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Brochure

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Geothermal energy

Introduction

Geothermal energy in the shallow zone of the ground beneath the surface is one of the renewable sources of thermal energy and can be used anywhere on Earth.

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Low-temperature geothermal energy

Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources sets a binding Union target of a share of at least 32 % of renewable energy. This goal can be achieved by increased use of geothermal energy for space and water heating. In places where it is not possible to obtain the energy from the deep Earth, the heat pumps are used to obtain heat energy in sufficient quantities.

The Earth is a source of thermal energy, which can be used for space and water heating, provided that the temperature rises from about 10 – 20 °C, common in the shallow ground, up to 40 – 60 ° C. This can be achieved by connecting the heat pump to a suitably designed system. In addition, an increase in the performance and efficiency of the system can be achieved by accumulating thermal energy from the top layer of the surface during the summer for its reuse in the winter. The system can thus also serve to air-condition the building and thus further reduce the consumption of primary energy sources (mostly fossil fuels) and carbon dioxide production.

Systems using heat pumps

Ground Source Heat Pump (GSHP) systems *extract heat from the ground, heats it and releases it where required for space and water heating. The GSHP function can be reversed for cooling purposes.*

The number of geothermal heat pump installations in Europe is on the rise. At the end of 2013, according to (1), the number of installations reached more than 1.3 million. In 2019, the European

geothermal heat pump market reached the milestone of 2 million installed heat pumps (2). This milestone is an important part of the story of this technology, as it becomes a mainstream heating and cooling solution in some regional or national markets. The increase in the number of installed units is highest in Sweden and Germany. Other countries such as France, Finland, Austria, the Netherlands, Denmark, Poland, Switzerland, and Norway are significantly increasing the number of GSHP units installed. However, not all countries except Sweden have met their targets for 2020 (2).

In addition to air-water systems, which make up the majority of installed systems in the Czech Republic, one of the most common heat pump systems installed in standard climatic conditions are heat pumps using a ground and a medium circulating in a closed loop system (*closed-loop* GSHP or *ground/water system*, see Fig. 1, Fig. 2). These systems are suitable for all sizes of installations, their output and heating factor $SCOP_{net}$ are not so significantly affected by seasonal climatic influences.

The disadvantage of these systems is the higher initial investment in a heat exchanger. However, in long term, this apparent negative is overcome in the building stability of the provided heat output, which is almost independent of climatic conditions, even for large installations with heat demand in the order of several MW. The advantage of these systems is the possibility of accumulating thermal energy for its later use.

- **Ground/water system**

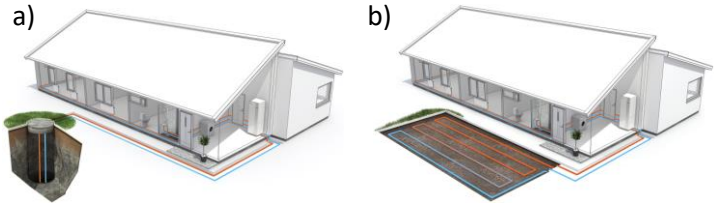

Fig. 1: Examples of ground / water systems: a) vertical closed-loop heat exchanger (GSHP; closed-loop); according to (SOLOHEATING, undated); b) horizontal closed-loop heat exchanger (GSHP; closed-loop); according to (SOLOHEATING, undated).

- **Systém voda / voda**

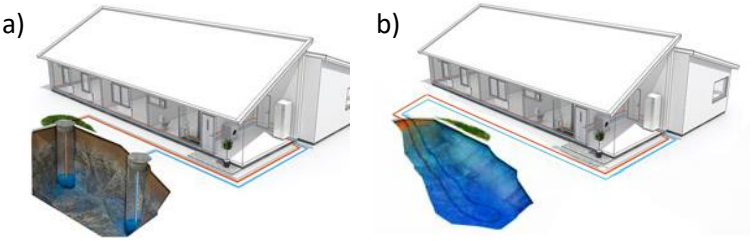

Fig. 2: Examples of a ground / water system: a) open-loop system (GSHP) and a pair of wells - pumping (left), infiltration (right); according to (SOLOHEATING, undated); b) closed-loop (GSHP) system - use of surface water accumulation; by (SOLOHEATING, undated)

Required Geothermal Power

For example, heat pump installations can be divided according to the required geothermal power, or according to the required amount of heat energy either obtained or consumed/accumulated in the ground over a period of time. Installed systems with heat pumps are divided into standard categories, see Tab.1.

Table 1: Classification of heat pump systems according to the size of their installation

Installation of heat pumps		Annual thermal energy consumption *
Czech	English	(MWth)
malé instalace	Residential Houses	< 50
střední instalace	Light Commercial	50 až 300
velké instalace	Commercial	> 300
*The classification of annual thermal energy consumption is derived from published data and personal experience		

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3. SOLOHEATING. *Renewable Energy Installers.* [Online] *Solo Heating Installations.* [Citace: 5. 1 2021.] http://www.soloheatinginstallations.co.uk/ground_source_heat_pump.htm.

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VŠB-TUO

Expertise in Geothermal Energy

VSB – Technical University of Ostrava is among the Czech institutions with the richest experience and most modern academic facilities for the assessment of the rock environment and a comprehensive design of systems for the use of low-potential geothermal energy for variously large systems in the fields of civil engineering.

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Design of Geothermal Systems

The installation of heat pumps for the use of low-potential thermal energy of the rock environment has a growing tendency worldwide. Small heat exchanger systems used mostly for heating, and in a smaller number of cases also for cooling, are now commonly installed, but often only on the basis of experience and without a thorough analysis of the rock mass in terms of its heat capacity. These are systems with an output in the order of tens of kW. Proper system design is combined with an assessment of the rock environment and heat output needs for heating, hot water, and cooling over time.

The optimized system design will result in financial savings on the overall operation of the system over the life of the building, especially for large systems. Optimally designed systems lead to a reduction in the consumption of primary energy sources (mostly fossil fuels) and the production of carbon dioxide.

Assessment of the Installation Potential of the Ground Source Heat Pump

It is vital to correctly evaluate all data important for the decision-making process of investors considering the possibility of using heat exchangers of various capacities installed in the rock environment as renewable energy sources.

Another important task is improvement of heat exchanger installation technology in a specific rock environment, described by reliable parameters necessary for its design and implementation

obtained by a combination of "in situ" testing, laboratory tests and subsequent modeling of heat transfer.

Analysis procedure:

1. Evaluate the requirements for the planned needs for the transfer of thermal energy of the building in individual seasons and with regard to its use.
2. Create a 3D model of the rock environment at the construction site.
3. Obtain the values of thermal characteristics of the rock mass by measuring in situ.
4. Carry out a simulation of heat extraction or injection into the rock mass.
5. Prepare a "tailor-made" drilling technology and equipping wells for the construction of a borehole heat exchangers (BHE).
6. Consider the possibilities of heat accumulation in the rock mass.

- **3D geological modelling**

Natural conditions represent the whole spectrum of geological, hydrogeological, morphological and climatic conditions, of which the thermal characteristics of the rock environment can be considered essential – thermal conductivity and thermal capacity. Creating the most accurate spatial (3D) geological model at the installation site of a drilled heat exchanger for use by a ground-to-water heat pump is an essential prerequisite for correct installation.

