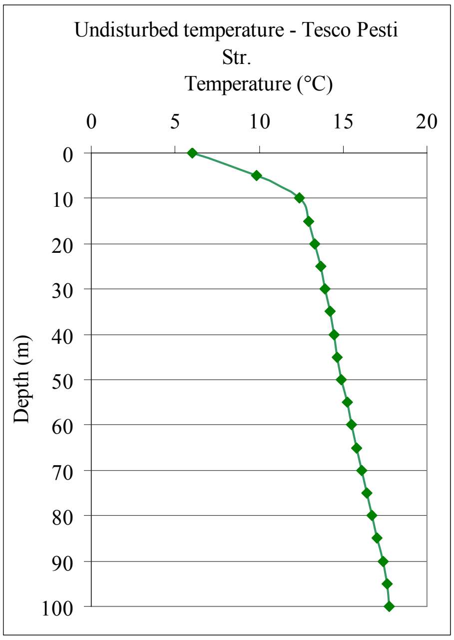
It resulted in installing 180 pcs of 100 m simple BHE type U, 40 mm for an all-time high 818kW output (figure 10).



1: Location of Telenor House and borehole field

3.1.3 Tesco - Trigeneration roof-top heat pump system

In 2010, we could infer the geological structure of the area in Budapest, XVII. Pesti str. 5-7 from the on-spot deepened exploring borehole with shoe depth of 127.0 m and from geophysical logging. Holocene topsoil lies on the surface that is followed by Pleistocene sand, clay complex in the successive layers. The quaternary formations (Holocene-Pleistocene) are followed by Upper-Pannon clayey, aleurite clay, sand and calcareous sandstone layers (Zagyva Formation).



2: Undisturbed formation depending on depth

A gas-driven unit of 30 kW is connected to the heat pump system that, in addition to power generation, provides heating for the bakery with its “waste heat”, and is operated for absorption cooling on demand. In case of excess heat, it loads the heat to the BHE field and heats the rocks.

Before starting with response test we recorded the steady state (figure 11), then during measuring we recorded the temperature of the ongoing and returning section as well as the outside temperature and the mass flow of the circulated fluid. The measured temperature values varied between 6.03 – 17.78˚C.

The most probable thermal conductivity in the traversed section amounts to: λ = 2.62 W/mK. For sizing thermal heat exchanger we used EED 3.0 software.

Table 3: Data of EED sizing – Tesco, Budapest Pesti str.

Geothermal heat output in heating hours	645 kW
Geothermal heat output in heating hours	860 kW
Number of geothermal heat exchangers	130 pcs
Depth of boreholes	100 m
Total borehole length	13 000 m
Borehole type	400 mm simple borehole
Distance of boreholes	6.0-8.8 m
Thermal conductivity (on basis of response test)	2.62 W/mK

Results of both the geological successive layers and response test/heat absorption test show that there are formations of high thermal conductivity (2.62 W/mK) available on the area. As result of the geological exploration and on-the-spot measuring (response test) we can state that the 130 pcs of simple geothermal heat exchangers, each of 100 m shoe depth, with 6.0-8.8 m basis distance can meet 402 kW heating and 740 kW cooling demand. Results of sizing are valid in heating hours at a value of 3.93 COP and in cooling hours with 4.03 COP.

Evaluation of the three sample systems is on basis of performed measurements:

Table 4: Comparison of data of the three presented projects

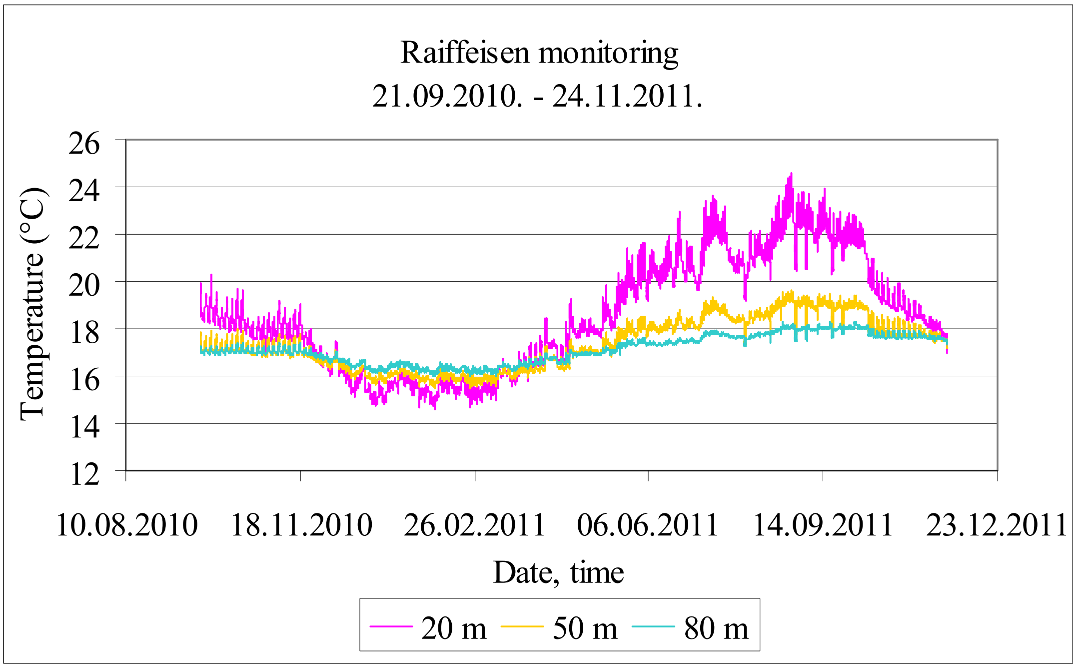
	Geological characteristics	Type of borehole	Thermal conductivity (W/mK)
Raiffeisen Bank	Holocene - Pleistocene - Upper-Pannon clay, sand, pebble, rhyolitic tuff	Double 32x3 mm	2.61
Telenor House	Holocene - Pleistocene - Miocene clay, sand, pebble	Simple 40x3.7 mm	2.80
Tesco, Pesti ut	Holocene - Pleistocene - Upper-Pannon clay, sand, pebble, aleurite, calcareous sandstone	Simple 40x3.7 mm	2.62

3.2 Evaluation of monitoring data

3.2.1 Raiffeisen monitoring

For testing the BHE system of Raiffeisen Bank we placed in October, 2006 a multichannel temperature recorder chain in one of the boreholes. We adjusted the frequency of recording to 30 minutes before installing the selected device type DA-S-TRB 118, 200509022. We applied this type of device to all of our further monitoring systems.

In winter, when we produce heat with heat pump for supplying heat demand of the building, the temperature of the borehole environment decreases. In summer, when the system is used for cooling, the heat is to be absorbed in the geological agent, it means, the increase of the temperature can be seen on basis of the measured data (figure 12).



3: Raiffeisen monitoring

It can be stated that the BHE system has been sustainably operating between 14-22°C temperature levels since years.

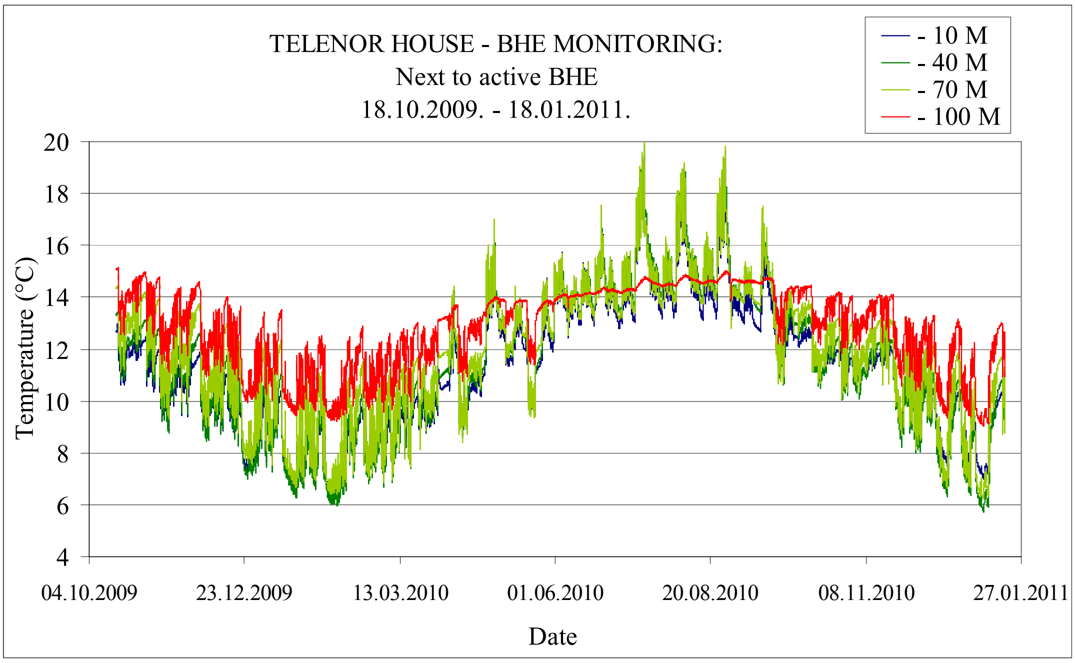
3.2.2 Telenor monitoring

During boring processes we placed 3 further pieces of heat exchangers in addition to the 180 pcs for monitoring geothermal heat as well as for monitoring the operation of geothermal heat exchanger. Thus, we can record the continuous temperature changes between boreholes and rock environment out of the borehole field. The individual temperature recorders showed similar temperature values considering the normal state in the four different recording depths:

