PROCEEDINGS, 46th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 15-17, 2021
SGP-TR-218

Teaching and Research with Borehole Heat Exchange Systems in Krakow (Poland) and Oshawa (Canada)

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Keywords: geothermal energy, borehole thermal energy storage, thermal response test, borehole heat exchanger, geothermal heat pump, geoenergetics, geothermal heating and cooling

ABSTRACT

The authors describe teaching and research activities related to two borehole heat exchange systems that form parts of ground energy systems at two universities: AGH University of Science and Technology in Krakow, Poland and Ontario Tech University (formerly University of Ontario Institute of Technology) in Oshawa, Canada. The systems are utilized in research as well as heating/cooling systems with geothermal heat pumps. The applications of borehole thermal energy storages are increasing. In Oshawa, there exists a borehole field containing 384 drilled borehole heat exchangers. Each borehole has a depth of 213 m. Altogether, the drilled system length is more than 81 km. In Krakow, the system consists of 19 borehole heat exchangers with smaller depths (78-84.5 m), but each has a different construction. The variables are: pipe diameter, pipe thickness, number of pipes in a well, pipe turbulisation system, pipe length and location in the well, and grout. The borehole heat exchangers are part of the Geoenergetics Laboratory.

More than ten years of operation have provided many experiences with these systems. These experiences cover the areas of operation, research and teaching. In Krakow, a post-diploma program exists on the study of Geoenergetics and Geoengineering. In 2019, a new specialisation on Geoengineering and Geothermics commenced in the field of Mining and Geology Engineering. Many theses have been prepared based on data from Geoenergetics Laboratory and other geothermal installations in Poland.

In Oshawa, research has been carried out on borehole heat exchangers and the heat transfer within and around them, the integration of ground source heat pumps with borehole fields, the behaviour of building energy systems using these technologies, and the heat storage capacity of borehole heat exchanger fields.

1. INTRODUCTION

Currently, renewable sources, including geothermal energy, are becoming increasingly important in the energy sector (including heat engineering). This type of energy can be made available through boreholes. Geothermal energy can be divided into two main types: low-temperature and high-temperature.

According to Haenel et al. (1988), conduction is responsible for thermal energy movement in the shallower part of the Earth's lithosphere, to a depth of 20-40 km. The main source of Earth’s thermal energy (over 80%) is the continuously produced thermal energy resulting from the decay of natural radioactive elements contained in rocks. From the perspective of heat exploitation, the most interesting geothermal areas are related to igneous zones in seismically active areas. They are usually located on the edges of tectonic plates, where the temperature can reach high values even at shallow depths. The most important anomalies, located in seismic zones, occur in continental areas, and are observed in the western part of the United States, in the Philippines, Japan, New Zealand, Iceland, Italy and in Central America (Bauer et al. 2014, Śliwa et al. 2017). On a global scale, the largest usage of geothermal energy in terms of installed power and heat consumption in direct applications has been recorded for space heating (using the heat of water extracted from deep wells and heat pumps linked to borehole heat exchangers).

Nevertheless, the use of geothermal energy, especially of the low-temperature type, is becoming increasingly common, e.g. in Poland and Canada. Shallow geothermal energy has been considered for a long time (Crandall 1946, Kemler 1947, Ingersoll 1950, Sliwa 1996, Sliwa 1998, Rosen and Koohi-Fayegh 2017). Most commonly, the energy from these systems is obtained using borehole heat exchangers. Such options are available to both individual and industrial users, and can be performed with any lithology (Śliwa et al. 2016, Bertani 2009). Energy piles are a similar option, which is currently under development (Koene et al. 2000, Vasilescu 2019, Schröder and Hanschke 2003, Brandl 2006). Borehole heat exchangers enable heat supply to both large facilities, such as shopping centres, and small ones, e.g. single-family houses, which enhance their multidimensional operational ability. Such facilities are often integrated with district energy systems (Rosen and Koohi-Fayegh 2016) and energy storage (Rosen 2012, Koohi-Fayegh and Rosen 2020). As of the end of 2018, the number of ground source heat pumps (from 10 to 200 kW) in Poland is estimated to be over 56,000. Their total capacity exceeds 650 MWt and their heat production is about 3100 TJ/year (Kępińska 2020).

LABORATORY INSTALLATIONS WITH BOREHOLE HEAT EXCHANGERS

Underground thermal energy storage (UTES) is becoming an increasingly popular technology for maintaining thermal comfort in residential and commercial buildings. Most UTESs are based on borehole heat exchangers (BHEs), which can be used for heating and air conditioning of building interiors. The largest existing installations have over 1000 BHEs. One such example is the system of Ball State University, Indiana, USA (Lund et al. 2010), for which the BHE field distribution is shown in Figure 1. This installation has BHE depths ranging from 122 to 152 m.