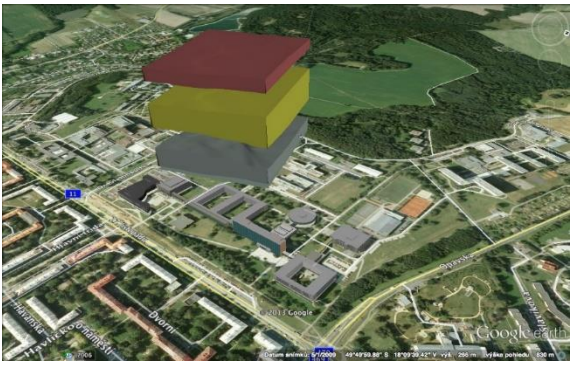

Figure 3: 3D geological model of the campus of VSB – TUO

- **Measurement of geothermal characteristic**

For larger heat exchanger installations (typically more than 10 boreholes) it is necessary to obtain accurate values of temperature in a massif at different depths, their development over time, thermal conductivity and thermal capacity of the rock mass at the BHE installation site. VŠB-TUO has experts at the Faculty of Electrical Engineering and Informatics who are able to operatively measure or design an automatic measuring system for long-term monitoring so that accurate temperature of the rock mass is obtained. To obtain exact values of thermal conductivity of the rock mass, the use of an "in situ" test called Thermal Response Test (TRT). This is the most accurate determination of the thermal characteristics essential for proper system design. VŠB-TUO has the equipment available to perform such test.

- **TRT Principle**

The TRT principle is based on supplying a heating medium of constant volume flow into a borehole equipped with a collector loop. This medium is heated by the heating spiral of the TRT system with a constant heating power and the response of the rock massive is measured by following quantities:

- Thermodynamic temperature at the input to the collector T_{IN} (°C) and at the output from collector T_{OUT} (°C),
- Volume flow Q_V (m3 · s-1),
- Pressure p (Pa),
- Power $P_{\mathrm{el.}}$ (W),
- And others quantities.

All quantities are archived during the test.

- **Measurement process**

The standard TRT experiment includes the collection of data intended for the design and modeling of a large number of heat exchangers (vertically drilled) in the form of a so-called borehole polygon. The conventional approach to evaluate the obtained TRT data is usually based on the so-called Kelvin's line source theory requiring a longer period of TRT test, typically 48 to 72 hours.

The TRT experiment methodology typically includes:

- **Measurement of unaffected temperature profile** – it is carried out using a resistance temperature sensor (type Pt1000 / A in a four-wire connection) once before the beginning of the TRT test in the entire depth of the given well; after averaging by the

sample average, it represents the basis for the value of unaffected temperature $\boldsymbol{T_0}$,

- **Implementation of the TRT test –** this process takes a maximum of 72 hours under favorable conditions. The data processed i represent the basis for the averaged values of the coefficient of thermal conductivity $\boldsymbol{\lambda}$ and thermal resistance of the well $\boldsymbol{R_B}$.

- **Measurement of affected temperature profiles -** these temperature profiles are typically measured at 20-minute, 30-minute or 60-minute time intervals after the end of the TRT test; this measurement is focused on examining the temperature changes within the rock mass (the temperature field) when returning to the initial state before the TRT test (the so-called *afterglow process*).

- **The second stage of data evaluation** – an optional part intended for the analysis of the design (using EED) of the borehole polygon and for the subsequent installation of heat pumps at the site.

The implementation of TRT experiments is especially important in the design of large drilled heat exchangers, where a good knowledge of the physical properties of the rock mass leads to a more accurate design of the heat exchanger parameters and to a more accurate estimate of its stability during long-term operation.

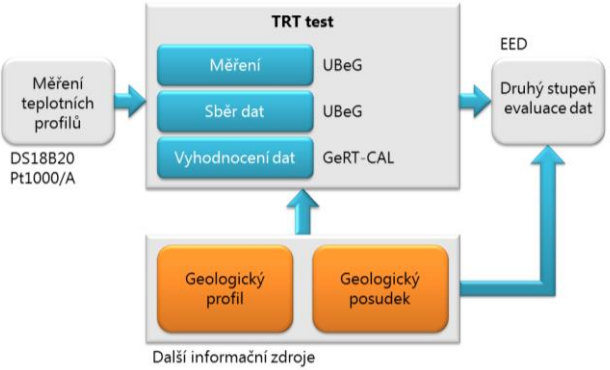

Fig. 4: Block diagram of the TRT experiment - input parameters (measurement of temperature profiles, other information sources), base structure (TRT test) and output parameters (outputs of the TRT test in the first stage of data evaluation and for the second stage of data evaluation)

Fig. 5: TRT measuring equipment

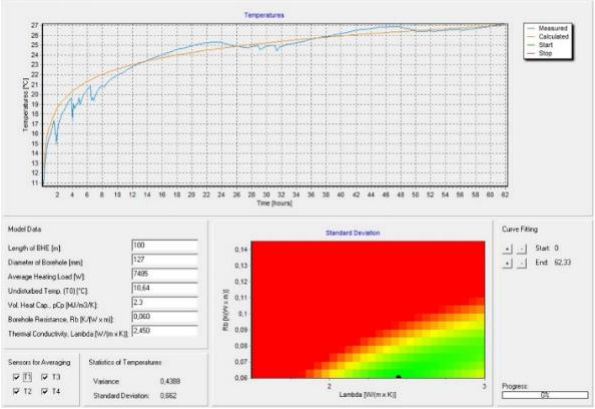

Fig. 6: TRT measurement output

After obtaining accurate data on the thermo-physical properties of the rock mass, it is necessary to simulate the long term heat flow in the rock mass.

- **Heat flow simulation**

Based on a knowledge of the thermal needs of the planned object, the rock environment and the climate, verified in the case of larger planned installations by "in situ" measurement, a comprehensive analysis can be used to simulate the conditions of heat collection or accumulation in the rock mass.

In the case of smaller installations of the family house type, analytical software is used, in the case of larger installations, numerical software is used.

- **Analytical simulation**

One of the most commonly used analytical simulation software is EED (Earth Energy Designer), which was developed by Building Physics. The simulation results are used as an expert estimate, which corresponds to the technical standard (VDI 4640). The software can be used for an analytical solution of heat transfer depending on the geometry of the borehole. However, it is only a solution of heat transfer by conduction from/to a simple linear source. The convective proportion of heat transfer, i.e. the proportion transported by the flowing groundwater, as well as the dispersion and conduction of the transported heat by the transfer liquid, are not taken into account in the computational formations. This solution is recommended in a simple rock environment and only for small installations of ground-water heat pumps, e.g. for a family house.

- **Numerical simulation**

The FEFLOW program is widely used for numerical simulations. This program is extended for the simulation of the behavior of ground probes and energy piles in combination with heat pumps and technical equipment of buildings. FEFLOW version 7 is a software complex of tools for calculating water flow, mass, and heat transfer in porous media. This program is used worldwide in leading research institutes, universities, engineering companies and offices. Applications range from simple local models to complex large simulations. To illustrate the thermal effect of geothermal facilities, the program has already been used on more than 20 large geothermal projects. The application of numerical models in simulations and forecasting of groundwater movement and the associated heat transfer corresponds to the standard of current

procedures and allows the simulation of the transport of complex thermal processes.

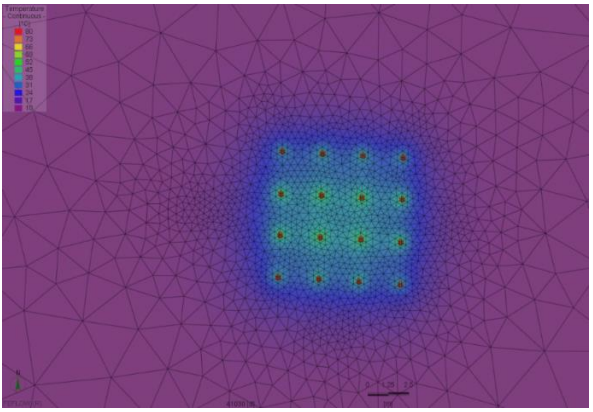

Fig. 7: Numerical model - temperature distribution in the massif within the simulation of thermal energy transfer in the research heat storage in the Paskov area

The results of the simulations verify the ability of the rock mass to provide a sufficient amount of thermal energy for long term heating and hot water preparation of the designed object. VŠB-TUO has powerful computers, the software and experts for simulating heat flow in the rock environment.