1st temperature recorder: 10 m: 11.5˚C; 40 m: 12.7˚C; 70 m: 14.0˚C; 100 m: 15.0˚C

2nd temperature recorder: 10 m: 11.4˚C; 40 m: 12.6˚C; 70 m: 13.8˚C; 100 m: 15.2˚C

3rd temperature recorder: 10 m: 11.9˚C; 40 m: 12.3˚C; 70 m: 13.8˚C; 100 m: 15.0˚C



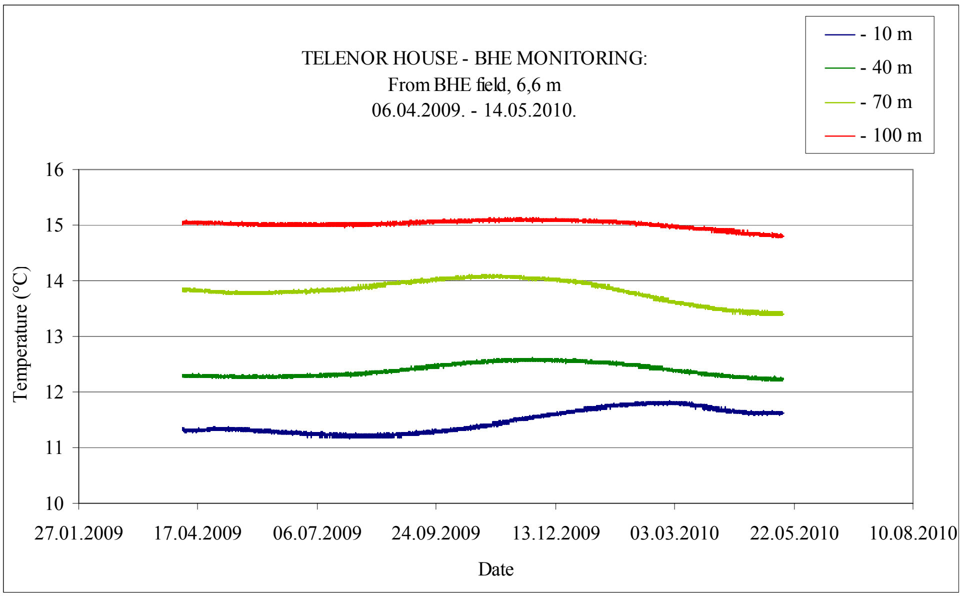
4: Temperature measured at monitoring point 1

The temperature "has been cooled" to 13.41˚C during test operation on January 20 and 21, 2009, while the temperature has been regenerated up to 14.68˚C in two days (figure 13).

At point 2 and 3, at half of the both geothermal heat exchangers respectively 6.6 m from the field, the heating and cooling hours did not cause any important changes in temperature in the period of starting the system.

At point 1 the shape of graphs measured at 10, 40 and 70 m is nearly symmetric, it means, that it fluctuates around the normal temperature. At 10 m the maximum fluctuation amounted to 12°C, at 40 m 13°C, and at 70 m again 12°C. At 100 m deep the fluctuation between the winter minimums and summer maximums amounted to only 6.5°C. Furthermore, the temperature measured at the deepest, at 100 m shows asymmetrical view: in summers the system can heat the rocks at a minimum value, and cooling in winter is also moderate. Thus, it is conspicuous that the operation of the geothermal heat exchanger system has less influenced the changes in subsurface temperature in this depth than that in the shallower regions.

The measuring point 3 was placed in a distance of 6.6 m from the borehole field (figure 14). We intended to test the distance action of the system this way, it means, how far the temperature anomaly generated by the operation spreads in geological environment. The operation of the system caused scarcely any changes in the temperature. According to measuring data this value did not exceed 0.41°C.

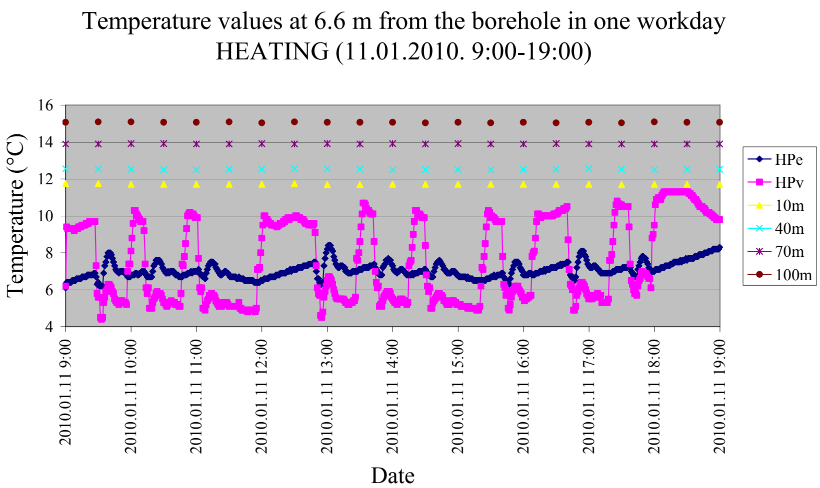


5: Temperature measured at monitoring point 3

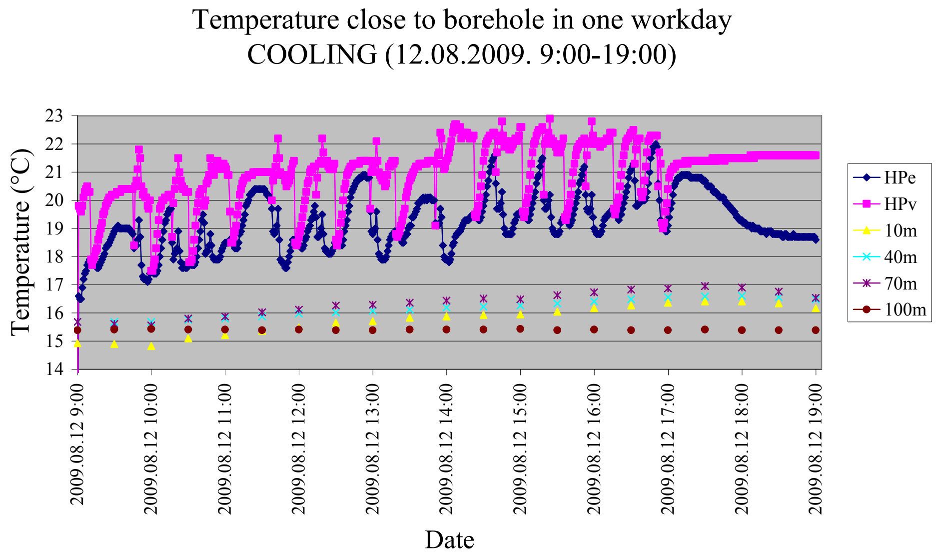
Monitoring result: close to the operating geothermal heat exchanger the heating caused reduction in temperature by 5.74°C, the cooling resulted in temperature increase by 4.30°C.

The heating resulted in temperature decrease by 0.28°C in a distance of 3.5 m from the operating geothermal heat exchanger. Effected by cooling, the temperature of the geological agent that has been cooled due to heating, has been increased by 0.08°C. At measuring point placed 6.6 m from the geothermal heat exchanger field the changes in temperature were scarcely observed in comparison to normal state.

In addition to seasonal temperature effects I also tested the effect of one-day heating and cooling hours on the monitoring points and rock environment (figure 15, 16). In the selected daily operation the environment temperature effect of the start and stop of heat pumps and that of the "regeneration standstill" can be tested in heating and cooling hours.



6: Monitoring depending on the operation of heat pumps in heating period



7: Monitoring depending on the operation of heat pumps in cooling period

The heat pumps and the integrant borehole fields are operating in weekly sequence in order to compensate the operating output of the heat pump and to equally load the borehole fields.

The thicker curves show the fluid temperature on the heat exchanger of the heat pump by way of per minute reading, the blue curves show the temperature of the influent fluid from borehole, and the pink one shows that of the outgoing fluid. The rock temperature is measured in every 30 minutes.