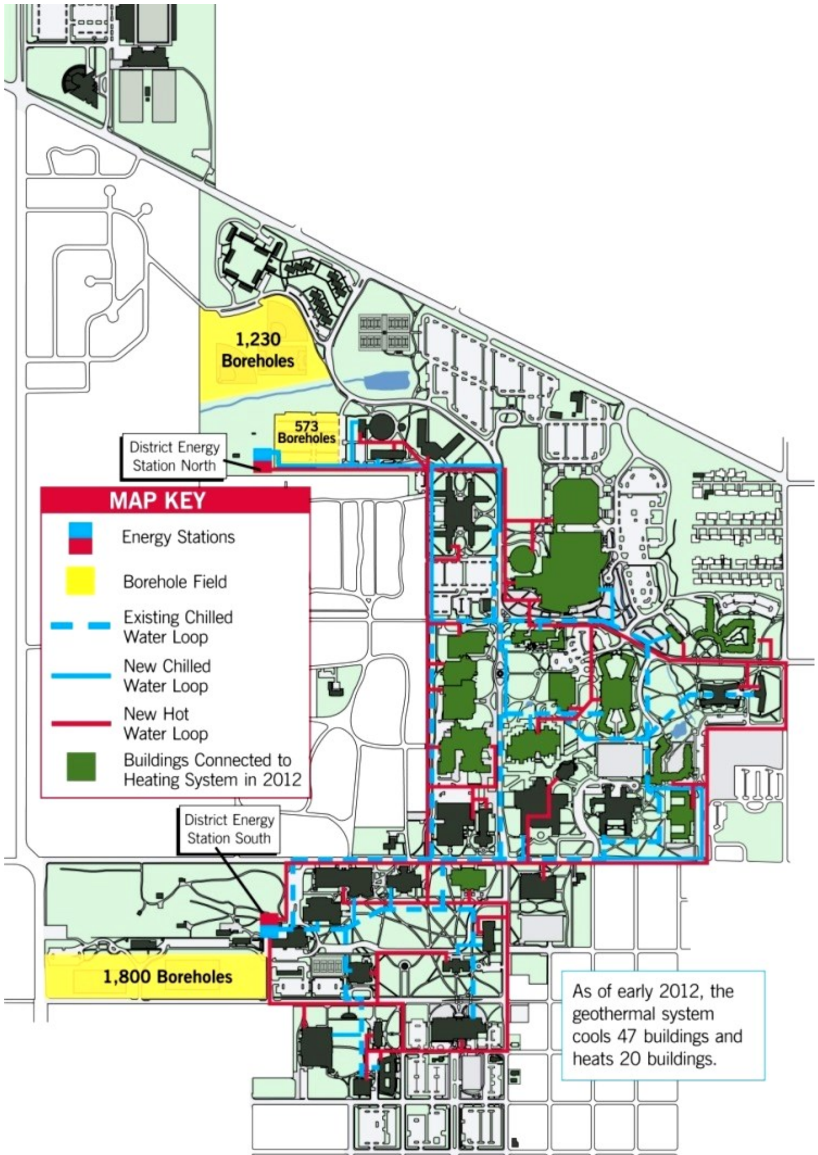


Figure 1. UTES at Ball State University, Indiana, USA, showing BHE field and pipeline map (cms.bsu.edu).

The growing interest regarding BHE favours the intensification of research and the development of advanced systems in this area. Some BHE systems for heating or both heating and cooling are installed in universities and government facilities for operational, demonstrational and research purposes. These include the Ball State University system, as well as:

a) Technical University of Ostrava (VSB) (Czech Republic). The borehole heat exchanger system at this university is shown on Figure 2 and described by Bujok et al. (2012),

b) Luleå University of Technology, Luleå (Sweden). This university has the first major borehole heat exchanger system, installed in 1982-83 (Nordell 1994),

c) University of Ontario Institute of Technology, Oshawa (Canada). This system is shown on Figure 3 and described by Koohi-Fayegh and Rosen (2012),

d) AGH University of Science and Technology in Krakow, Faculty of Drilling, Oil and Gas, Department of Drilling and Geoengineering. The locations of the borehole heat exchangers are shown in Figure 4 and described by Śliwa and Gonet (2011).

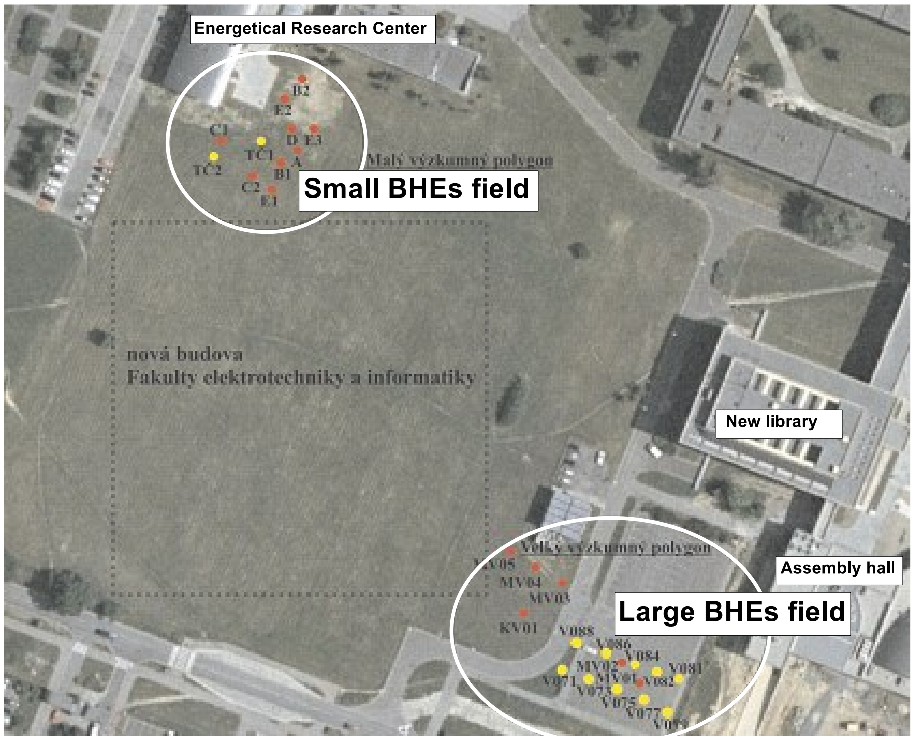


Figure 2. Boreholes and test wells at the TU in Ostrava (VSB) (Bujok et al. 2012). Borehole heat exchangers are marked as yellow dots and test wells as red dots.