- **Drilling and borehole technology of the BHE**

Designing the right technology for drilling, grouting, and equipping the wells of a drilled heat exchanger is essential for the proper functioning of the entire heat pump system. At the same time, it is the most financially demanding part of the system and its optimization leads to significant financial savings. Important factors

are the designed length of boreholes and their spacing to prevent the temperature of the rock mass to fall to significantly negative values throughout the operation of the BHE system.

- **Heat accumulation in the rock mass**

In the case of suitable conditions given mainly by the spatial structure of the rock mass and hydrogeological conditions, the whole system can be used to cool the building in the summer and recover thermal energy in the rock mass. Recuperation cannot be designed without an accurate analysis of the rock mass, because in case of unfavorable conditions the heat could spread, e.g. due to the flow of groundwater outside the accumulation space, and the wells could not be taken back in the heating season. The premises of VSB-TUO include a small research polygon for experimental verification of heat pumping/accumulation in the rock mass at lower temperatures, e.g. from solar panels and in cooperation with the company GreenGas DPB, a.s. Moreover, VSB-TUO has a unique experimental high-temperature heat storage tank, where the efficiency of heat accumulation in the rock mass in the seasonal regime is evaluated. It is the only facility in the Czech Republic.

Only a comprehensive analysis of the needs of the building and the environment can create a design of a properly dimensioned and economically efficient system ensuring optimal thermal comfort or the need for the building. VSB - Technical University of Ostrava can provide experts and material-research background for the design of such systems.

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Sensors for Geothermal Application

Advanced research in the field of geothermal applications places increasing demands on a technically sophisticated approaches to monitoring installations and controlling installed technologies. There are many research areas in which the development and improvement of sensor systems of geothermal applications can be realized. In this short contribution, however, we will mention only two main directions.

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Energy Independent Sensors

Power converter technologies for embedded systems currently allow electronics to be powered without direct connection to the mains. Energy independence can be realized by means of various energy converters (e.g. solar panels or thermocouples). Fig. 1 shows an example of the implementation of such a device powered by solar panels with energy storage by supercapacitors.

Figure 8: Intelligent sensory system with for obtaining energy from the environment, including wireless transmission.

The sensors are connected via connectors and data is transmitted to the Cloud via an implemented wireless interface. Such a monitoring system solution has the ambition to facilitate installation from several points of view:

- **Elimination of external power supply need**

  For some types of geothermal installations, it is technically complicated to use the system, which requires an external power supply. This is especially the case when there is no cabling infrastructure in place or the situation requires that the cabling is not visible, especially in public places (for safety

reasons). For these cases, energy-independent monitoring is a perfect solution.

- **Fast deployment and modularity**

  The second aspect is the speed of implementation of the system on site. In the case of an energy-independent solution, the system can be prepared in advance and simply connected to the sensors at the installation site. Due to the absence of cabling, the monitoring device can be flexibly moved as required, and can also be modularly expanded or duplicated.

Intelligent monitoring systems

A large part of the development of sensor and monitoring systems for geothermal applications is devoted to the application and implementation of machine learning methods in these devices. These procedures will enable adaptive functionality that works effectively with methods that are able to obtain energy from the environment. Thus, the device can adapt its operation to the available energy. Machine learning methods are also able to evaluate the information value of data or preprocess data. This will allow the implementation of modern Internet Of Things (IoT) interfaces, which are limited by the amount of data transferred.

The figure below shows the behavior of a system that has an adaptive data collection system implemented using the backpropagation method.

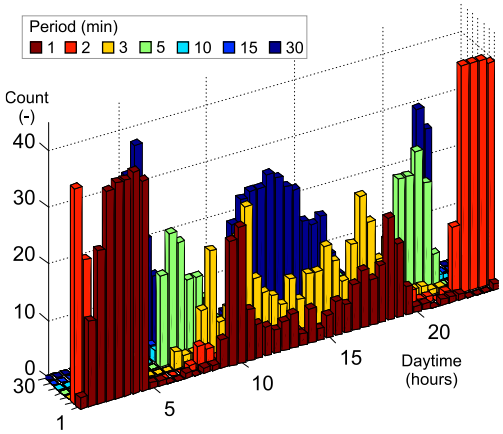

Fig. 9: Illustration of dynamic strategy for measuring the required parameters at different times of the day using the backpropagation method.

This strategy is based on a system powered by solar panels. The algorithm is able to recognize different parts of the day and select measurements in the time range from 1 to 30 minutes according to the current availability of energy, and also dynamically store energy in supercapacitors, for the cases when the energy is not available. The implemented strategy will ensure that there are no system outages in worsened conditions.

Fig. 10 shows the detailed behavior of the monitoring system in terms of internal parameters in the period of low energy production (winter).

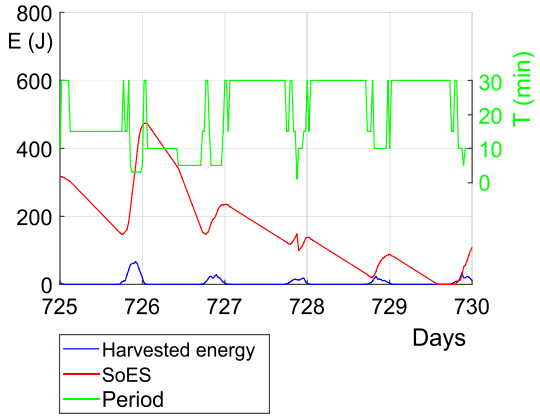

Fig. 10: Graph corresponding to the device behavior in terms of availability of energy from the environment in the winter.

It can be noticed that in cases where energy is not available, the system has long data collection times in order to save energy and prevent the system from failing. Thus, in cases of data collection with low frequency, the information value will be limited, however, there will be no system failure.

In general, it can be stated that intelligent methods of machine learning are a very promising area for implementation of monitoring systems for geothermal applications. These approaches will allow many technical installation conditions to be addressed, as well as open implementation options for next-generation IoT technologies.

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VŠB-TUO

Background in Geothermal Energy Utilization

VŠB – Technical University of Ostrava has a unique opportunity to investigate temperature changes in the rock mass during long-term operation of heat pumps. For this purpose, two research polygons are designated, which are located on the campus of the university and others in partner organizations.

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Temperature Changes in Geological Structures

For the needs of research of temperature changes in geological structures associated with installation of low-temperature geothermal systems, research polygons were built within research projects in the VŠB-TUO and partner organizations. This fact, along with personnel and laboratory base, enables comprehensive research in pumping and accumulation of geothermal energy using heat pumps.

Research polygons at VSB-TUO

Research polygons at the campus of the VŠB-TUO have been gradually built since 2007. A total of 3 GSHP systems are available for research purposes.

- **Small research polygon**

The small research (Figure 11) is intended primarily for research of the thermal, regenerative and accumulation behavior of the geological structures in the vicinity of energy wells in small buildings and is located near the Research Energy Center VŠB-TU Ostrava. The set includes two heat pumps (IVT, type Greenline E 11 Plus, heating output 2 × 11 kW) connected to two operating wells (depth 140 m), a group of nine measuring wells in the vicinity and a small polygon monitoring system. The Small research polygon makes it possible to measure temperature in a larger number of levels than the Large research polygon. It is also able to monitor the effect of solar radiation on the geological structures. One of the goals is to verify

different types of sensors to monitor the behavior of the entire system.

Figure 11:. Small research polygon - well situation. Yellow boreholes BHE. Red monitoring wells.

