Project geo:base – Energetical and Ecological Optimization of Strategies for Operation and Control of Complex Energy Supply Systems based on Shallow Geothermal Energy in Commercial and Non-Residential Buildings

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ABSTRACT

The use of shallow geothermal energy for heat and cold supply in production facilities and related processes is investigated with the example of two existing, operating installations, the manufacturing facilities of Leica Camera AG in Wetzlar, Germany, and a production hall at the Volkswagen AG works in Emden, Germany. BHE are used for ground heat exchange in Wetzlar and heat exchanger piles in Emden. Short-term storage equipment complements the thermal capacity of the respective geothermal storage (Underground Thermal Energy Storage, UTES). The control strategies implemented in the digital building control system adapt the operation of the individual components according to fixed target criteria. For comparison, two more production facilities using a storage system as key component for heat and cold supply are considered in the project. The systems at Solvis GmbH and Oeding Print GmbH also have rather complex structures, however, no shallow geothermal is used in these plants.

The main objective of the project is an analysis and optimization of the operation of these plants. Of particular interest is the energetic and economic evaluation of the integration of shallow geothermal installations for heat and cold supply to production facilities and processes. The installations in buildings, production processes and various storage systems (UTES and water) are monitored and will be simulated in numerical models. The results of parameter studies performed with the simulation models and the subsequent optimization of operations will be the basis for design recommendations and strategies for operation and control. The additional monitoring of two further production facilities without UTES allows for a general evaluation of storage in complex energy supply systems. The potential of UTES in comparison to more short-term storage options can be elucidated that way, addressing in particular the specifics of thermal inertia of the underground during loading and unloading of UTES.

1. INTRODUCTION

Shallow geothermal energy is a proven technology to provide heat and cold to buildings, both residential and non-residential (Sanner, 2017), with meanwhile about 2 Mio installations all over Europe. However, the use in industry and in particular in industrial processes is still not widespread, albeit shallow geothermal technology being highly suitable for industrial application. Technologies comprise thermal energy storage in the underground (UTES), with or without the use of heat pumps, and classic geothermal heat pump systems, which, when used in industrial environment, usually make some use of underground storage effects.

The use for cooling purposes and for low-temperature heat (up to about 50 °C, which is similar to residential applications) is done routinely, with good economy and reliability. UTES at higher temperatures (50-95 °C) still is in a pilot phase after many years of development (Sanner, 2003), and the BTES (borehole thermal energy storage) system in a factory in Emmaboda, Sweden is one of few applications (Andersson and Rydell, 2012). Temperatures close to 100 °C or higher do not seem suitable for shallow geothermal technologies, as experiments in the 1990s showed. Not yet explored are the opportunities for providing cold at low temperatures e.g. for refrigeration.

Also direct uses of deep geothermal energy are increasingly addressing industrial applications, with many examples e.g. in the food industry (cheese, beer, drying of fruit, vegetables and fish, etc.). Higher temperatures are attempted, and the first enhanced geothermal system (EGS) for industrial heat purposes in the range of 150 °C was developed in Rittershoffen, France (Baujard et al., 2016).

The project described in this paper is investigating the use of shallow geothermal energy for heat and cold supply in production facilities and related processes. It looks at two examples of existing, operating installations, the manufacturing facilities of Leica Camera AG in Wetzlar, Germany, and a production hall at the Volkswagen AG works in Emden, Germany.

2. ENERGY CONSUMPTION IN INDUSTRY AND OPTIONS FOR RENEWABLE SUPPLY

The statistics on industrial heat use are not very detailed on a European level. Weiss et al. (2009) estimate that the needs of industrial heat users represent up to 44 % of the heat market in Europe. Industrial heat demand varies by temperature levels, sectors, countries, and energy supply, since many different industrial processes appear. The European Technology Platform for Renewable Heating and Cooling has targeted the opportunities for renewable energy supply in different sectors (ETP-RHC, 2013), and has found that the industry sector is particularly difficult. Required temperature levels can reach more than 1000 °C, and the share of heat >400 °C is substantial (Fig. 1). However, there is room for renewable energies, and in particular for shallow geothermal, in low temperature industries and in cooling.

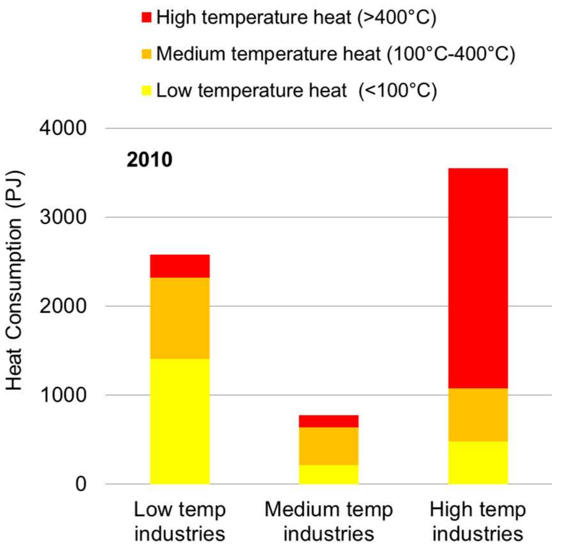

Figure 1: Annual heat consumption in industry in Europe in 2010 at different temperature levels (after data from RHC-ETP, 2013).