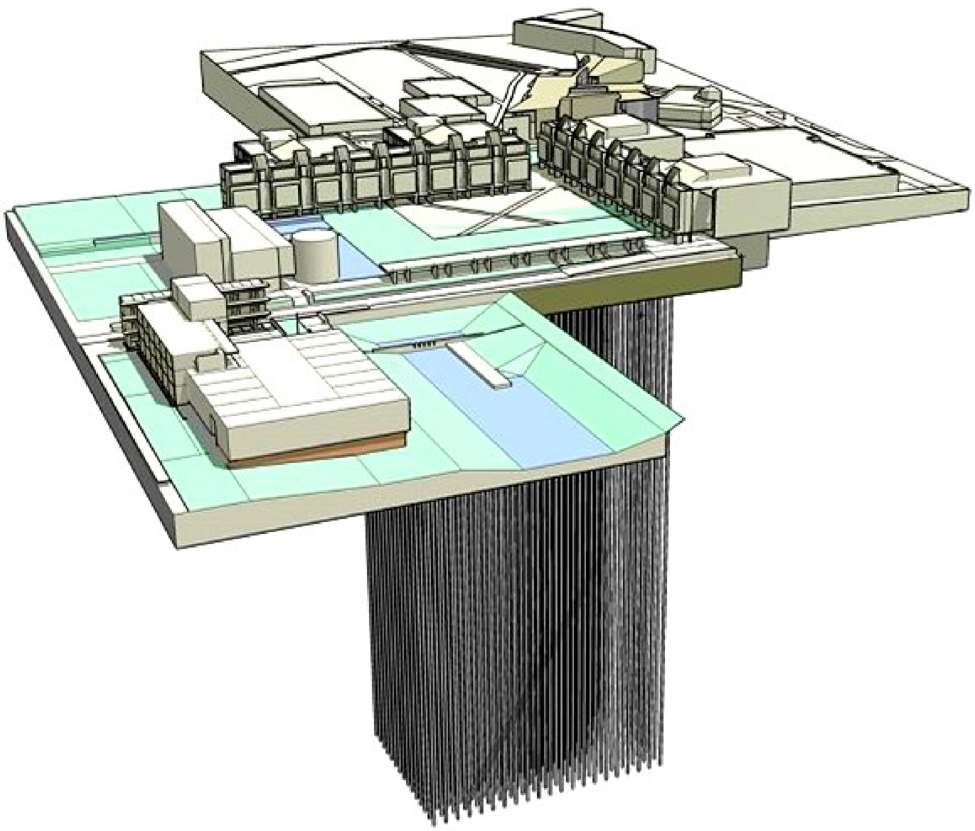


Figure 3. Thermal energy storage system in the rock mass under university buildings of the University of Ontario Institute of Technology (engineering.uoit.ca).

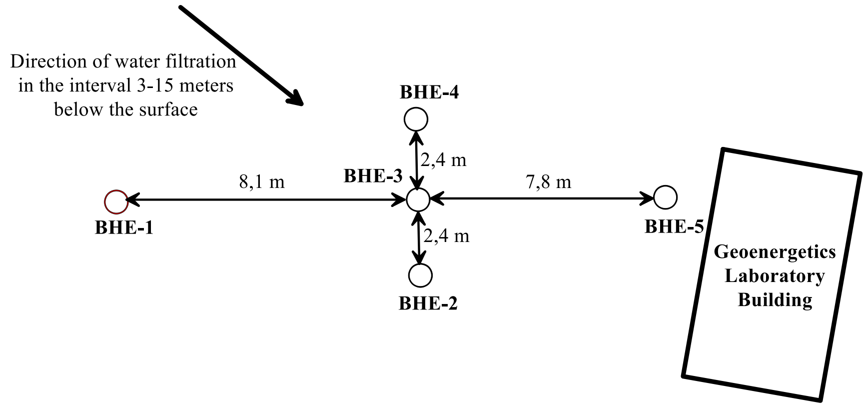


Figure 4. Borehole field layout in the Geoenergetics Laboratory, Faculty of Drilling, Oil and Gas, AGH UST in Krakow. BHE-1 is a coaxial system, BHE-2, BHE-3 and BHE-4 are wells with a single U-tube design and different sealing materials, and BHE-5 is a double U-tube design (Sliwa and Gonet 2011).

While single or multiple shallow borehole heat exchangers (<200 m deep) are often used for heating (and/or cooling) in conjunction with a heat pump, deep borehole heat exchangers (up to several kilometres deep) produce temperatures high enough for direct use and are able to heat several buildings and sometimes districts, depending on the depth, diameter and flow rate of the heat carrier (Mottaghy and Dijkshoorn 2012).

2. TEACHING AND RESEARCH OF BOREHOLE HEAT EXCHANGE SYSTEMS IN KRAKOW (POLAND)

Actions taken at the Faculty of Drilling, Oil and Gas of the AGH UST in Krakow are a response to the increased interest in geothermal energy, and mainly borehole heat exchangers. The research team conducts wide-ranging activities in the field of geothermal energy, both in terms of research and education.

2.1 Establishment of the Geoenergetics Laboratory

The AGH Geoenergetics Laboratory was established in 2008 at the Faculty of Drilling, Oil and Gas of the AGH UST in Krakow, and from the beginning of its activity has been involved in a series of scientific research and specialized analyses in the field of geothermal energy, with particular emphasis on issues related to borehole heat exchangers.

As the beginning of the Geoenergetics Laboratory's activity, its creators launched three main initiatives, which include: the preparation and submission of a grant application for creation and testing of borehole heat exchangers (January 2007), the development and conduction of the first thermal response test (TRT) in Poland, which took place at the turn of 2007/2008, as well as the start of drilling boreholes to obtain the Earth's heat - borehole heat exchangers - at the AGH UST in 2008 (Figure 5).

Figure 5: Creation of borehole heat exchangers on the AGH UST premises.

At the field station near the Laboratory building (BHE Field A), five borehole heat exchangers of various designs are located (Table 1). The exchangers serve as a source of heat and cold for heating and air-conditioning of the auditorium in the Faculty building. The system is supported by solar collectors (Figure 6), from which the heat is stored in the rock mass. There are two heat pumps, 13 kW each, located in the Laboratory building.

Table 1: Designs of borehole heat exchangers (Field A) drilled in 2008 (Śliwa et al. 2016).