- **Large research polygon**

The large research polygon is designed mainly to monitor the impact of large heat exploitation from the rock environment. It is located near the New Hall building and the Information Technology Center, which is heated by the GSHP system consisting of 110 wells with an output of 700 kW. The large research polygon consists of a group of operational wells, a group of monitoring wells and a control well.

There are ten operating wells (see Figure 12) and they are arranged in two parallel rows 10 m apart. The pitch of the boreholes in both rows is the same. All operating wells are equipped with pairs of collectors made of polyethylene pipes with a diameter of 32 mm. Resistance temperature sensors *Pt1000* are located between the pipes on the inlet (cold) side of the collectors at depths of 20, 50, 100, and 140 m. These sensors are also placed between the pipes on the outlet (warm) side of the collectors at depths of 20 and 100 m.

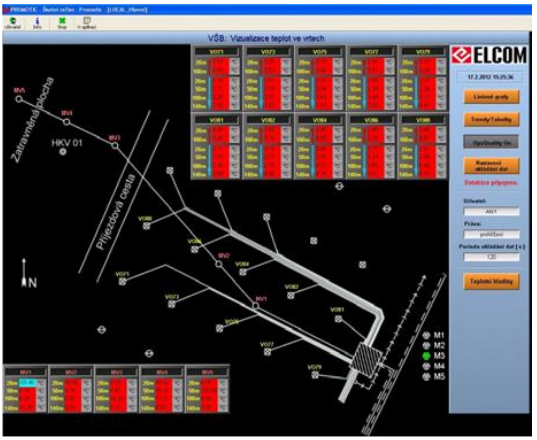

Figure 12: Situation of wells on a large research site.

- **Passive house research polygon**

This research polygon is located on the campus of the Faculty of Civil Engineering, where a model passive house is built. One of the possibilities of its heating is the installation of GSHP consisting of 1 well, which is a typical installation at family houses. The GSHP system is connected to vacuum solar collectors, which allows to draw thermal energy from the rock environment, but also to accumulate thermal energy obtained from solar radiation in times of its excess.

- **Thermal energy storage research polygon**

This research polygon was designed and implemented to verify the possibility of accumulation of thermal energy in the ground. It was built within the TAČR project in the premises of the partner company GreenGas DPB, a.s. in Paskov.

The system consists of:

- 16 boreholes with a depth of 60 m, equipped with a double U-tube, forming a heat exchanger.
- 80m deep monitoring well situated in the middle of the drilled heat exchanger.
- 3 shallow wells with a depth of 15 m for the water-bearing horizon monitoring.

Figure 13: Research polygon of thermal energy accumulation in the hall of the company GreenGas DPB, a.s.

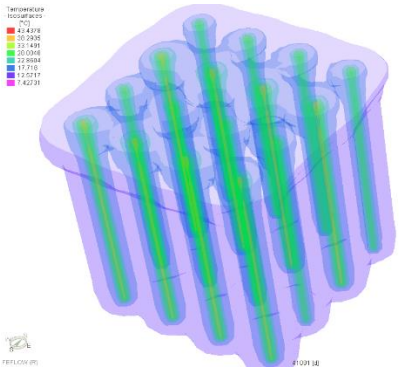

Figure 14: Heat exchanger model for heat energy storage.

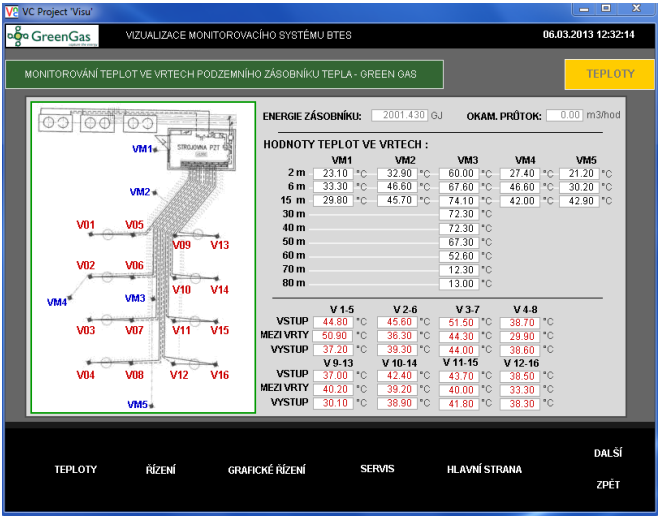

Figure 15: Borehole situation and wiring diagram in the heat exchanger control system.

Geothermal LARGE-SCALE technological system

Partner company ROBOTSYSTEM, s.r.o. is focused on research and development of a geothermal LARGE-SCALE technological system for extracting geothermal energy from pumped mine water (e.g. in the Ostrava-Karviná district).

It means research and development of a large-scale technological system for the use of geothermal energy of pumped mine water, including the design of a large-scale heat exchanger for inclusion in the pipeline, with the possibility of changing output parameters according to the source's potential.

Figure 16: Container heat pump with controlling unit.

Table 2: Technical parameters of container heat pump

Parameter	Value	Unit
External dimensions (W; H; L)	2438 x 2573 x 6058	[mm]
Voltage net	3/N/PE AC 400/230 V 50 Hz / TN-S	
Container structure weight	4500	[kg]
Heating power	100	kW
Heat pump block output	25	kW
Heat pump coolant	R 410 A	3 kg
Performance factor (COP)	5.2 (W26/W60)	

Testing of technology at the installation site:

- Putting into operation and verification of complex system function.
- Verification of material system stability in relation to mine water aggressiveness.
- System operation started 9/2017.
- SCOP efficiency coefficient 5.2.

Delivered thermal energy between 9/2017 and 9/2020 was in total: **172 628 kWh.**

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Energy Geostructures

The base constructions (structures) are an integral part of every building. Their character is different mainly depending on the type and size of the building, the natural conditions of the foundation soils and other factors. The primary purpose of foundation structures is to ensure their reliable and safe static interaction of the building with the surrounding rock environment. Such contact of the base structure with the rock environment predetermines their use as a heat exchanger.

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Energy geostructures (energy piles, walls, tunnels, etc.) represent an innovative way of heating or cooling buildings and their applications in the world are constantly growing.

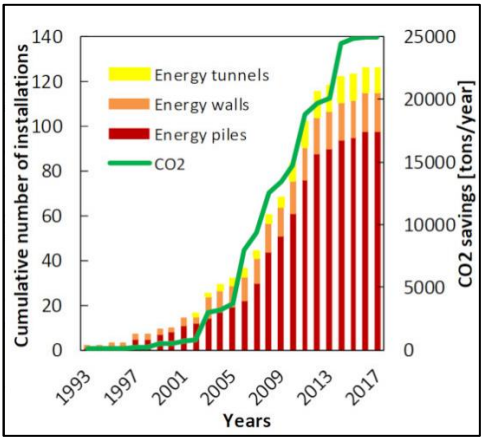

Figure 17: Development of the number of installations of energy geostructures in the world [1]

Principle of base geostructures

The basic element of energy geostructures (EGS) is a network of tubes, which are built into the concrete foundation structure and through which the heat transfer medium flows, enabling the exchange of heat between the concrete and the surrounding environment. The efficiency of the whole system includes two basic elements: energy efficiency and static efficiency.

The design of the energy structure must take into account both of the above aspects. An example of the attachment of a network of

pipes to the construction of an armored basket for energy piles and a diagram of the system of pipes in the tunnel lining is shown in the following figure.