Findings

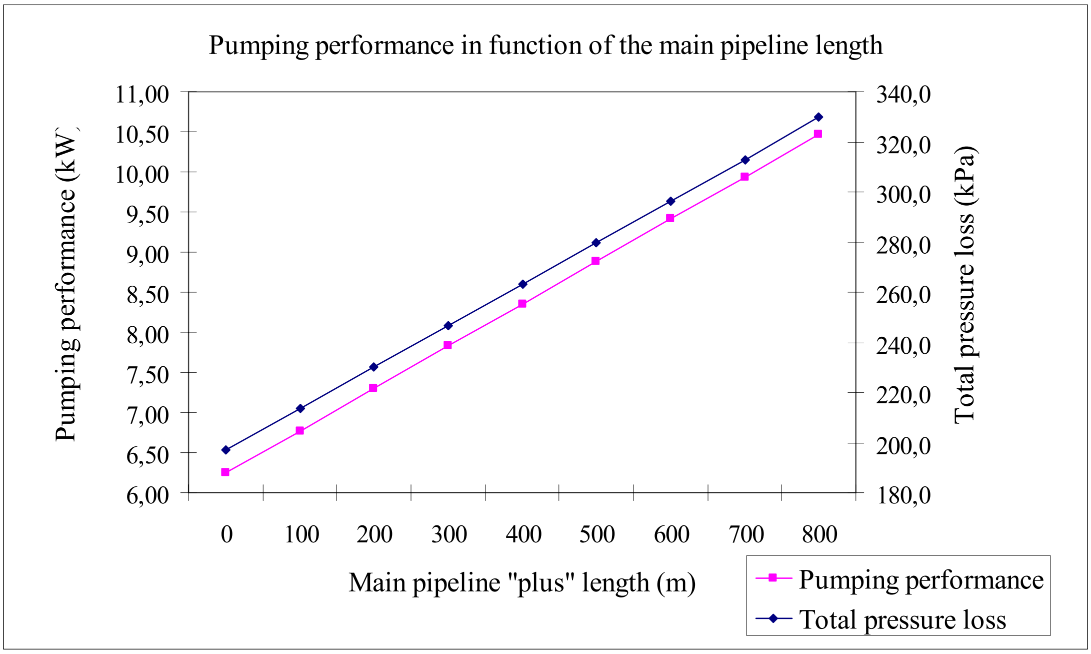
Temperature of rock changes available in the field I directly at the borehole in only 70 and 100 m deep by 1.5°C, and the delayed regeneration of 1.5-2.0 hours can be seen after heat pump stops. The average rock temperature amounts to 9°C at the borehole field I, to 13°C at the II and 14°C at the III.

In cooling the colours of the thicker curves are reversed, the pink shows the temperature of the influent fluid from borehole, and the blue one shows that of the outgoing fluid. Temperature difference is 2°C. The effect on the rock temperature is rather less, the four curves are running together since the difference is minimal between the fluid temperature of the heat pump and the rock temperature (13-14°C).

Conclusion: also in case of daily heating and cooling operation the switching on and off, the running time of the heat pump cause only 1-2°C change in the rock temperature, but only for short time and equalize until the beginning of the work the next day.

SPF monitoring:

Control of the operation of BHE heat pump systems is performed by installing monitoring devices. The effects of pumping output differences can be seen. Arrangement and replacing of BHE borehole field from the original place means 200 m main pipeline surplus pumping output up to the heat centre with its increased demand on electricity. I made its calculation and figure 17 shows function describing the necessary surplus pumping output.

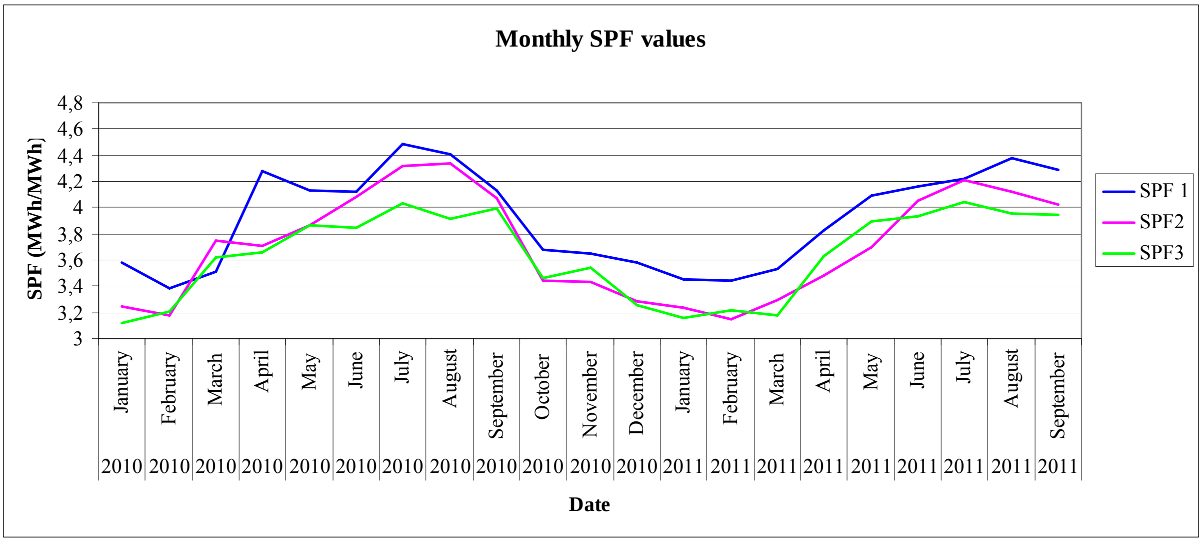


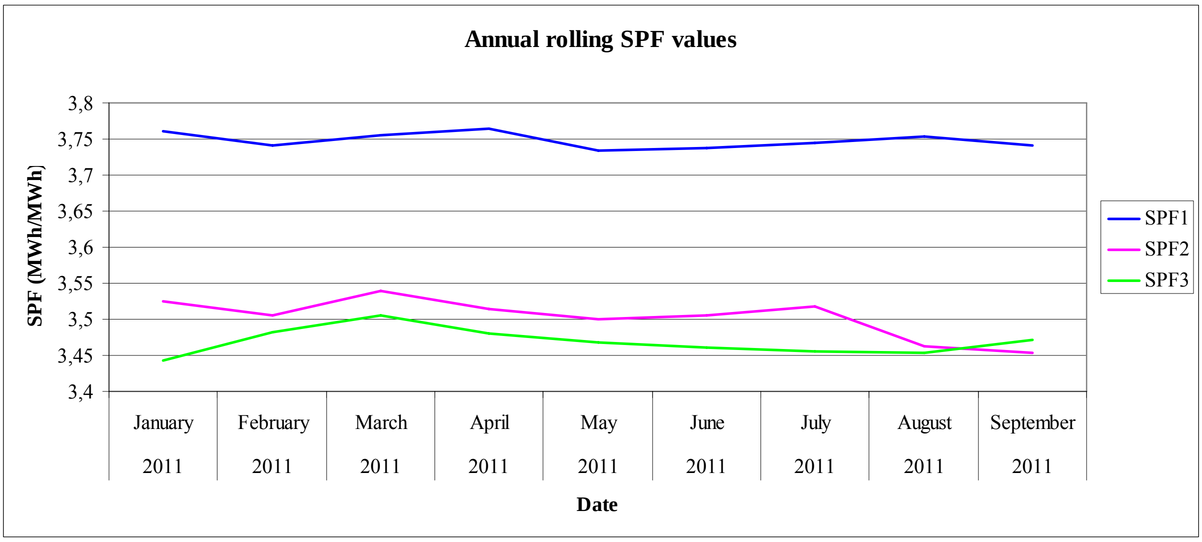
8: Pumping output depending on the length of main pipeline

Generally, we can say that a badly designed primary system may even in a drastic extent deteriorate the average seasonal output factor of a heat pump system.

The figure 18 shows the SPF curves of the three independent systems of Telenor. It is apparent that the SPF values of the heat pump 1 operating with the nearest borehole field are the highest. It is comprehensible since the main pipeline of this borehole field is the shortest and comparing the three systems the pump of the lowest output (let’s say No. 1) can also supply the system. The main pipeline section of the middle borehole field is longer, its circle resistance became larger and it was necessary to provide a one size larger pump (let’s say No. 2 that also has a larger electricity output than that of No. 1). The third outermost field has the longest main pipeline section combined with the pump No. 2 of the largest output.

Comparing the average SPF values of the three systems we can state that the SPF values of the systems 2 and 3 as compared to the system 1 with the best values are lower by 5-8 %.