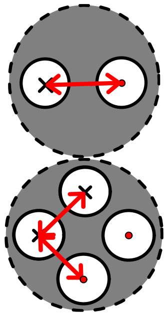
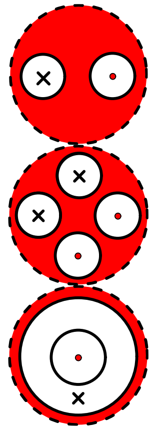
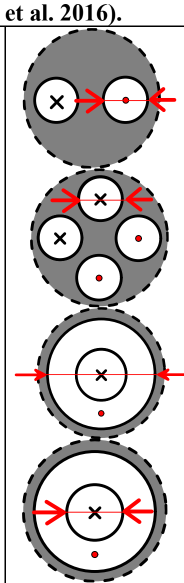
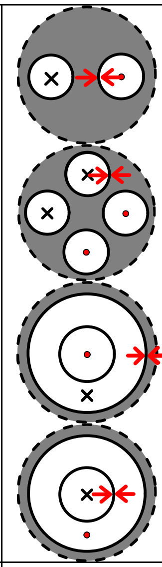
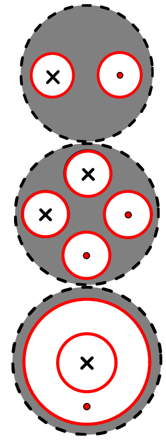
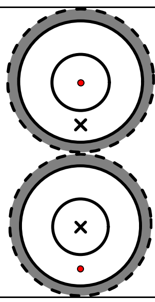
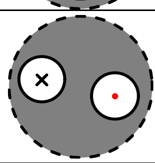
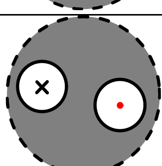
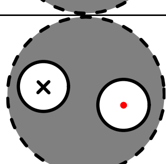
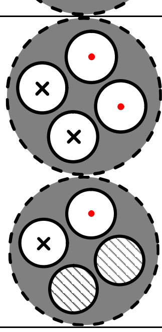
BHE No.	BHE Name	BHE construction and research possibilities	 Distance between tube axes, mm	 Filling material	 Outer pipe diameter, mm	 Pipe wall thickness, mm	 Pipe material
1	LG-1a		not applicable	Filling material based on cement, λ=1.2 W/(mK)	90 40	5.4 2.4	PE
2	LG-2a		70	Filling material based on cement, λ=1.2 W/(mK)	40	2.4	PE
3	LG-3a		70	Filling material (ThermoCem) based on cement with increased thermal conductivity, λ=2.0 W/(mK)	40	2.4	PE
4	LG-4a		70	Gravel with granulation from 8 to 16 mm and two clay cork – Compactonit, λ=1.8 W/(mK)	40	2.4	PE
5	LG-5a		64	Filling material based on cement, λ=1.2 W/(mK)	32	2.4	PE

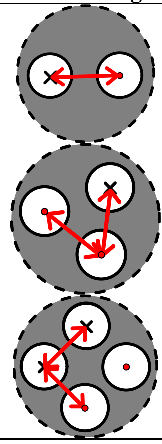
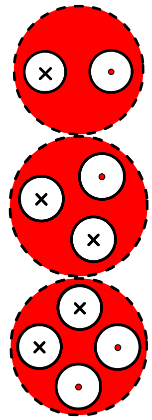
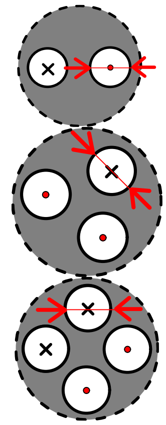
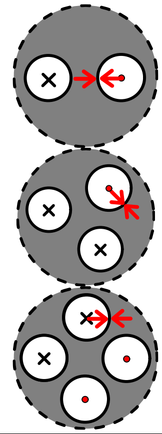
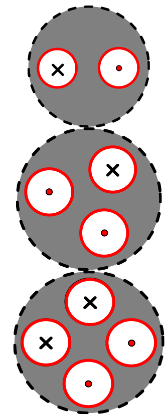
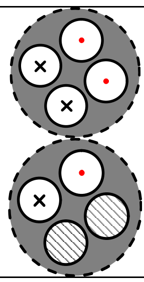
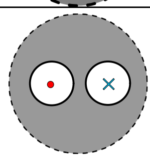
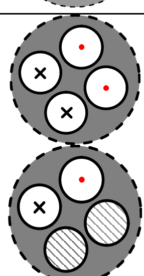
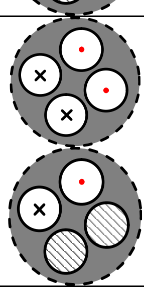
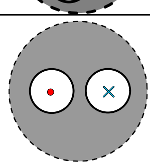
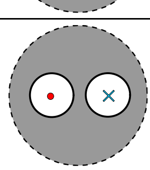
Figure 6: Solar collectors at the field station (Field A) and manhole flaps of BHEs in front of them.

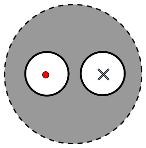
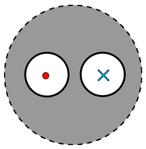
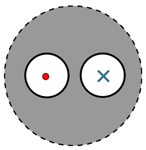
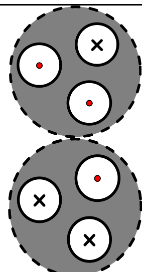
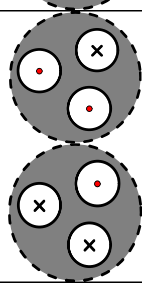
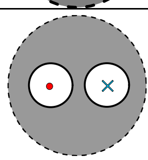
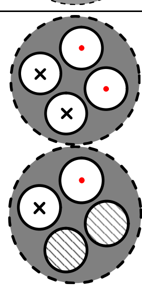
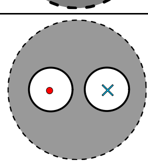
The Geoenergetics Laboratory is equipped with: TRT equipment, borehole heat exchangers, thermal conductivity equipment FOX 50, heat pumps that can provide two-directional heat flow (heating and cooling), heating power measuring station, a laboratory model of a coaxial BHE, NIMO-T for temperature profiling in BHEs, thermal camera and infrared thermometer, ultrasonic gauge for non-invasive measurements of fluid velocity (and volumetric flow rate), two humidity meters for solids, mini weather station, solar collectors of various kinds (5 pcs), parking lot snow-removal installation fed by heat sourced from the rock mass, borehole water level gauge, and specialist software: TOUGH 2.0 (Transport Of Unsaturated Groundwater and Heat), BoHEx (Borehole Heat Exchanger), EED (Earth Energy Designer), OZC auditor and others.