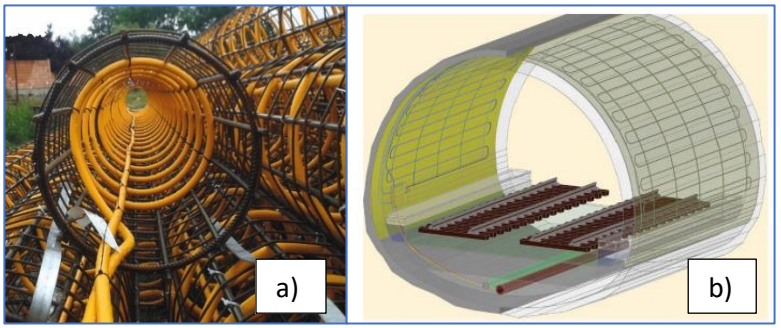

Figure 18: a) Illustration of the attachment of the network of tubes to the structure of the pile armory, b) diagram of the system of tubes in the lining of tunnels [2]

Structural and geotechnical aspects of the behavior of energy geostructures

Temperature cycles in energy geostructures affect the behavior of the energy geostructure itself and subsequently of the entire building, the foundations of which are energy geostructures. However, temperature cycles are also reflected in a change of the surrounding rock environment, which then subsequently affects the interaction with energy geostructure. These effects of thermal stress of energy geostructures must be taken into account during their design in order to ensure the reliability and safety of these structures. Research in the field of energy geostructures and their interaction

with the surrounding rock environment focuses on the following basic problems:

- Optimal quantitative and qualitative parameters of tube distribution in EGS.
- EGS implementation technology and their monitoring.
- Changes in mechanical characteristics of construction materials and rock environment due to cyclic temperature changes.
- Problems of additional thermal stresses in energy geostructure during temperature cycles with regard to the magnitude of stresses, their character and distribution in the structure.
- Problems of deformations manifested in energetic geostructures during temperature increase or decrease (shrinkage or expansion in certain partial parts of the structure) and possible manifestations of these changes in interaction with above-ground parts of buildings.
- The issue of the interaction of energy geostructure with the surrounding rock environment, especially in terms of friction changes at the contact of the structure with the rock environment.
- Combined thermo-hydro-mechanical analysis of the rock environment associated with temperature changes during cycles.

- Optimization of EGS efficiency depending on the character of the object using EGS, the character of the EGS itself and the nature of the surrounding rock environment.

VŠB-TU Ostrava has software equipment for simulating the interaction of energy foundation structures with the ground and the design of energy piles (Thermo-Pile software).

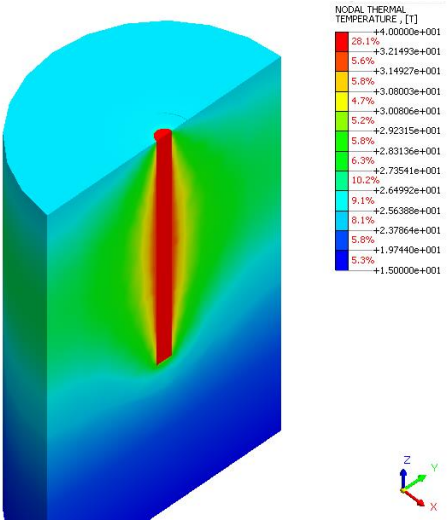

Figure 19: Simulation of the temperature field distribution in the energy pile and in the surrounding rock environment (pile temperature 40 °C) (MIDAS GTS NX software)

Energy Geostructure application potential

Energy geostructures represent a renewable energy source for heating or cooling buildings. The main advantage compared to conventional closed geothermal systems is the significant reduction of initial installation costs, which results mainly from the fact that geostructures would be built due to static and without energy use.

The highest number of practical EGS applications worldwide is in the field of energy piles, several successful applications have also been made in the Czech Republic. Energy wall structures and energy linings of tunnels are currently used to a lesser extent, but with growing knowledge and experience in this area, their growth is expected in the future. The amount of heat obtained from energy piles on major construction sites in the world is illustrated in the following figure.

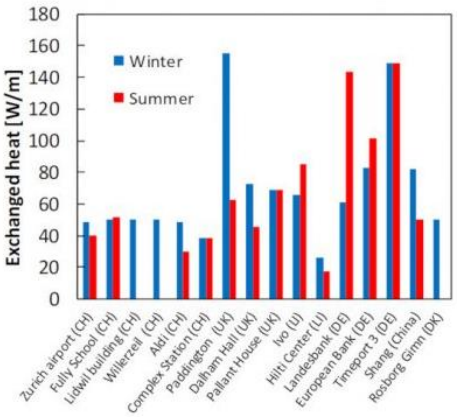

Figure 20: Graph of the amount of heat obtained from energy geostructures in the world [1]

Reference

[1] Di Donna, A., Barla, M., M., and Amis, T. 2017. Energy geostructures: a collection of data from real applications. In *15th IACMAG*, Wuhan, China.

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Fraunhofer IWU

Fraunhofer IWU is one of the world's leading application-oriented production engineering research institutes. The knowledge and innovations gained in the fields of design, simulation, experiments, condition monitoring and sensor data fusion are transferred to the field of geothermal energy.

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Heat exchanger design and development

At Fraunhofer IWU, the development of complete heat exchangers, their assemblies or individual components can take place. The expertise of the research institute covers the entire development chain from material selection, testing and subsequent simulations to demonstrator production. This can be implemented for conventional materials (copper, aluminum, stainless steel) as well as for corrosion-resistant materials (titanium). Manufacturing processes such as (temperature-supported) hydroforming or incremental sheet forming are used here. These processes are economical even for small quantities and allow initial demonstrators to be produced quickly. Further competences of Fraunhofer IWU with regard to heat exchanger systems are:

- Development of design tools (CAD).
- Flow simulation for verification.
- Automated design for bionic structures.
- Sheet metal-based designs for all common materials (titanium, copper, aluminum, stainless steel).
- Manufacturing of prototypes.

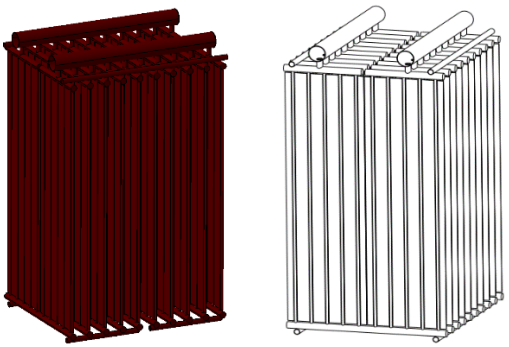

Figure 21 Heatexchanger Mogesowa 1 project (copper)

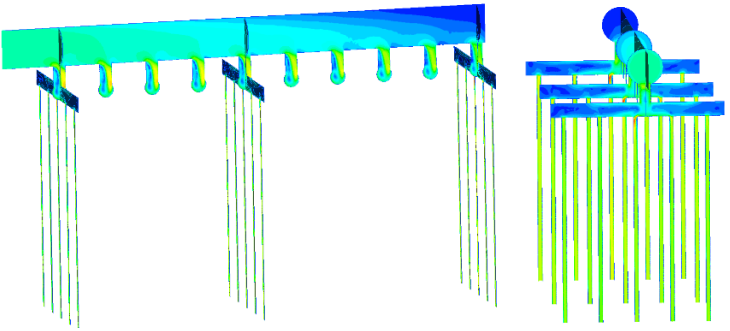

Figure 22 Velocity distribution as result of CFD simulations at the example of the heat exchanger Mogesowa 1.

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Simulation-based investigation of heat transfer

The reasons for simulative investigations of the influence of heat transfer coefficients are as follows:

- It is the most important physical quantity of heat transfer from solid to fluid (like air or water).
- A high number of technical components are surrounded by fluids.
- It indicates the heat exchanged per area with the environment (Requirements for a physically correct model).
- Measurement is difficult.
- Calculation via empirical formulas already very complex for simple geometries.
- Strongly locally dependent on the flow condition.
- Cannot be determined with the FEM but has to be specified by the user as a boundary condition.