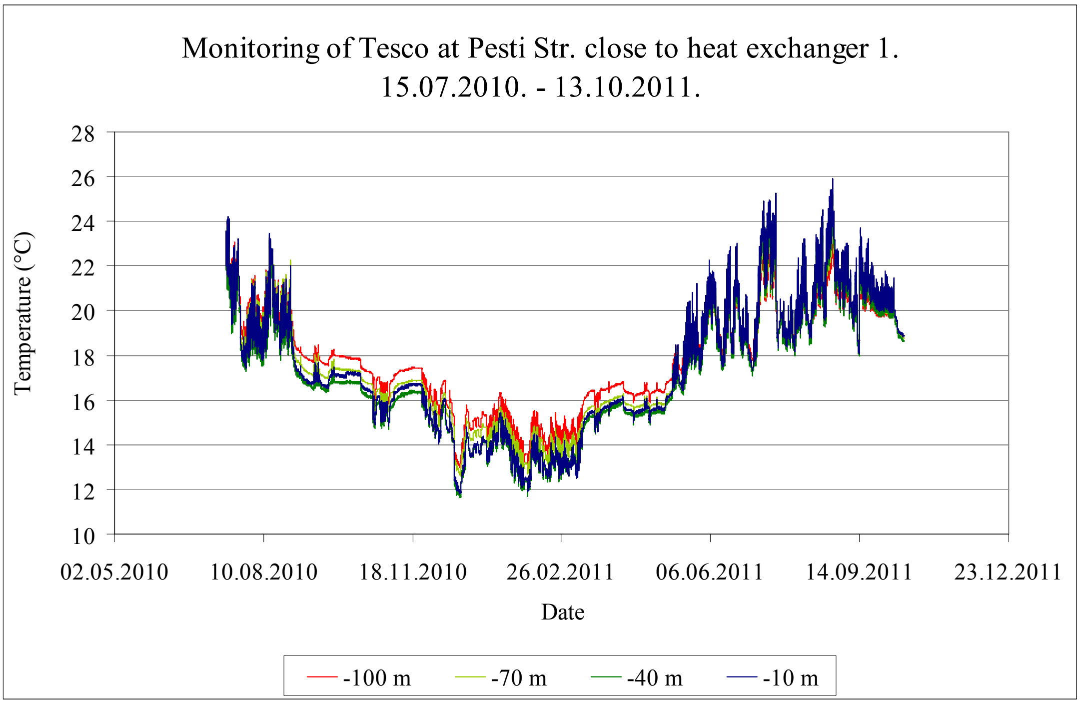
9: SPF curves of Telenor House

Its effect on the SPF value is shown by heat pump No. 1 and the annual surplus of 0.25-0.3 of the blue SPF1 curve belonging to borehole field I. located nearest to the building.

3.2.3 Tesco monitoring

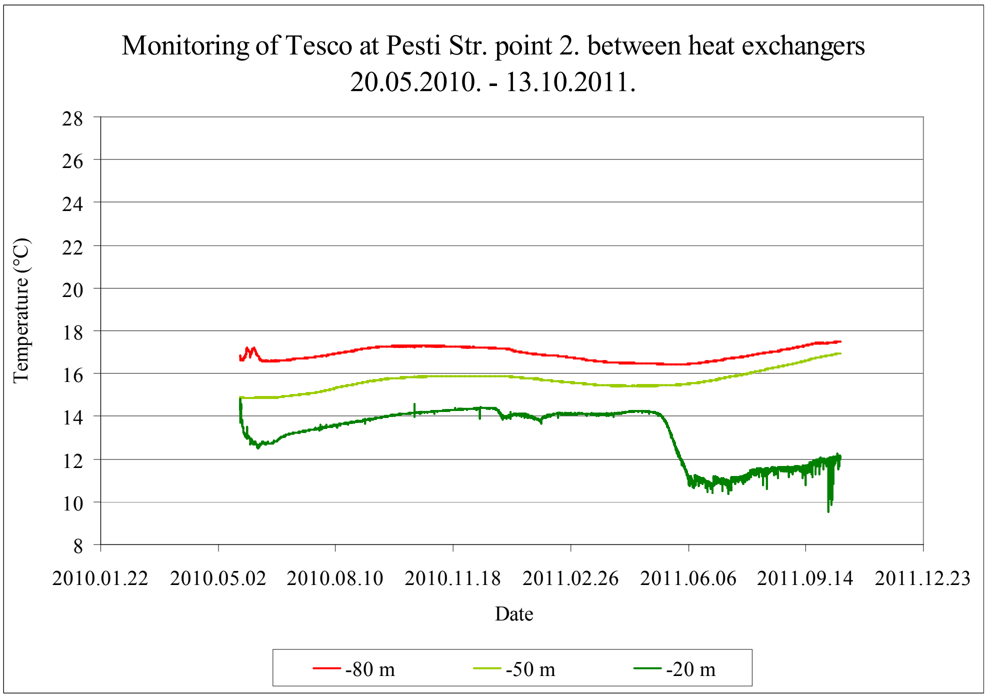
On basis of measurement data the upper 100 m of the area are characterized by the geothermal gradient of 59.44°C/km that is higher than the world average of 30°C/km and higher also than the Hungarian average of 40-50°C/km.

A 100 m temperature chain has been installed next to the geothermal heat exchanger that is provided with sensors in distances of 10 m, 40 m, 70 m and 100 m.



10: Values recorded in measuring point 1

Figure 19 shows the temperature in four depths measured next to the operating borehole. Commissioning of the system was launched in the summer cooling period, we made the geological agent absorb heat and therefore warming was experienced there. At starting the heating season we extracted heat from the soil. As a result, the devices recorded cooling. Consequence: in heating hours there is a minimal decrease in rock temperature.



11: Data recorded in Tesco monitoring point 2

The temperature chain is placed in a monitoring borehole, 5 m from the operating boreholes and the temperature is measured in 3 depths: in 20 m, 50 m and 80 m deep. The temperatures measured in 3 depths are shown in the graphic one under the other depending on time (figure 20).

On basis of data the upper 80 m are characterized by geothermal gradient of 64.66°C/km. This value is rather higher than the world average of 30°C/km and higher also than the Hungarian average of 40-50°C/km.

In 5 m distance from the active boreholes the subsurface temperature was not significantly affected by even the warm summer weather conditions during the one month operation.

On basis of several years' experiences, in case of independent heat pump systems the well-designed systems showed in winter heating season a rock temperature decrease of 10°C directly next to the boreholes as compared to the initial approx. temperature of 15°C. In present case, due to gas engine waste heat removal and in spite of the heating hours, there is an increase in temperature in 5 m distance from the operating boreholes. Thus, the temperature changes of the geological agent are rather lower than that of the heat pump systems without trigeneration system. Its positive effect can be experienced in the increase of the heating SPF factor.

3.3 General findings

Earlier, still before the measurements, a great number of the players in the scientific community expressed doubts about the sustainability of BHE systems. They meant that the BHE heat pump system would cool the rock environment of the field in a few years after commissioning and thus it cannot be effectively operated.

On basis of the conscious measuring and monitoring program managed by me we were succeeded in disproving this opinion. It proved especially in case of the balanced heating-cooling project that the well-established measurement provides cooling of the rock environment of BHE field in limited constraints as compared to in situ temperature and provides warming adjusted to changes of season.

Measuring and modelling form the basis of cost effective and effective systems. Each BHE system provides the expected SPF level considering the different installation and other engineering designing aspects.

Nowadays, the built-in heat pump capacity reaches 40MW. The calculated thermal heat abstracted by vertical borehole amounts to its 50%, i.e. to 20MW. It means the operation of

400,000 m thermal heat exchangers on national level in case of average 5 kW thermal heat abstraction/100 m vertical boreholes.

At this order, the defects in completion, the non-appropriate measurements and undersizing problems will cause significant differences as compared to vertical geothermal boreholes installed with professional boring technology and grouting. When we just estimate its order to an average of 20 %, we receive a value of 4MW that, calculated on an annual national average of hours run output (2000 hours), shall already mean a surplus energy consumption of 8,000 MWh. Calculated by "A-1" tariff (48.5 HUF/kWh) it means HUF 388 million operation surplus costs; calculated by geotariff (31 HUF/kWh) it means HUF 238 million operation surplus costs in case of heat pump systems. Just let's imagine how much surplus costs originate during the 25 years lifetime. **About HUF 7 billion!**

Another oversizing effect is the unnecessary costs of geothermal borehole boring amounting to **HUF 320 million** in case of 20% difference calculated with an average price of 4,000 HUF/m.

Therefore we can state that undersizing has a rather larger effect on the operation costs of geothermal heat pump systems than the investment costs of unnecessary bored boreholes in case of oversizing.

The exactly measured and sized BHE system can only meet the expected environment protection and CO_2 saving indexes.

It is a result of great importance that, on my personal contribution, the principles of BHE heat pump systems, especially the measuring and modelling methods are already involved in the university and professional training system as part of the geothermal energy education. It provides national wide the possibility for sanitary engineering designers and architects to involve the presented measurements and modelling already in the stage of elaborating the project conception when designing BHE heat pump systems.

3.4 Geosciences and technical findings for TRT tests

- Facts influencing the accuracy of TRT measurements that should be considered upon measurements:
    - When performing measurements the voltage fluctuation of electricity supply must stay under 5 %. Therefore, the TRT equipment of own development is supplied with voltage, with the stabilized 230 V by the built-in constant-voltage regulator of 3 kW output. Due to fluctuation in circuit voltage, we experienced significant fluctuation also in the measured inlet and returning fluid temperatures, while the

balanced current supply provided by the aggregate resulted in more constant measurement.