In 2017, at the AGH UST in Krakow, a borehole heat exchanger research field (Field B - Figure 7) was established, which includes fourteen vertical and oblique borehole heat exchangers of various designs (Table 2).

Figure 7: Drilling of new borehole heat exchangers at AGH UST in 2017 (Field B).

Table 2: Designs of borehole heat exchangers (Field B) drilled in 2017 (Śliwa et al. 2016).

BHE No.	BHE Name	BHE construction and research possibility	 Distance between tube axes, mm	 Filling material	 Outer pipe diameter, mm	 Pipe wall thickness, mm	 Pipe material
1	LG-1b		40	Sealing slurry with increased thermal conductivity (TermorotaS)	32	3.0	PE, smooth pipe
2	LG-2b		50	Sealing slurry with increased thermal conductivity (TermorotaS)	32	3.0	PE, turbocollector type pipe
3	LG-3b		40	Sealing slurry with increased thermal conductivity (TermorotaS)	32	3.0	PE, turbocollector type pipe
4	LG-4b		40	Sealing slurry with increased thermal conductivity (TermorotaS)	32	3.0	PE, turbocollector type pipe
5	LG-5b		50	Sealing slurry with increased thermal conductivity (TermorotaS)	40	3.0	PE, smooth pipe
6	LG-6b		50	Sealing slurry with increased thermal conductivity (TermorotaS)	40	3.0	PE, turbocollector type pipe

7	LG-7b		55	Sealing slurry with increased thermal conductivity (TermorotaS)	45	3.0	PE, turbocollector type pipe
8	LG-8b		40	Sealing slurry with increased thermal conductivity (TermorotaS)	32	3.0	PE, turbocollector type pipe
9	LG-9b		40	Sealing slurry with increased thermal conductivity (TermorotaS) in 0-20 m interval	32	2.9	PE, turbocollector type pipe
10	LG-10b		40	Sealing slurry with increased thermal conductivity (TermorotaS)	40	3.0	PE, turbocollector type pipe
11	LG-11b		40	Mortar	40	3.0	PE, turbocollector type pipe
12	LG-12b		40	Cement	32	2.9	PE, turbocollector type pipe
13	LG-13b		40	Sealing slurry with increased thermal conductivity (TermorotaS)	First U-tube: - φ32 – Turbocollector - φ40 – Turbocollector Second U-tube: - φ32 – smooth pipe - φ40 – smooth pipe	2.9 3.0 3.0 3.0	PE, turbocollector type pipe ad smooth pipe
14	LG-14b		40	Sealing slurry with increased thermal conductivity (TermorotaS) with graphite	32	2.9	PE, turbocollector type pipe

2.2 Research grants

The Geoenergetics Laboratory team is involved in numerous scientific activities, both in Poland and abroad. The most important present research activity is briefly described below (https://geotermia.agh.edu.pl/).

2.2.1 Innovation in Underground Thermal Energy Storages with Borehole Heat Exchangers (BHEsINNO)

This project is implemented as part of the POLNOR 2019 call program. The duration of the project is 36 months. The project is the result of cooperation between AGH, University of Stavanger and MuoviTech Polska Sp. z o.o.

Currently, Underground Thermal Energy Storage (UTES) is a particularly good way of providing thermal comfort in northern countries (e.g. Norway and Sweden) as well as in central and eastern Europe (e.g. Poland and Ukraine). The project “Innovation in Underground Thermal Energy Storages with Borehole Heat Exchangers” involves development of innovative structures of Borehole Heat Exchangers (BHEs). Structures tested as a part of the project will aim to maximize the energy effect (which is defined as a unitary power obtained in BHE, in Watt per meter).

Innovative constructions include the pipe system in the borehole. New composite coaxial pipes system will be developed. Coaxial constructions will be analyzed and compared to the traditional, U-pipe based ones. The coaxial construction can be used in boreholes with greater depth in comparison to the U-pipe design.

The research methodology is based on mathematical modelling of an individual BHE as well as fields consisting of multiple BHEs, taking into account their interference. Modelling will be verified by in situ tests on created BHEs. It is expected to conduct Thermal Response Tests (TRT) on every borehole. Next innovation is TRT results interpretation by using three methods. Additionally, a thermal conductivity test will be conducted with a minimum three TRTs on a single Borehole Heat Exchanger. It is a new test of BHEs.

A very important innovation for making BHE fields in the future is the optimization of drilling technology parameters. A new methodology will be developed for in situ application - at the beginning of BHE drilling with a large number of boreholes.

2.2.2 Deep Borehole Heat Exchangers - Sękowa GT-1

The research grant is commissioned by the Sękowa Commune and the National Fund for Environmental Protection and Water Management in Warsaw, regarding the concept of a deep borehole heat exchanger. The contractors of the grant include AGH UST and the Department of Renewable Energy Sources and Environmental Research of the Polish Academy of Sciences in Krakow.

The project will be based on the analysis of the temperature measurements from the Sękowa GT-1 well in terms of its use as a deep borehole heat exchanger. A variant concept of a deep borehole heat exchanger using the Sękowa GT-1 well will be presented (based on the already existing data on the borehole construction, supplemented with information obtained from post-completion documentation). An optimal design will be recommended. The operating conditions in cooling (storage) mode will be described. In addition, an assessment of the potential and energy parameters of a deep borehole heat exchanger using the Sękowa GT-1 well (negative geothermal well) will be developed, as will the geoenergetic characteristics of a deep borehole heat exchanger. The construction, technical condition, potential and energy parameters of the decommissioned Gorlice-12 and Gorlice-13 wells (adjacent to the Sękowa GT-1 well) will also be assessed in terms of the possibility and justifiability of their use in the form of deep borehole heat exchangers. The proposed concept of deep borehole heat exchangers using Sękowa GT-1, Gorlice-12 and Gorlice-13 wells has a real chance of being implemented.