The simulation-based analysis of heat transfers can be used in various applications. Steel reinforcements in concrete structures geothermal equipment or high precision machinery are potential applications.

The goals are:

- Increase of energy efficiency.
- Situated optimal tempering of technical structures through modelling and decentralized control.
- Adaption of the temperature systems to temporal variable inner and outer thermal loads.
- Fast variation comparisons for constructive design and control concepts.

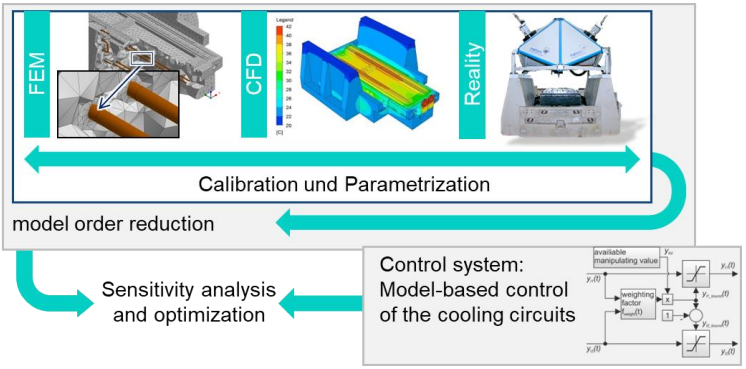

Figure 23: Analytical approach for model building, reality matching and optimization.

To reduce the computation time and at the same time increase the predictive quality of the calculations, a methodical approach is used:

- Combination of CFD and FEM simulation, temperature control system modeling by line models.
- Situational optimal temperature control.
- Model order reduction for short computation times.

Material	Specific heat capacity [J/(kg K)]	Density [kg/m³]	Heat conduction coefficient [W/(m K)]
Steel (S235JR)	461	7850	54
High performance concrete	900	2400	1,7

Figure 24: Material characteristics and associated application

In the transfer of the presented approach to the real application, the following steps were carried out on the specific application:

- Considering the reinforcements in concrete by usage of equivalent material data, determined on reduced models:
    - Fastest calculation time, like homogeneous body.
    - High accuracy in case of sufficient model quality.
    - High effectivity for material pairings with highly different material data.
- Considering the influence of the mesh fineness to the calculation time.
- Iterative determination during the modeling process.

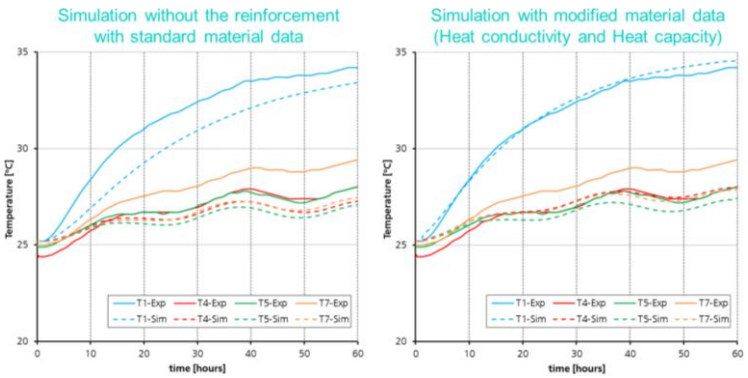

Figure 25: Contribution of the simulation without (left) and with (right) consideration of the reinforcement

Climate chamber – analysis of thermal behaviour of technical equipment

The determination of the thermally induced displacements occurring under different operating conditions and fluctuating environmental influences is a necessary prerequisite for the development of thermally tolerant technical equipment due to increasing accuracy requirements. Knowledge of the influences of various thermal boundary conditions, in particular also the ambient temperature, on the accuracy behavior and the long-term stability of the technical equipment is necessary. With the climate chamber an excellent basis for experimental investigations and can thus create the foundations for accurate modeling of thermal effects.

Figure 26: Climate chamber

With a climate chamber it is possible to determine both the influence of internal heat sources of a machine at constant ambient temperatures and the determined thermal behavior of technical equipment at systematically changing ambient temperatures. Considering the thermally induced deformations and displacements of the equipment, including the thermal interaction with the environment, improved design and compensatory measures and methods for minimizing them are derived. The control of humidity from 10 to 90 % RH. allows to simulate almost any climate worldwide: In 30 min, a change from a mild winter day in the Czech Republic (10 °C at 30 % RH) to a summer day in Thailand (35 °C at 85 % RH) is possible. With the climate chamber and our measurement equipment, the following further objectives can be realized:

- Correction of deviations using control-integrated methods.
- Derivation of design and material-specific measures from the knowledge of the thermal behavior.

Technical data:

- External dimensions: 10.7 m x 7.5 m x 5.0 m.
- Air/floor temperature: 10 °C to 40 °C (+/- 0.15 K).
- Air exchange: 20 000 m^3/h (outlet: < 0,2 m/s).
- Max. mass of tested equipment: 20 t.

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Xeidana® Analysis for Multi-Sensor Systems

Xeidana ® (eXtensible Environment for Industrial Data Analysis) is a modular development environment for the realization of data analysis tasks in research and application. It was originally developed for quality monitoring systems. The software contains a variety of libraries for connecting various sensors, for data analysis and data processing, for visualizing results and for providing response mechanisms. Thus, the user has access to an extensive set of solutions, covering all tasks ranging from data acquisition to automated quality inspection, machine monitoring or process control and which is also suitable for geothermal applications due to its vast functionalities and its modular design for the online processing of large amounts of data.

General characteristics:

- Online and offline operations.
- Extensive project management capabilities.
- Projects transferable to other computers.
- Various methods of visualization.
- Data export to other evaluation systems.
- Fast parallel data processing.
- Operations can be automated.

Sensor fusion:

- Integration of various sensor types and signal transmitters.
- Data from a multitude of physical quantities can be used and combined.

Modular design:

- Expandable framework regarding data analysis algorithms and the integration of new hardware.

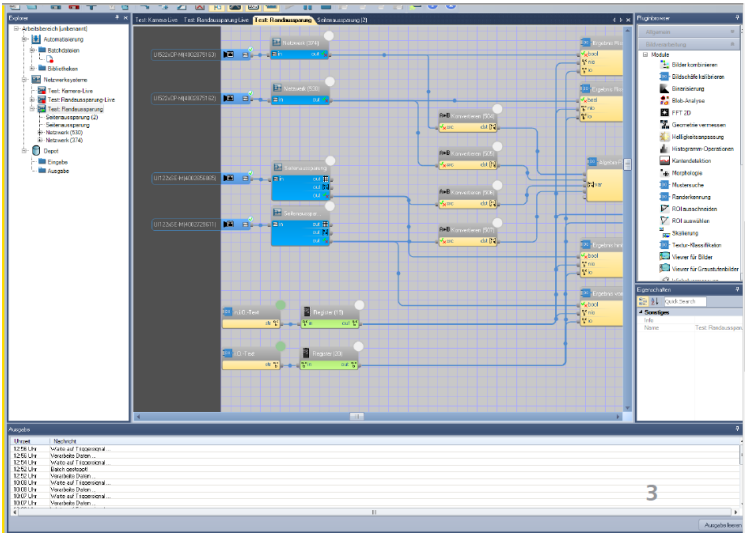

Figure 27: Xeidana's graphical user interface

Xeidana® is used among other tasks, in the classification and visualization of large amount of data. With the provided pattern recognition methods, complex relationships in datasets can be found and patterns identified. A comprehensive repertoire of algorithms and methods for data processing and classification allows, for example, the analysis of thermographic images and live videos together with data from ultrasonic or other systems. The aim of such investigations is to simultaneously, reliably detect deviations or even defects of the used equipment.