- The measuring device should be installed as closer as possible to the measured borehole. The insulation of the BHE connection should be carefully .performed.
- Measuring process can be started in 5 days after boring, after expiring of the delay time, for the sake of the in situ temperature being restored.
- Collection of measuring data depends also on the capacity of data logger. Generally, the data collection in every 2, 5 and 10 minutes is used. The more frequent data collection can better show the electricity supply and insulation defects.
- Before measuring a preliminary circulation of 30 minutes is necessary to avoid some decimal measuring defaults in heating effect of the circulation pump.
- The accuracy requirement for measuring devices is of decimal scale.
- At the end of the maximum 72 hours measurement process it is necessary to carry out heat recovery measurement after stop of circulation. The temperature curve has to be made after 1, 2, and 3 hours of waiting. This measurement is necessary due to impact assessment of aquifer layers.
- As to the other heat conduction test processes we can state that they give exacter values per layers. They can be obtained from the borehole fluid during boring respectively by means of the optical cables placed in the borehole or in the bore next to the pipe, but the competitiveness of the methods is determined by the price/value ratio at any time on the heat pump market. In the domestic practice the traditional TRT measurements are applied. The domestic market is unable to finance even these measurements. This thesis aimed, in one respect, at presenting how important the well-established measurements, modelling of BHE systems on primary side are and what economical and sustainability advantages they mean.
- The expectable development of TRT measurements lies in the simplification of numerical modelling, in the further improvement of accuracy in addition to current practicality and affordability.

• The exact knowledge of the geological successive layers is of great importance for the effective operation of BHE systems.
• The domestic, mainly anemoclastic rocks can be drilled by means of the so-called wet drilling method. Efforts should be made for the smallest drilling diameter possible as compared to the BHE size that enables thermal conductivity improvement.

- Due to the anemoclastic, often caving borehole wall the installation of BHE cannot be solved by the installation weight generally used in the West but introducing of BHE necessitates drill rods. This will increase the drilling diameter. Efforts should be made for finding the optimal hole size to let the mentioned aspects become effective. One of the methods is to employ the so-called filling stick for introducing the probe that is of smaller diameter than the drill pipe but provides filling of packing rock.
- The thermal conductivity depends mainly on grouting of the borehole. Avoid opening up of different water aquifers along BHE.
- Application of bentonite-cement-water suspension is generally used in the domestic BHE grouting practice. It is of great importance to choose the percentage of components depending on the current successive layers. Some examples for producing 1 m^3 packing rock:

Table 5: Examples for choosing packing rock components

	I.	II.	III.
Bentonite:	50 kg	100 kg	50 kg
Cement:	50 kg	25 kg	150 kg
Water:	880 litre	880 litre	880 litre

- Grouting with the thermal improved material results in 10 % improvement. In hard rock where the drilling costs are double than the normal price, the application of thermal improved material is unambiguously worth but only in places where the cracked layers and breaks do not abstract the packing rock.
- In case of low-capacity heat pump systems where there is not enough place for installing 1-2- or 5 pcs BHE boreholes on plots of i.e. family houses, it is of great importance to adjust the designed borehole length to the primary circulation pump output built in the heat pump. The total length of the geothermal heat exchanger should be adjusted to its hydraulic data.
- In case of hard rock it can occur that the big faults or maybe holes impede to continue air drilling still before arriving at the designed shoe depth. In these cases we must stop at holes. Installation of BHE will be carried out until the achieved depth and following it a special grouting is practical.
- It can occur in the above-mentioned case that the designed BHE will not be the same length. In this case data of tests and measurements should be adjusted to the realized BHE length and the hydraulic adjusting valve must be applied, by all means, when joining to distributor-collector.

- Taking the direction and speed of subsurface flow of water into consideration is of importance.
- Material, size and arrangement of the test pipe can influence the BHE output. Instead of the simple U test pipes of 40 mm we employ 32 mm since their output differs only by 8-10%. At the same time, the installation technology of the simple U test pipe of 40 mm is simpler.
- The heat-transfer agent in BHE is generally ethylene- or propylene-glycol mixed with water to maximum 20 %. TRT measurements showed that, if they are applied, the pumping output is increased and their heat conduction is lower than that of the water. From safety point of view, it is however necessary in order to protect its heat exchanger.

3.5 Economy evaluation of BHE heat pump systems

The key of popularizing the BHE heat pump systems lies really in the cost efficient operation and in reducing the specific investment costs.

In my dissertation I only deal with the connections of the primary side of BHE heat pump systems that really affect the cost efficient operation.

Here it is also worth separating small and large systems.

3.5.1 Economy analysis of low-capacity (less than 30 kW) BHE systems

The company managed by me has designed and completed 150 pcs of low-capacity BHE systems. On basis of data obtained from them I compiled a representative sample consisting of 15 pcs for the economic analysis:

Thus, from the sample of 15 pcs: the investment costs amounts to 331,111 HUF/kW net + VAT.

The other factor influencing the economic efficiency in a great extent in addition to the current gas price is the demanded “H” or “GEO” tariff for the heat pump. Compared to the present A1 tariff of: 48.50 HUF/kWh we can count on the price of the both preferential tariffs of 32 HUF/kWh.

The specific costs of investment amount to gross: **413.862 HUF/kW** and the payback period is: **8.96 years,** if no subvention available, and in case of 30 % subvention the payback period is: **4.23 years.**

It can be seen that similar to the Western European heat pump market developments the investment support system should be operated and its minimum intensity should be at 30%.

3.5.2 Economy analysis of high-capacity BHE systems

It can be stated that the specific investments costs are lower at the high-capacity BHE systems.

For this test, I took the investment data of 10 pcs BHE heat pumps of highest capacity into consideration that were also designed and completed by the company managed by me.

From the 10 pcs of samples the specific investment costs amount to **168,012 HUF/kW** net + VAT = **210,015 HUF/kW.**

I also reviewed the payback period for the calculated investment costs.

An important aspect is that at what price the investor can be provided with electricity by the service provider.

In the sample calculations I calculated with a price of (likely) 20 HUF/kWh. I made the calculations here also without and with subventions but here I considered several possibilities depending on subvention intensity since the rate of subventions depends on the seat of the enterprises - i.e. depending on region it amounts to 25%-50°-60%. In addition, the local authorities may enjoy 85 % subvention.

Table 6: Average of payback period of the 10 sample projects

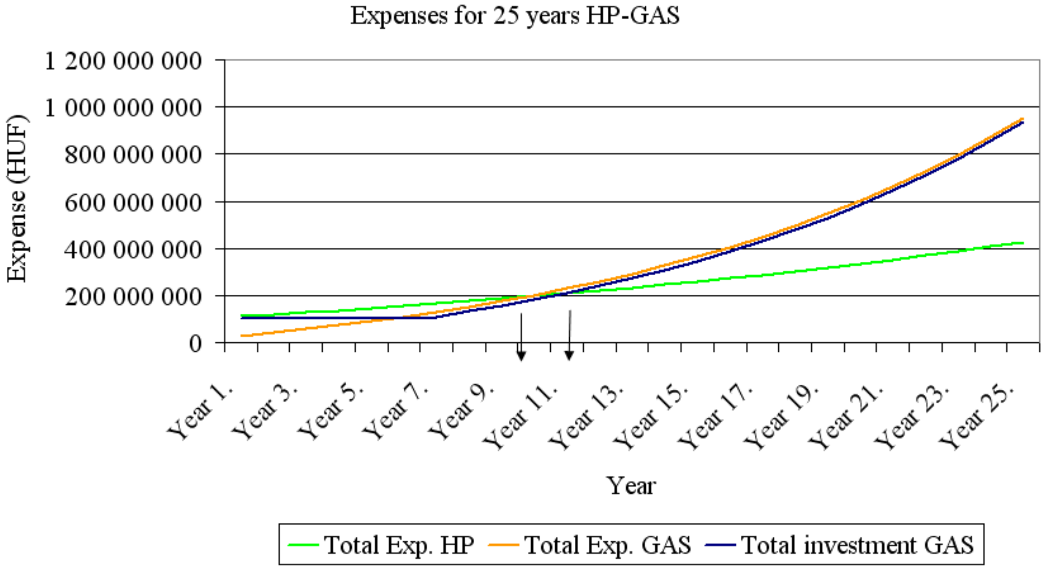
10 pcs	Output (kW)	Difference in costs [million HUF net]	Operation costs [HUF /year]	Payback period (year)
Average:	619	79,277	15,614	4.95

I made efficiency calculations and calculations on return also for the average output of the table 6 while taking also the bank profits for 25 years into consideration. Basic data used for the calculation (investment costs, energy prices, bank interests, etc.) are shown in table 7.