2.2.3 Geothermal energy: the basis for low-emission district heating, improved living conditions and sustainable development

The members of the Geoenergetics Laboratory’s team participated in the international grant “Geothermal energy: the basis for low-emission heating, improved living conditions and sustainable development”. The main grant contractor was the Institute of Mineral and Energy Economy Research Institute of the Polish Academy of Sciences, Division of Renewable Energy Sources. This project aimed to transfer the knowledge, technologies and good practices in district heating in geothermal energy buildings (RES) from Norway and Iceland to Poland. The project contributed to building capacity, increasing the acceptance and knowledge of several stakeholder groups about the wider use of geothermal energy, low-emission sustainable economy, improving living conditions and building bilateral cooperation (https://min-pan.krakow.pl/projekty/2017/12/01/energia-geotermlna-podstawa-niskoemisyjnego-cieplownictwa-poprawy-warunkow-zycia-i-zrownowazonego-rozwoju/).

2.2.4 Balneological Geothermal Clinic

The members of the Geoenergetics Laboratory’s team participate in the preparation of the project entitled "Balneological Geothermal Clinic". It is a research project on the use of geothermal waters in balneotherapy and rehabilitation (including post-Covid rehabilitation). The Geoenergetics Laboratory is a co-consortium member of the scientific and industrial team. The industrial partner for the project is Tatra-Termal Sp. z o.o. company, based in Szaflary, owner and administrator of the “Gorący Potok” thermal swimming pool complex. "Gorący Potok" is a complex of several unique outdoor pools with natural, raw sulfur geothermal water, the temperature of which is 34-40°C on the surface (https://www.goracypotok.pl/en).

2.2.5 Excellence Initiative - Research University

The Geoenergetics Laboratory’s team conducts research supported by the project "Excellence Initiative - Research University". It is a program introduced by the new Law on Higher Education and Science and is one of the key elements of the science and higher education reform. The program’s priority is to select and support universities that will strive to achieve the status of a research university, and will be able to effectively compete with the best academic centres in Europe and the world. AGH UST in Krakow is among the universities implementing the project (https://www.agh.edu.pl/uczelnia-badawcza/, https://www.gov.pl/web/edukacja-i-nauka/program-inicjatywa-doskonalosci--uczelnia-badawcza).

One of the activities carried out by the Geoenergetics Laboratory is a university grant for research conducted with the participation of doctoral students "Research on deep borehole heat exchangers based on boreholes intended for decommissioning". The work is carried out within the Priority Research Area – "Sustainable Energy Technologies, renewable energy sources, energy storage, and resource management. Design, production, application, synergy and process integration". The grant works will include developing methods of adapting deep wells, mainly oil (oil and gas), for the acquisition of geothermal heat. If the geological conditions are favourable, it is possible to obtain geothermal waters by appropriate adaptation of the well. On the other hand, if there are no usable aquifers, each of the wells can function as a deep borehole heat exchanger.

The second activity within the "Excellence Initiative - Research University" is equipping the existing scientific and research infrastructure. It is planned to build innovative borehole heat exchangers and a geothermal doublet in the research fields of the Geoenergetics Laboratory (Field B and new Field C). The work is carried out within the Priority Research Area – "Sustainable Energy Technologies, renewable energy sources, energy storage, and resource management. Design, production, application, synergy and process integration".

2.2.6 INGA

As part of the Intelligent Development Operational Program 2014-2020 - Joint Undertaking INGA, the Geoenergetics Laboratory's team submitted an application for a research grant entitled "Development of an energy management system integrating the production and storage of energy and heat/cold from renewable energy sources on the example of a designed and built installation". The project involves the implementation of a modern methodology for managing cooperation between the client and the supplier of energy carriers at the investment and operational stage in the field of customer service using 5G technology with the prediction of the volume of deliveries based on meteorological data and forecasts. Installation of the internet transmission kit at the customer's premises with the current reading of energy consumption, payment processing by means of internet tools, monitoring of the payment by the customer, checking the correctness of the customer's tariff selection with cyclical proposals of more favourable solutions in this area and debt collection control/monitoring. The project also includes operation of an autonomous heating and cooling energy system with a minimal share of conventional energy carriers. The system will be based on a ground heat pump, which will supply heat and/or cold to the rooms from the ground functioning as an underground heat/cold store through borehole heat exchangers. In private facilities, heating and cooling needs account for up to 85% of energy needs (EU data). The heating and cooling system will be supported by solar collectors, an air heat pump for domestic hot water, and regeneration of heat resources in the ground. The system will be supported by photovoltaic panels with electricity storage, which will supply the heating and cooling system (geothermal heat pumps) and the building with electricity. The grid connection will be designed to cover the peak demand and take off excess electricity production (prosumer tariff). Communication with the external energy supplier will be based on 5G technology. Continuous monitoring will enable the optimization of the system's operation, e.g. deciding on the transfer of excess electricity to the power grid or after conversion into heat to the ground and execution of a pilot installation.

2.3 Thermal Response Tests

Using the Thermal Response Test (TRT) it is possible to ascertain the thermal parameters of the drilled rocks. This is a particularly important issue for properly selecting the design, number, and location of borehole heat exchangers. The thermal response test is a method of assessing the actual thermal properties of the rock mass in the studied location (Śliwa et al. 2016, Gonet and Śliwa 2010). A thermal response test of borehole heat exchangers consists of measuring the temperature changes of the heat carrier during its circulation in a closed circuit with the supply or receipt of thermal energy with a constant heating power. In the surface system, it should be ensured that there is no influence of weather conditions on temperature measurements (Gonet et al. 2011). The Geoenergetics Laboratory has carried out over 100 thermal response tests during 10 years of its existence. Figures 8 and 9 show the improvement of TRT equipment over the years.