Furthermore, Xeidana® can be used as modular condition monitoring system for technical equipment & components (bearings, vibration, energy consumption, temperatures, forces, ...). It offers:

- Early detection of wear and overloads for predictive maintenance and long-term trend analysis.
- Model-based formation of virtual sensors at non-accessible measuring points.
- Integration of learning methods.
- Adaptive process control and process monitoring.
- Identification of relevant sensor data and signals.
- Control-integrated data processing.
- Algorithms for process control and error detection.

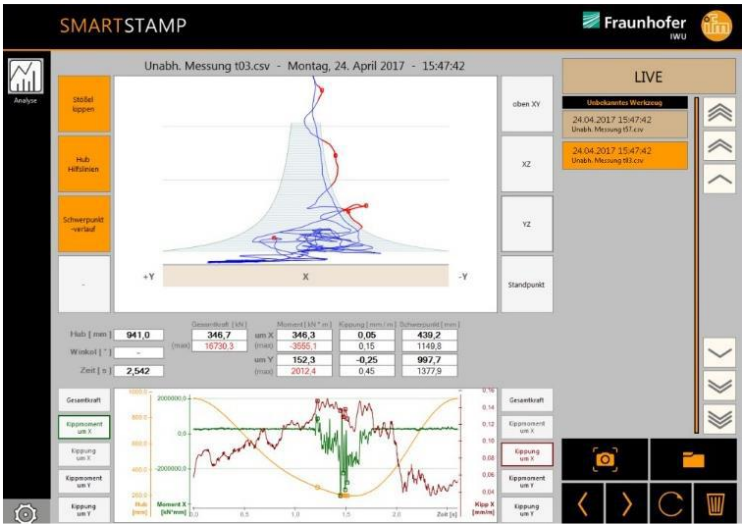

Figure 28: User interface for a specific machine monitoring application

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University of Vaasa

University of Vaasa has strong experience in the areas of renewable and geothermal energy. The experience covers both technical, economic, and innovational aspects. The technical knowledge includes measurement devices, monitoring and IoT, experiments, simulation, living labs, thermal storages, and sector coupling.

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Living Labs

University of Vaasa has several living labs. One of them is Suvilahti residential area in Vaasa. Suvilahti has a sediment heat network (low temperature district heating) for 43 single-family houses. Each house has a heat pump to extract heat from the low temperature district heating network (Fig. 29). The network can also be used for cooling.

The heat is collected from pipes pushed in the seabed (Fig. 30c). The pipes are connected to a collection well (Fig. 30a shows the two collection wells). The heat collection can be monitored via a distributed temperature measurement system (Fig. 30b). The system itself consists of several heat pipes.

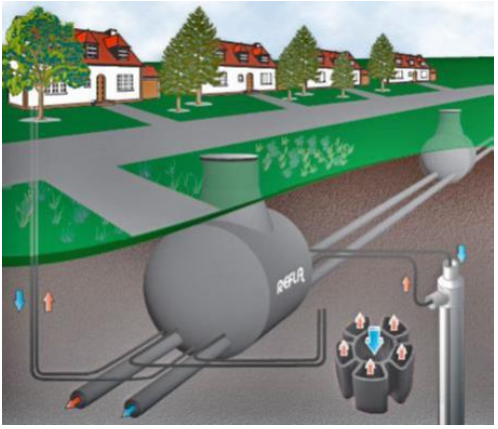

Figure 29: Low temperature district heating system is used by 43 households. Source of the figure: Vaasan Eko-Lämpö Oy.

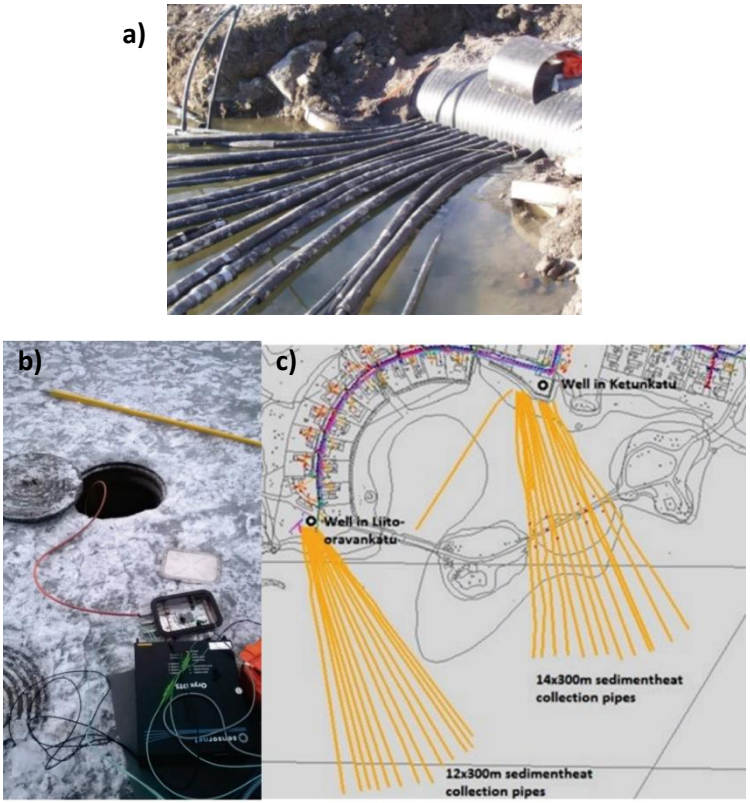

Figure 30: Details regarding heat pipes connected to collection well a) optical cable installed in one of the pipes; b) DTS measurement; c) installed pipes.

The second living lab is an experimental test field for studying heat collection under a parking lot. Fig. 31a shows the constructed test field as a whole; Fig. 31b shows different material layers of this parking lot. The temperatures are measured using a DTS system as shown in Fig. 31c. The graphical illustration of the tested field is shown in Fig. 31d.

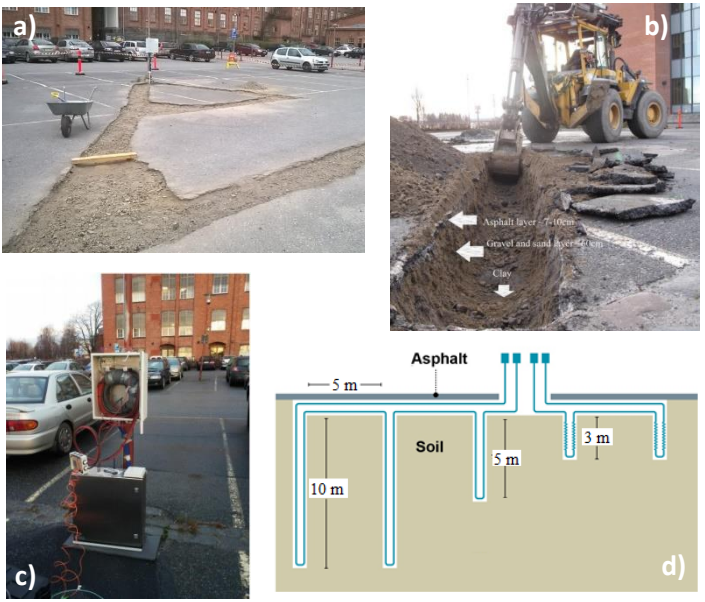

Figure 31: Living lab at the campus of University of Vaasa: a) asphalt heat test field constructed in a real parking lot; b) detail of the material layers; c) optical cables and measurement rig for DTS; d) a graphical illustration of installed optical cables.

Simulations and heat storages

Comsol simulation has been applied to several different geothermal targets like thermal storages and pipes. Fig. 32 presents an example of a simulation of a heat storage. The purpose is to optimize the heat storage arrangement and model its behavior as a function of time.