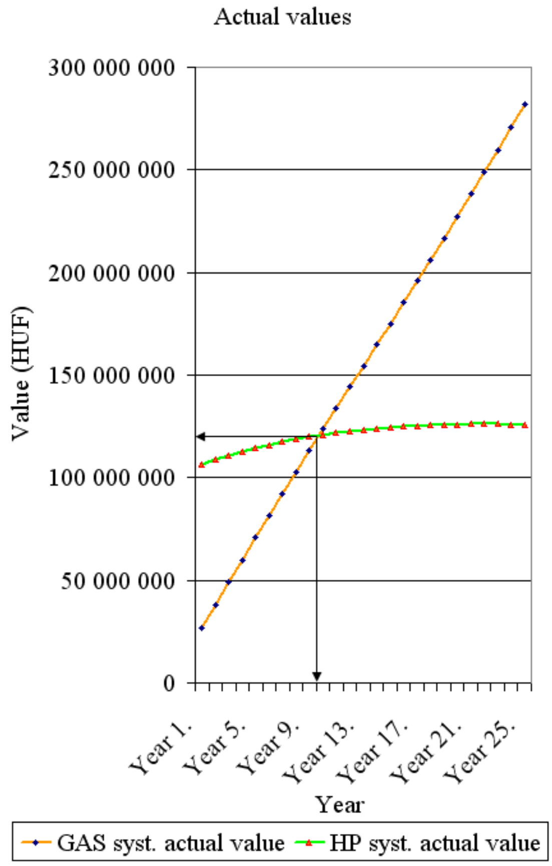
Table 7: Basic data for background calculation

Basic data for background calculation	High-capacity system
Specific commercial value HUF/kW	168,012
Output (kW)	619
Investment costs (HUF)	103,999,428
Electrical energy price (HUF/kW)	25
Electrical energy price increase	4.00 %
Gas price (Ft/m3)	100
Gas price increase	8.00 %
Bank interest	5.00 %
Heat pump COP	4.00
Boiler efficiency	102.00 %
Boiler investment costs (HUF)	15,000,000

Figure 21 shows, if we do not consider the return on financial investment, the payback period is 10 years. If we take the expected return on investment into consideration, then the payback period of the heat pump investment increases to 11.5 years.



12: Costs for 25 years: heat pump-gas



13: Actual values

Figure 22 shows the connection between the actual value calculation of the heat pump and gas boiler system. Actual value is in case of both systems the investment sum of money that is necessary to be available for covering investment and operation costs until the year indicated on time scale.

On this basis, the actual value concerning the heat pump amounts to about 120 million HUF for 11 years that will not be significantly changed projected for 25 years, while in case of gas boiler the actual value of the system is continuously increasing from the 11th year in same extent. Until the end of the 25th year the actual value of the gas boiler system shall increase to 280 million HUF.

It can be stated that the high-capacity BHE heat pump systems are cost efficient and sustainable, especially if they are operating for meeting heating-cooling demands of balanced output.

In the thesis I have already presented how the currently operating heat pump capacity is affected by the measuring, 20% oversizing and modelling errors of primary side of BHE heat pump systems projected to the potential non-recurrent investment costs. This amounts to 320 million HUF.

The additional operating costs of additional boreholes are as follows:

When calculating 80,000 m additional borings I based on simple borehole, Ø40, with 100m bore length, with 25 vol% of glycol solution. The average pressure difference of the systems at distributor amounts to 30-35 kPa. Volume flow rate of antifreeze solution circulating in one borehole is: 1,200 l/h.

I consider the additional boring in the calculation as 800 pcs simple boreholes. The volume flow rate of the antifreeze solution circulating in the 800 pcs of simple boreholes is:

$$\dot{V} = 800 \times 1200 \, {}^{l}\!/_{h} = 960 \, {}^{m^3}\!/_{h} = 0{,}26\dot{6} \, {}^{m^3}\!/_{s} \qquad (4)$$

I fixed the average efficiency of the circulation pumps at $\eta = 0{,}6$. Calculated with these values, the "excess" pumping output is:

$$P = \frac{\dot{V} \times \Delta p}{\eta} = \frac{0{,}266 \times 35000}{0{,}6} = 15.554W = 15{,}554kW \qquad (5)$$

This pumping output should be granted for 2,000 hours that means $2000h \times 15{,}554kW = 31.108kWh$ electricity energy. This amount of energy means annually about HUF 1.5 million calculated with 48 HUF/kWh public electric current tariffs and annually about HUF 1 million calculated with GEO tariff.

Projected to 25 years, these costs mean HUF 25 million calculated with GEO tariff and HUF 37.5 million calculated with public tariff. **Consequently, the oversizing results in excess investment and operation costs amounting to totally about HUF 357.5 million.**

On the other hand, due to undersizing and other engineering designing and modelling defaults and faults the annual operating costs of BHE system amount to HUF 7 billion for the present built-in capacity, i.e. about 20 times higher than the affect of oversizing.

Considering the planned development of the heat pump market until 2020 and the 24-fold increase of the built-in capacity we count on additional electrical energy costs amounting to HUF 168 billion until 2020! This is why the proposed national thermal conductivity measuring program, the databank and mapping are of greatest importance, even combined with tendered state subvention.

3.6 Environment protection advantages of BHE heat pump systems

My thesis studies the environment protection advantages exclusively of the electromotor-driven BHE heat pump systems.

For starting let's see some terms for calculation:

- My study involves exclusively new investments
- The comparison shall exclusively be made with gas condensing boiler alternative
- I calculate with the average national electric power reactor's efficiency and transport loss
- Taken low secondary temperature difference (35/30) into consideration
- I calculate with the national expectable SPF value of 4.0 of the BHE system

Economy calculation of heat pumps and gas boilers

When determining the heat centres of newly built properties respectively when modernizing the heat centres of existing buildings we always ask if "it was worth" to install heat pump.

The question can be checked from several points of view. I will explore the question from three aspects as follows:

- In what case is the heat pump energy effective?
- In what case is the heat pump ecologically beneficial?
- In what case is the heat pump cost efficient?

During my study I based on the following formula, especially the value of CO_2 quantity discharging during the production of per unit consumed energy and transporting to consumer's site, considering the Hungarian structure of central power stations:

$$CO_{2,finalenergy} = 0{,}56 kg / kWh \quad (6)$$

A) In what case is the heat pump system energetically efficient?

Energetically the heat pump system can be considered as advantageous if its figure of merit is higher than the efficiency generated during the electrical energy production and transport. Taking the capabilities of the Hungarian power generation network into consideration, considering 32.3 % as central power station efficiency and 10 % as network loss (Source: Energy-Statistics Almanac, 2006), it means mathematically formulated:

$$SPF_{crit,en} \geq \frac{1}{\eta_{powerstation} \times \eta_{network}}$$

$$\frac{1}{\eta_{powerstation} \times \eta_{network}} = \frac{1}{0{,}323 \times 0{,}9} = 3{,}44 \quad (7)$$

$$SPF_{crit,en} \geq 3{,}44$$

It means, that the heat pump systems operating with a better efficiency than the value of $SPF_{crit,en}$ can be considered as energetically efficient systems.

B) In what case is the heat pump system ecologically beneficial?

The heat pump system is ecologically beneficial if it releases less gas of greenhouse effect (CO_2) during the operation than the traditional calorific system of equal heat output.

The quantity of carbon dioxide generated by the heat pump system is the difference between the carbon dioxide released by the generated fossil firing equipment and carbon dioxide emitted to production of electrical energy consumed during the operation of the heat pump. I remark that if the electrical energy consumed by the heat pump will be utilized from local, autonomous renewable energy production systems then it is possible to establish even CO_2-neutral heat pump systems.

When calculating we need to see that the heat pump system produces heating energy by utilizing electrical energy. The heat pump systems are characterized by the quotient of these two energies as figure of merit. Considering this value on a certain interval (between A and B date) we receive the SPF value.

$$SPF_{A-B} = \frac{Produced\_energy_{A-B}\_(kWh)}{Consumed\_energy_{A-B}\_(kWh)} \qquad (8)$$

I made the calculation for a geothermal heat exchanger system with figure of merit of: SPF=4.0. As the quotient of the carbon dioxide quantity released upon production and transport of electric energy consumed by the heat pump respectively of the figure of merit of the heat pump system it will be resulted how many carbon dioxide has been released during the production of per unit heating energy:

$$e_{HP} = \frac{0{,}56(kg_{CO_2} / kWh_{el})}{4{,}0(kWh_{hö} / kWh_{el})} = 0{,}14(kg_{CO_2} / kWh_{hö}) \qquad (9)$$

This value has to be calculated also for gas boilers. The EU-conform specific natural gas consumption indexes corrected according to the Hungarian conditions are in case of traditional and condensing gas boilers:

$g'_{hk}=1.1765$; $g'_{kk}=1.02$.

Making use of the Hungarian H-natural gas heating value: 9.44 kWh/m^3, we receive the following specific demands on natural gas (r_x):

r_{hk}= 0.125 m^3/kWh; r_{kk}= 0.104 m^3/kWh.

With knowledge of these data we can calculate the specific CO_2-emission of gas boilers, considering that 2.1 kg CO^2 is released upon combustion of 1 m_3 natural gas:

$$e_{hk}= 2.1\ [kg\ CO_2/m^3] \times r_{hk} = 2.1 \times 0.125 = 0.263\ [kg\ CO_2/kWh] \qquad (10)$$
$$e_{hk}= 2.1\ [kg\ CO_2/m^3] \times r_{hk} = 2.1 \times 0.104 = 0.218\ [kg\ CO_2/kWh] \qquad (11)$$

Thus, the saving rate of CO_2-emission is with heat pump system:

- In case of traditional gas boiler: $\Delta e_{hk}=e_{hk}-e_{HP}=0.263-0.14=0.123$ [kg CO_2/kWh] (12)
- In case of condensing gas boiler: $\Delta e_{hk}=e_{hk}-e_{HP}=0.263-0.14=0.123$ [kg CO_2/kWh] (13)

Thus, in case of heating with heat pump an emission reduction of 0.078-0.123 [kg CO_2/kWh] is expected.