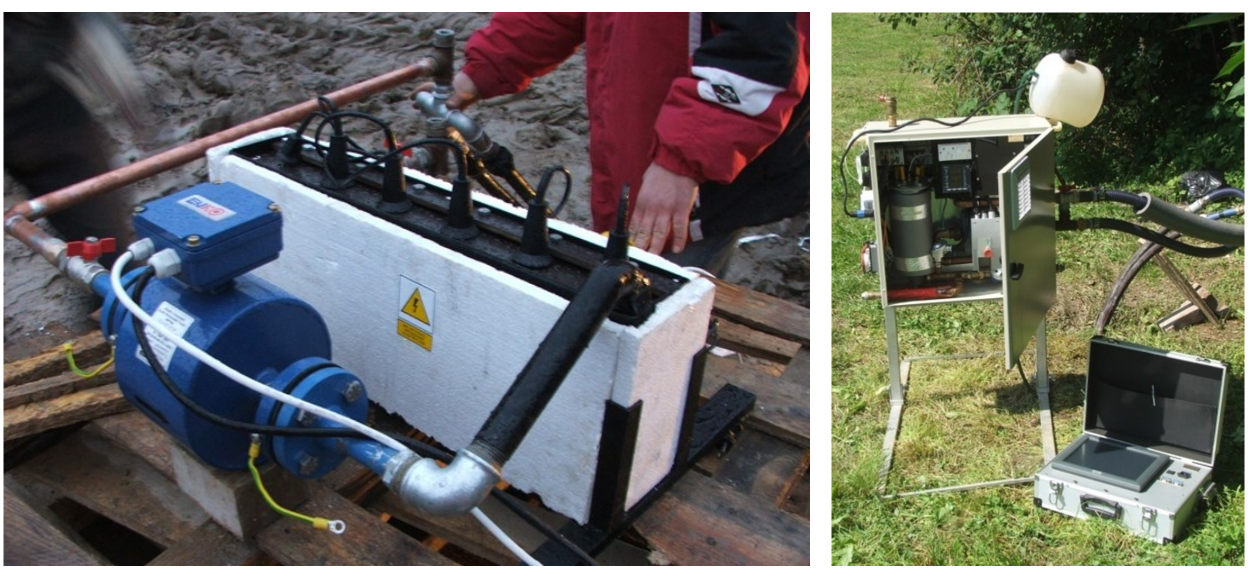


Figure 8: Thermal Response Test kit, ver. 1 on the left (2006), ver. 2 on the right (2008).

Figure 9: Thermal Response Test kit, ver. 3 on the left (2015), ver. 4 on the right (2016).

2.4 Creation of a new speciality "Geoengineering and geothermal energy"

Further projects related to the Geoenergetics Laboratory are didactic activities for the creation of a new speciality "Geoengineering and geothermal energy" within the project co-financed by the European Social Fund under the Operational Programme Knowledge Education Development 2014-2020 Axis III Higher education for economy and development, Measure 3.5 Comprehensive university programs. The speciality creation is a response to the labour market needs. In addition, as part of this activity, 3 licenses for the latest versions of the specialized Earth Energy Designer software (EED4.1) and the FOX 50 thermal conductivity measuring device were purchased.

As part of the new speciality, students prepare master's theses in the field of broadly understood geothermal energy and geoengineering. Thermal conductivity measurements of the geological samples enable determination of the energy potential of borehole heat exchangers for obtaining the Earth's heat. Another subject of master's theses concerns slurries for sealing boreholes in geothermal energy and for creation of load-bearing piles in geoengineering. The thermal conductivity parameter is important for the reduction of heat losses during the exploitation of geothermal waters as well as for the intensification of heat exchange with the rock mass in the case of borehole heat exchangers and energy piles.

Moreover, the beneficiaries of the second round of the project - the Integrated Development Program of the AGH University of Science and Technology II (ZRP AGH II) will be students of the above-mentioned speciality. This project's activity will be to conduct an internship program guaranteeing the acquisition of new skills in accordance with the assumed didactic goals. The internships will take place in leading companies of the Polish market, operating in the broadly understood drilling industry, with particular emphasis on geoengineering and geothermal energy.

2.5 Doctorates

When addressing didactic and scientific issues, it is also necessary to mention education in the third cycle of studies. Currently, in the field of geothermal energy, both in doctoral studies and in the doctoral school under the supervision of the Head of the Geoenergetics Laboratory team prof. Tomasz Śliwa, research for doctoral dissertations is being carried out. At the moment, four doctoral dissertations are conducted on the following topics: "Development of a mathematical model of underground heat storage in terms of the location of borehole heat exchangers", "Influence of technological parameters of sealing slurries used in boreholes on their thermal conductivity", "Development of sealing slurries with reduced thermal conductivity for geothermal wells" and "Statistical optimization of drilling technology for borehole heat exchangers".

2.6 Activities of students in the Geowiert Scientific Circle

At the Faculty of Drilling, Oil and Gas, the Geowiert student scientific circle is very active. It consists of three sections: a drilling section, a geoengineering section and a geothermal section. Students participating in the circle deal with research in the field of drilling, geoengineering and broadly understood issues related to geothermal energy.

2.6.1 Rector's Grants

The Geowiert Scientific Circle submits applications for the AGH Rector's Grants. As a part of these activities, much interesting scientific research has been carried out in recent years. In 2018, grants with the following titles were completed: "Modeling the results of the thermal response test for the effectiveness of underground heat storage" and "Research of sealing slurries with an addition of graphene products in geothermal energy". In 2019, a grant "Research of slurries with an addition of powdered metal and their ores for sealing boreholes in geothermal energy" was implemented. In 2020, following grants were carried out: "Laboratory model of a borehole heat exchanger" and "Research on sealing slurries with reduced thermal conductivity in the perspective of preventing heat loss in deep geothermal wells". In 2021, grant applications submitted to the AGH UST competition are: "Selection of technological drilling parameters for cost reduction of large borehole heat exchangers installations" and "Research on heat distribution in the rock mass for underground storage".