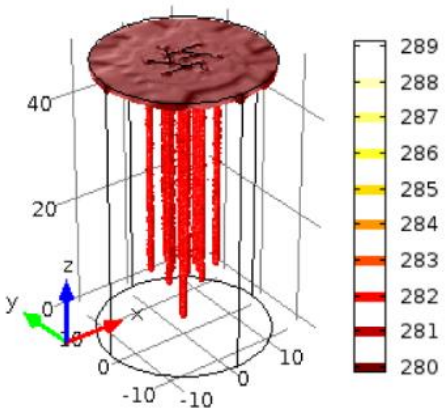

Figure 32: An example of Comsol simulation.

Devices and instruments

Thermal response test (TRT) is a basic method for characterizing thermal properties of a borehole. University of Vaasa is able to provide bi-directional distributed thermal response test. The bidirectionality means that this device can both heat or cool the borehole. A distributed TRT (DTRT) test produces temperature data along with the depth information. The device is constructed on a trailer (Fig. 33).

Figure 33: TRT-trailer.

Distributed temperature sensing (DTS) device is shown in Fig. 34a. The guaranteed accuracy of temperature measurement is ± 0.5 °C according to manufacturer. The temperature is sensed by an optical fiber with spatial resolution of 1 m. The spatial resolution can be increased to 1 cm by wrapping around an object such as in Fig. 34b. The device is suitable for geothermal measurements (Fig. 34c).

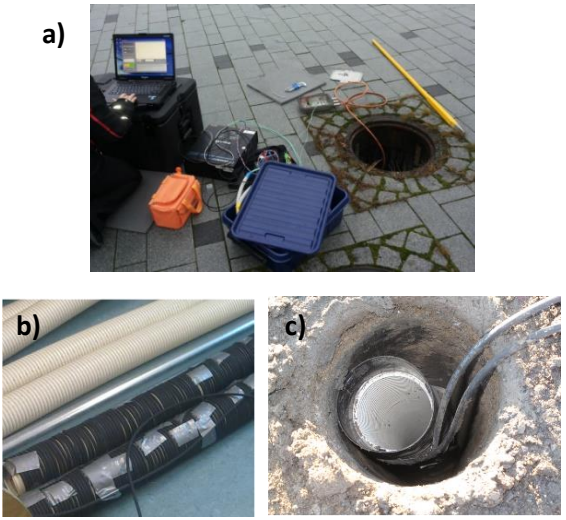

Figure 34: Example of DTS system: a) DTS measurement setup to obtain spatial resolution of 1 cm; b) optical fibers used for DTS c) DTS measurement system.

University of Vaasa owns a water heat exchanger which can be used to collect heat energy from water (Fig. 35a). It can used for both heating and cooling of spaces or domestic water. Its rated power is 9.6 kW. Utilization of geothermal energy benefits from monitoring which requires specific sensor systems. Sensors need energy which is typically obtained via batteries or electric grid. However, University of Vaasa studies energy harvesting from environment to provide energy for sensors which are connected IoT systems. Fig. 35b presents an energy harvester utilizing vibrations.

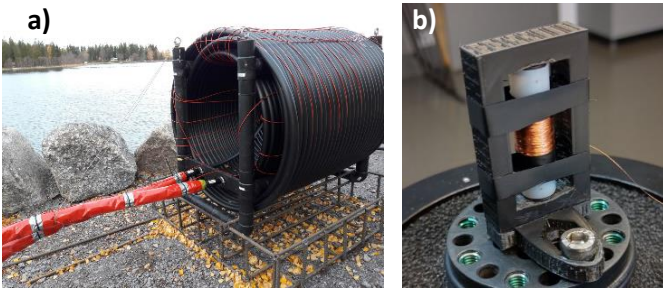

Figure 35: Examples of systems owned by University of Vaasa: a) Water heat exchanger, b) energy harvester based on vibrations.

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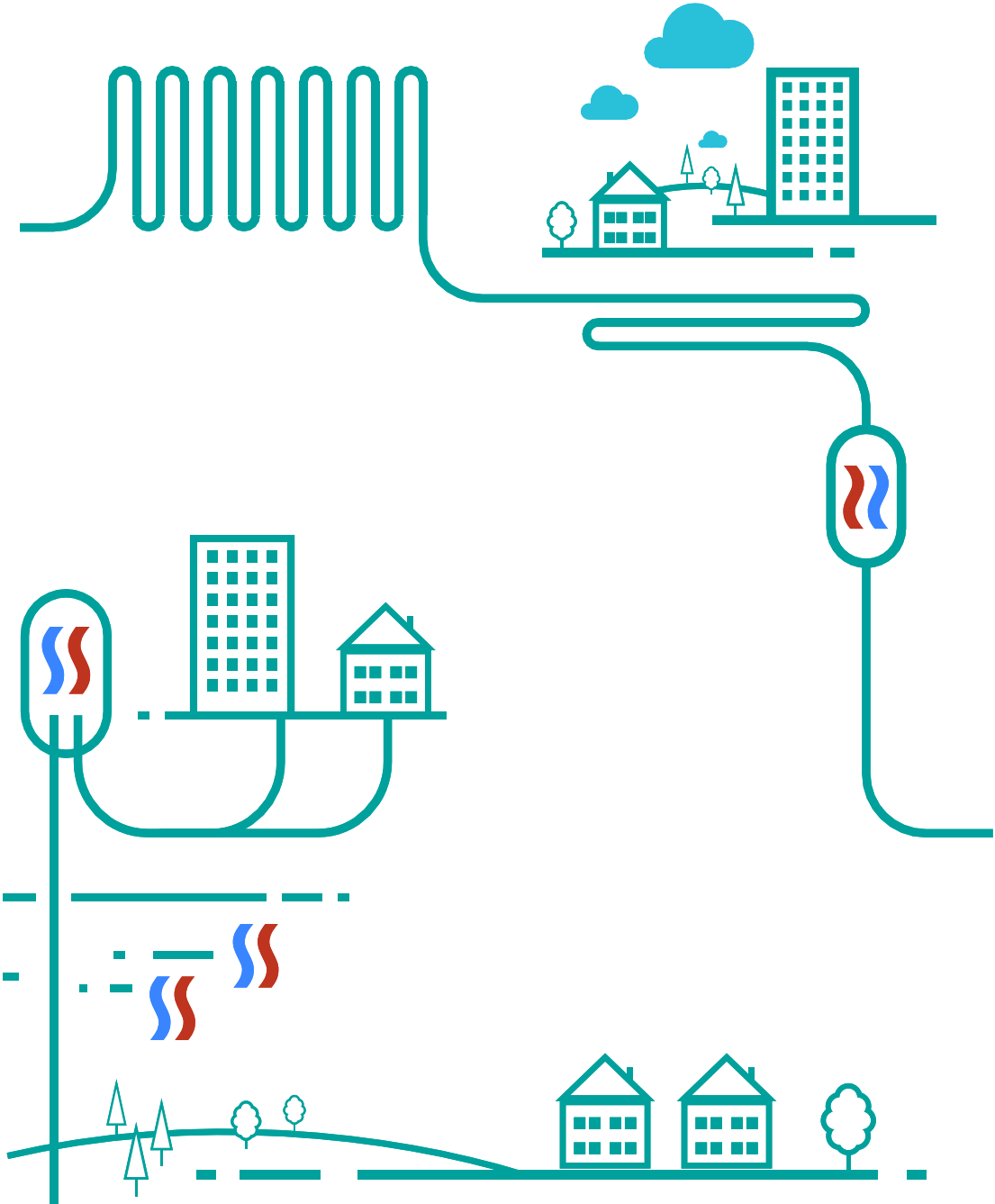

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