When using the heat pump system not exclusively for heating but also for cooling, this comparison has to be made between the heat pump and the traditional air conditioner. Based on a heating figure of merit of EER=3.5 in case of heating operation, furthermore on a value of 1.3 for the air conditioner we can state the following CO_2-saving for the benefit of the heat pump:

$$\Delta e_{cooling}=e_{lk}-e_{HP}=(0.560/1.3) - (0.560/3.5) = 0.271 \text{ [kg } CO_2/m^3] \quad (14)$$

It can be seen that the heat pump system resulted in CO_2-saving based on figures of merit compared to the traditional system. The question is that what extent it is true, i.e. in what case a heat pump system is ecologically beneficial?

The CO_2-saving has been calculated by the following formula:

$$\Delta e_{cooling}=e_{hp}-e_{hk}=(CO_{2,\text{final energy}}/SPF)-e_{hk} \quad (15)$$

the value $\Delta e_{heating}=0$ assumed and the equation arranged for SPF value the result is:

$$SPF_{crit,env,tb}=CO_{2,\text{final energy}}/e_k \quad (16)$$

Replacing the values received, the critical SPF values with the traditional boiler and against the condensing boiler:

$$\mathbf{SPF_{crit,env,tb}=CO_{2,final\ energy}/e_{tb}=0.56/0.263=2.13} \quad (17)$$

$$\mathbf{SPF_{crit,env,cb}=CO_{2,final\ energy}/e_{cb}=0.56/0.218=2.57} \quad (18)$$

SPF value above this value can be considered as effective from environment protection considerations.

A) In what case is the heat pump system economically efficient?

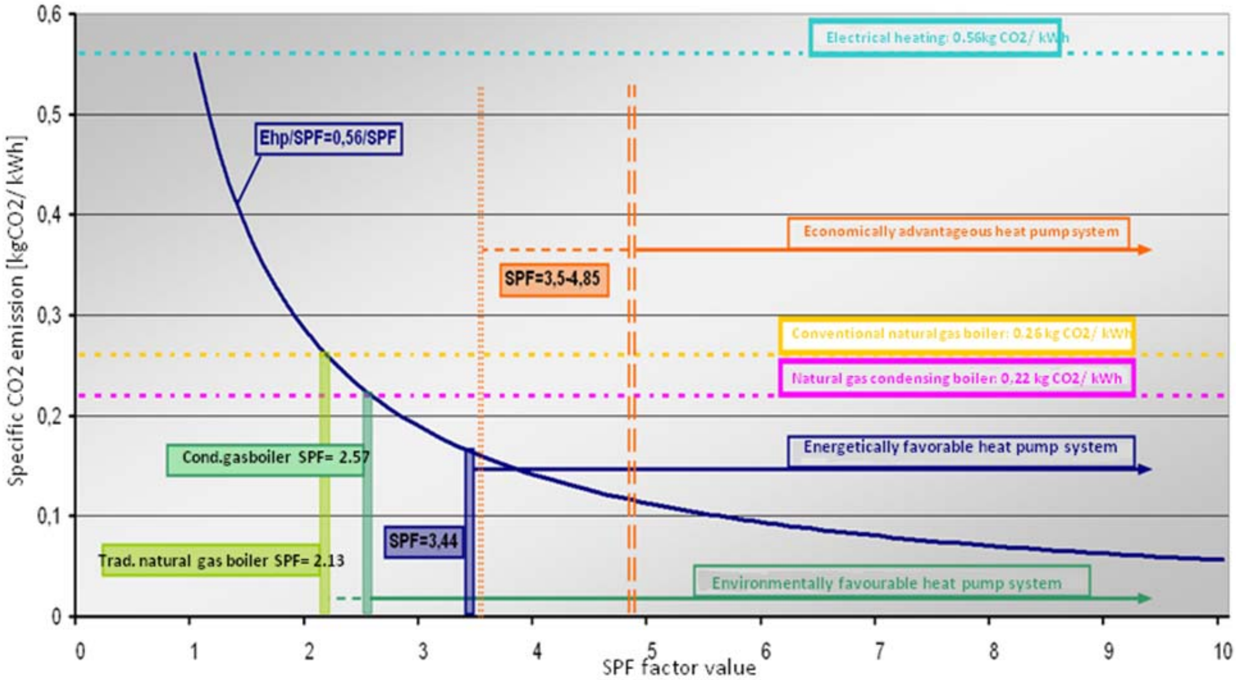
This question can be determined the least exactly. The $SPF_{crit,econ.}$ value ensuring the economic return depends in great extent on the type of heat pump technology (air, soil sample, water well, soil collector, energy piles, etc.), on the character of utilization (continuous or periodic, heating, cooling or both, etc.), on the character of installation (new establishment or renewal, discharging, reconstruction of the old system), on capital requirements, changes in energy prices, etc. In concrete knowledge of these parameters we can only state if the related heat pump investment could be considered as economically effective.

In case of summer-winter continuous operation of heat pumps the scientific literature estimates the **$SPF_{crit,econ.}$ value to 4.0.**

It is to mention that in case of having granted the appropriate subvention structure, the otherwise energetically and environmentally efficient investment can be made economically more reversionary, i.e. the $SPF_{crit,econ}$ value decreases in case of subvention.

Considering a concrete investment, the heat pump investment of Telenor House can be considered as economically efficient even with its SPF=3.576 value. According to analysing the experiences and calculations the payback period of the investment is 5.60 years.

The different efficiencies are shown by the diagram of the figure 23:



14: Dependence of carbon dioxide emission on SPF factor and the connection with efficiency

The dark blue curve means the CO_2-emission of the heat pump system that by improving the SPF value decreases in inverse proportion.

The CO_2-emission of the traditional and condensing gas boiler is marked with pink and yellow coloured broken line. These are straight and the points of intersection of the heat pump curve show the limit of the economically beneficial heat pump system.

3.7 Future possibilities, expectable improvement of BHE heat pump systems

To ensure the undisturbed development the regulated and qualitative controlled heat pump market should be created.

Therefore the geological measurements, modelling should be generally accepted.

In geosciences education institutions the analysis of geothermal BHE heat pump systems, expected to become a general heating possibility, should be managed as key topic of education and research.

For basis of the reliably sustainable BHE systems serve the previous measurement and designing, modelling then finally the continuous monitoring.

As a result thereof and considering also the government subvention policy, it may happen until 2020 that the number of heat pump installations amounts to annually 5,000 to 10,000 units.

4 NEW SCIENTIFIC RESULTS

1. I proved that the geothermal statements of Rybach and Eugster concerning the sustainability of heat pump systems can also be applied under the geological conditions of Hungary. If BHE (VERTICAL GEOTHERMAL HEAT EXCHANGER) geothermal heat exchanger system is utilized for heating, it will result in gradual cooling of the near-surface rock environment similar to reservoir cooling of super deep geothermal systems and will require at least the same regeneration time as of the heating hours until returning to 95% of in situ temperature. If the establishment is designed and used also for heating, we receive, on geological thermal side, a seasonally regenerative system and the SPF value will improve due to small winter-summer temperature changes, reducing the operation costs. But it would also reduce the investment costs. By utilizing waste heat (i.e. that generated by gas-driven generators), to its extent the total borehole length (heat exchanger surface) can be reduced by even 70-80 %. The additional heat of solar collector systems can also be an energy source but in this case the borehole length is unlikely to be reduced by more than 20-25 % even in case of correct sizing.
2. I proved that in case of heating-cooling system connected to BHE consisting of big borehole fields the winter cooling was resulted in temperature reduction of 5-6°C - in average, as to my measures, 5.74°C - directly close to geothermal heat exchangers operating in 100 m deep. In case of summer cooling the temperature increase was 4-4.5ºC - at my measurement calculated for the total length 4.3°C. When heating, in a distance of 3.5 m from the centre-line of the operating borehole the temperature decrease was only 0.2-0.3ºC, and as to my measures in average 0.28ºC. When cooling, the input heat resulted in insignificant warming of the rocks in same distance, and as to my measures in average 0.08ºC. At measuring point placed 6.6 m from the geothermal heat exchanger field there were no changes observed in temperature in comparison to normal state. As conclusion I stated that it is practical to fix the installation distance of the boreholes in 7.0 m to each other in the borehole field close to the successive layers of average thermal conductivity (it is of special importance in case of a great number of boreholes of raster arrangement). In case of good heat conduction and single-line borehole arrangement the distance of boreholes can be reduced to 5 m.
3. I proved by means of measurements and then by modelling that the arrangement of the borehole field (average distance) influences the SPF (SEASONAL PERFORMANCE

FACTOR) compared to the heat pump. SPF value decreases due to the additional pumping energy demand for larger distance and heat loss. We proved by means of modelling the value of SPF reduction may amount to 10-25% depending on actual boundary conditions.