2.6.2 Ministerial Grant

Additionally, the Geowiert Scientific Circle has submitted a grant application within the program "Student scientific circles create innovation". The title of the complex project is "Deep borehole heat exchanger based on a selected negative geothermal well." The project's aim is the creation of computer software for designing deep borehole heat exchangers based on: a) boreholes intended for liquidation (exploited and/or negative), b) liquidated boreholes. The initial validation of the project will be based on the existing coaxial borehole heat exchanger located on the AGH UST premises, and on the planned (currently at the stage of the tender) deeper borehole heat exchangers at the Palace and Park Complex in Młoszowa near Krakow. The initial validation can also be based on a deep borehole heat exchanger (over 2000 m), which can be created based on a negative geothermal well.

The main goal of the project is to increase the use of geothermal energy for electricity and heat production in Poland and the world, through various promotional activities regarding the designed heating system's operational simulations, as well as software developed for this purpose.

3. TEACHING AND RESEARCH WITH BOREHOLE HEAT EXCHANGE SYSTEMS IN OSHAWA (CANADA)

A closed borehole thermal energy storage (BTES) system using borehole heat exchangers at University of Ontario Institute of Technology (now called Ontario Tech University) in Oshawa, Canada has operated for over 15 years. The university BTES field is the largest and deepest in Canada, and the geothermal well field is one of the largest in North America. In addition to being an important component of the university's heating and cooling system, the BTES is used for research and student education. The systems is described here in terms of ground thermal characteristics, HVAC linkages and economics.

The underground BTES system (shown in Figure 3) is integrated into the university's HVAC services. The university campus includes several buildings designed to be heated and cooled with the BTES system. In the university system, energy is upgraded for heating by heat pumps, i.e. extracted from the ground at lower temperature and input to the building at higher temperatures, or the ground can absorb energy and be warmed using the heat pump in its cooling (reverse) mode. The university facility integrates ground energy with ground-based heat exchangers and storages and a system to exploit this energy (ground-source heat pumps, HVAC and distribution equipment). A glycol solution circulates in an underground network of polyethylene tubing. The BTES provides seasonal heating and cooling in the following manner:

- summer: The system extracts heat from the building and transports it to the ground via a fluid circulating through in-ground tubing.
- winter: The collects heat from the earth and transports it to the buildings.

For meeting the required energy demand, 370 boreholes, each 200 m in depth were used. In addition, five temperature monitoring boreholes were installed, increasing the total drilling for the project to 75 km. Some design changes were made to the BHEs as a result of the lack of groundwater flow in the rock (Kizilkan and Dincer 2013). 150 mm diameter steel casings of are seated for each borehole about 1.5 m into the limestone bedrock, and the surface annulus around each casing was sealed with bentonite grout to stop surface drainage from seeping downward. The Swedish practice of water-filled BHEs was utilized instead of the North American practice of grouted BHEs. Waterfilled BHEs improve the efficiency of the U-tube installation and extend the life of the boreholes indefinitely.

The hydrogeology of the site includes over 40 m of unconsolidated overburden deposits overlying shale bedrock, while groundwater resources are limited to isolated, thin sand deposits (Beatty and Thompson, 2004). Test drilling established the feasibility of thermal storage in the overburden and bedrock formations at the university site, and in-situ tests determined the groundwater and thermal characteristics. The overburden includes layers of glacial till, clay, silt and silty fine sand, and no water-bearing sand deposits are present in the 44 m of deposits. Two sedimentary bedrock formations exist: 14 m of shale and 142 m of almost impermeable limestone. The background temperature is 10ºC. The BTES field volume is approximately 1.4 million m^3, and has 0.6 million tonnes of overburden and 1.7 million tonnes of rock. An almost impermeable limestone formation exists from 55 m to 200 m below surface.

The BTES is integrated with heat pumps and a chiller to provide heating and cooling services to the university. Technical specifications for the two heat pumps are provided in Table 3. Further information on the BTES system can be found elsewhere (Dincer and Rosen 2007, 2021).

Table 3: Design values for the heat pumps.

Parameter	Heat pump operating mode	
	Heating	Cooling
Design coefficient of performance	2.8	4.9
Total energy load (kW)	1390	1240
Source water entering temperature (ºC)	9.3	29.4
Source water exiting temperature (ºC)	5.6	35.0
Load water entering temperature (ºC)	41.3	14.4
Load water exiting temperature (ºC)	52.0	5.5

The BTES system is designed to be economically advantageous, generating annual energy savings with the BTES system of 40% for heating and 16% for cooling. The simple payback period is 7.5 years for the geothermal well field design and 3-5 years for the high-efficiency HVAC equipment. Indirect financial benefits of the system include avoided costs for roof cooling towers and reductions in boiler plant costs, potable water use (23 million liters annually) and chemicals for water treatment.

CONCLUSIONS

1. Geothermal energy is a renewable energy source that is becoming increasingly popular every year. The construction of new research laboratories in the field of low-temperature geothermal energy is aimed not only at teaching and research, but also at promotion and raising public awareness of the benefits of geothermal energy.

2. Due in part to research work carried out in Poland and Canada, the market for geothermal heat pumps with borehole heat exchangers is growing. Over ten years of research and operation have provided significant experience with these systems, making it possible to optimize new installations in terms of performance and efficiency.

3. The establishment of the Geoenergetics Laboratory in Krakow has contributed to the creation of a new specialty Geoengineering and Geothermal energy, which is a response to the needs of the shallow drilling industry, particularly in the areas of geoenergy and geoengineering.

4. The development of geoenergy is possible through the acquisition of many research grants, that support the development and implementation of new and innovative ideas in the areas of both shallow and deep geothermal energy.

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Acknowledgements

Research project supported by program "Excellence initiative – research university" for the AGH University of Science and Technology.