4. I proved that undersizing has significant influence on the operation costs of BHE heat pump systems, since in this case the costs originating from the additional heating demand are greater than the investment costs originating from the oversized additional borehole length. I proved by calculations that the negative economic effect of a 20% oversizing is 20 times smaller than the later additional costs of electrical energy originating from 20% undersizing.
5. I proved that it is practical to place 3 pcs of monitoring boreholes in the mid and on border of raster-block borehole fields. Furthermore the monitoring temperature meters should be installed - vertically - in the boreholes, in places of the current successive layer of relevant thermal conductivity. Their number will be determined by the quantity of such places. On basis of arrangement according to this principle we can get more reliable data for determining the extent of positive heat conduction anomalies than at monitoring points determined randomly horizontally. The costs of vertical monitoring system are also lower.
6. I proved that in addition to definite geological conditions and measuring intensity a "heat conduction map" can be prepared for BHE systems by adopting the databank created on basis of heat conduction factors. Thus, the "designing of geothermal heat utilization" for smaller systems becomes more reasonably in knowledge of the geological data, without TRT (THERMAL RESPONSE TEST) measurements. In case of large systems, when detecting of possible local anomalies, it could not however replace performing of local TRT measurements at all.

   By means of country-wide BHE heat conduction measurement program and mapping the installation locations can be qualified in both environmental and technical aspects. Thus:

   a. To be installed unconditionally
   b. To be installed on conditions
   c. No installation possible, protected area, reservoir, cave groups can be established.

5 CONCLUSIONS AND PROPOSALS

- For tender-dependent investments the performance of TRT measurements and modelling should be obligatory above 30 kW.
- Development of TRT measuring devices is recommended for reducing measuring costs.
- In case of sanitary engineering data delivery the modelling of the annual heat demand curve should be obligatory concerning heating and cooling for heat pump.
- I recommend creating a MAFI-ELGI-VITUKI data set involving catharometer data.
- It is practical to launch a country-wide catharometry program for uploading the data set.
- Collection of catharometer data from previous geological exploratory boreholes and integration those in data set.
- Publication of information about water bodies and cave protecting zones concerning national shallow zones for establishing boring plans.
- Simplification of heat pump licensing by means of e-administration, application of standardized plans for low-capacity BHE systems with less than 30 kW.
- Introduction of duty of registration concerning the installation of heat exchangers (soil collector, soil probe, radial probe, energy spiral, energy bucket) used in shallow zones higher than 20 m in order to avoid harmful interference of heat exchanger systems.
- Performing further comparative TRT measurements depending on borehole sizes, probe-pairs and types of grouting material for their effective and cost effective utilization.

6 SUMMARY

Thermal conditions of geothermal heat exchangers in case of heat pump systems

The Hungarian heat pump technology became known for both public and professionals in the past 10 years. I have, however, to say that it is still not enough well-known.

During my work, beginning from the low-capacity BHE systems reaching also the high production until 2005, I was motivated by realizing a well-established designing process of the geological primary side of BHE systems. To realize it, I observed and studied the international research results and practice right from beginning and learnt from the Western European experiences.

To realize all these I was considerably supported by Prof. Dr. Laszlo Rybach with his personal upholding and providing specialized literature and promoting the practical introduction of the preparatory measurements and modelling of the domestic BHE systems in Hungary by this means.

Nowadays, measurement of the domestic BHE heat pump systems became a recognized and demanded scientific task. Its beauty lies in fact that we never meet again the same terms and conditions. It means, we have always to adapt ourselves to the challenges of the related project, which always requires creativity. Hereby I have to mention that the efficiency and cost efficiency so to say the success of heat pump systems depends always on the automatic good cooperation of several specializations such as: architecture, sanitary engineering, geology and drilling engineering. None of them can replace the others!

The development of the domestic heat pump systems was and is promoted by university research centres such as Geothermal Engineering specialists training on University of Miskolc managed by Prof. Dr. Elemer Bobok, the heat pump professional trainings and master courses organized by Prof. Dr. Gergely Buki and engineering specialists trainings managed by Dr. Istvan Barotfi and Dr. Laszlo Toth university professors; they all helped me during my work.

Luckily for me, my work was also helped and supported by young professionals committed to this profession such as my former subordinate, Laszlo Toth geologist, or some of my present colleagues, Zsuzsa Csernoczki environment researcher, Bernadett Klecsko hydrogeologist engineer and Zoltan Lipoczky sanitary engineer.

I think the first and important stage of recognizing and making the vertical geothermal heat pump systems general in Hungary has been completed. Both the academic players and administration interested in energy policy are aware of the possibilities of this technology.

I hope the coming next 10 years will mean further successful period in the Hungarian heat pump process for achieving the set goals (realization of 6 PJ geothermal heat pump capacity by 2020). At the same time, the country-wide measuring and mapping program proposed by me will scientifically support that we are in possession of much higher geothermal heat utilization possibility than the estimated 10 to 13 PJ. Its utilization is indispensable for achieving our long-term gas energy replacing goals.

As one of the representatives of the domestic heat pump special field I would like to express my thanks to all of you who helped the process of heat pump development with their well-meaning support and assistance respectively work.

7 IMPORTANT PUBLICATIONS RELATED TO SCOPE OF THE THESIS

Own publications in foreign language:

1. Tóth L., Šlihte, S., Ádám B., Petróczki K., Korzenszky, P., Gergely Z.: 2011 Solar Assisted Ground Source Heat Pump System, in Hungarian Agricultural Engineering, N°23/2011, Hungarian Institute of Agricultural Engineering, Gödöllő, 57-62.p.
2. Ádám B., Tóth L.: 2011 Heat Recovery From Thermal Waters Used For Heating By Heat Pump Before Back-Injection, in Hungarian Agricultural Engineering, N°23/2011, Hungarian Institute of Agricultural Engineering, Gödöllő, 67-72.p.
3. Ádám, B.-Tóth, L.: 2012 Heat Technical Measuring of Ground for Vertical Borehole Heat Exchangers Installations, in Journal of Agricultural Machinery Science, 2012, Turkey (in press under review)

Own publications in Hungarian:

1. Ádám B.- Tóth L.: 2011 Geotechnical Inspection of Ground for Vertical Borehole Heat Exchangers Installations, HUNGARIAN ENERGETICS, No. 5, 34-38 pp ISSN: 1216-8599
2. Ádám B. - Tóth L. (2011): Data for Installation of Shallow Borehole Heat Pump Systems in Hungary - New Items in Geothermic, Vol. 1. Periodical Publication of Geothermal Coordination and Innovation Foundation, ed: Szanyi J., 5-17 p.
3. Tóth L. - Ádám B.: 2010 Data for Installation of Shallow Borehole Heat Pump Systems in Hungary -Agricultural Technique, Godollo, Vol.51. No. 8 2-5p. ISSN 0026 1890
4. Tóth L. Ádám B. Csernóczki Zs.: 2011 Data for Installation of Trigeneration Heat Pump Systems - Agricultural Technique, Godollo, Vol. 52. No. 2 2-4p. ISSN 0026 1890
5. Ádám B.- Tóth L.: 2010 Heat Pumping of Thermal Waters Used for Heating Prior to Repressing, Agricultural Technique, Godollo, Vol. 52. No. 6 2-5p. ISSN 0026 1890
6. Ádám B.: 2009 Implemented Heat Pump Systems Utilizing Geothermal Heat and other National practical Experiences, Hungarian Sanitary Engineering Vol.LVII, 2008/4. 19-21.p.

8 MY R+D WORKS RELATED TO THE TOPIC

Period	Research, study task	Name of the institution:	Locations	Partner
2010	Connection of Gas Turbine Current Generation and Geothermal Heat Utilization for Monitoring and Energy Rationalization	Tesco Hypermarket	XVII. Budapest	InnoGeo Research and Services Nonprofit Public Ltd.
2010	Optimalization of geothermal heat utilization for buildings of public institutions	Bálint Márton School and Sport centre	Torokbalint	Swietelsky Hungary Ltd. by Shares
2010	Optimization of geothermal heat for local government building	Szeged-Agora-Polus	Szeged	Szeged Local Government
2009	Designing of measuring labour audited for Bosch heat pumps	Bosch Office Building	X. Budapest	Dimenzio Designing Ltd.
2008	Geophysical test (for BHE)	Warehouse building of Kovacs Ltd.	Mezokovesd	Kovacs Ltd.
2008	Monitoring of BHE system installed under building	El-Tech Center Kft. Office Building	IV. Budapest	El-Tech Center Ltd.
2008	Monitoring of water well under deep garage for heat pump installation	Corvin promenade project 119/A and 119/B	VIII. Budapest	Cordia Hungary Ltd by Shares
2008	Geothermal TRT (Thermal Response Test)	Europrint Warehouse	Eger	Europrint Ltd.
2008	Optimization of geothermal heat exchanger system	Unitef Office Building	XI. Budapest	Unitef 83 Zrt.
2008	Heat pump supply of heating-cooling air handling system	Porsche Motors	XI. Budapest	Porsche Real Estate Ltd.
2008	Monitoring of water wells under deep garage (connected to heat pump)	Strabag Office Building	IX. Budapest	Miskolc Shoppig Center Ltd.
2007	Central heating supply of the business park (several buildings) with heat pumps, monitoring (TRT)	Europolis real estate	Biatorbagy	Terminal Mid-Eurpean Real Estate-Development Ltd.