The share of the energy use in the industrial sector in Germany amounts to about 30 % of the total energy consumption. Because of the high consumption of electricity, heat and cold, pursuant to the industry sector, and often all day round, renewable energy sources usually cannot meet this demand. Main reasons are the high initial cost, large areal requirements for the installation, and, according to the type of the source, intermittent availability of the energy.

In Fig. 2 the share of the various energy sources for the different demand types in industry is shown. A calculation based on these numbers (Fraunhofer ISI, 2016) showed that renewable energies account for only 6.1 % of the total heat consumption and 4.4 % of the overall energy consumption in industry, both values not considering the renewable share in the electricity used. This value is much lower than in other sectors, due to the specific demands of industry processes. The most important energy source is gas (35 %, mainly natural gas), followed by electric power (32 %). Coal makes still a substantial contribution of 16.6 % (not counting the share of coal-fired power plants in the electricity used).

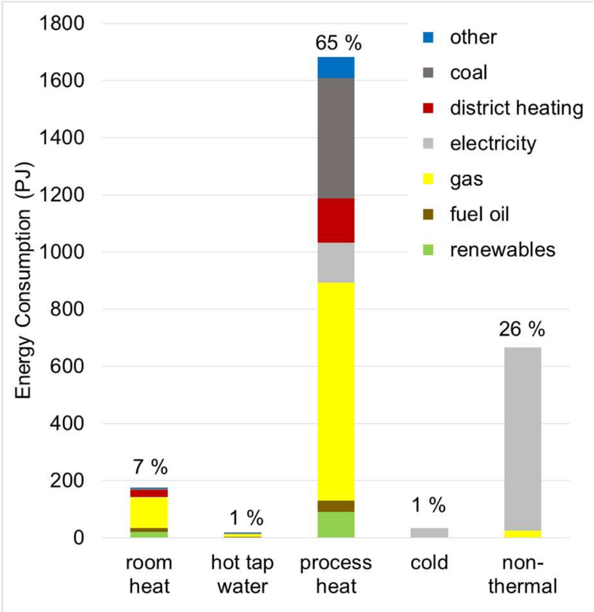

Figure 2: Annual energy consumption in industry in Germany in 2015, showing different usage types and distribution of energy sources (after data from Fraunhofer ISI (2016).

Efficiency measures can contribute substantially to a reduction in energy consumption and emissions, both in energy conversion and energy services. Typical energy services for heat in industrial processes are drying, evaporative concentration, pasteurisation, sterilisation and chemical reactions, usually at temperature levels below 150 °C. Avoiding batch processes and achieving continuous operation are suitable optimisation measures. Further potential for energy saving can be found in processes for cleaning and separation and related pre- and post-processing steps.

Once the core processes are optimised, the system architecture can be simplified by combination of several functionalities in integrated appliances with continuous process control. Similar potential exists in optimisation of the heat distribution networks in larger facilities, with adaptation of flow rates and reduction of thermal losses. If demand for electric power and low- to medium-temperature heat is in a suitable balance, heat and power co-generation offers adequate solutions, assisted by sorption chillers if necessary.

Contribution from renewable energy to further reduce the emissions from energy supply is best suited in the low- to medium-temperature range. Depending on collector area and demand patterns, solar heat might be integrated in process heat year round. Biomass can replace oil or gas in water and steam boilers. Biogas can be used for heat- and power co-generation, provided sufficient resources exist in the vicinity, or the facility itself (e.g in food industry) provides material for gasification. Own production of electric power from PV, wind or small hydro depends largely on the specific site conditions.

At production sites with both low-temperature heat demand and cooling demand, shallow geothermal energy has a good potential for substitution of fossil energy use (Mands et al., 2016). Shallow geothermal installations in such cases are suited to keep the room temperature within desired limits and can also assist in process cooling. The general feasibility of integration of shallow geothermal systems in base-load heat and cold supply might require further components like supporting (short-term) storage and other energy sources for meeting peak-load demand or high-temperature peaks, and thus lead to complex energy systems.

Small and medium enterprises might well consider the complete conversion to renewable energy supply. The solution usually would be a combination of energy efficiency, green electricity, solar heat, geothermal heat and –cold, and biomass/biofuels. Most important for such endeavours is a systematic approach. Economically advantageous energy concepts require thorough evaluation of demand patterns, temperature levels for heating and cooling, other potentials on site (surface water, roof areas, underground etc,), and finally a sound analysis of costs and benefits. Monitoring and optimisation of operation are in any case desirable for the resulting complex energy systems. Integration of renewable energies in industrial processes is just at the beginning of a promising development. Project geo:base is destined to prove the integration of shallow geothermal installations and thermal storages into production processes, and to provide recommendations for planning, sizing, operation and optimisation of such systems.

3. INTEGRATION OF SHALLOW GEOTHERMAL ENERGY IN INDUSTRIAL FACILITIES

The use of heat pumps and shallow geothermal energy in industry is generally limited to covering base-load demands, due to usually high energy demands, high investment cost for the technical installation, and the resulting areal requirements. Demand patterns have to be analysed diligently and the integration of storage devices must be evaluated. An over-arching control system with integration of the different energy sources for base- and peak-load supply has to be developed in order to guarantee the desired high shares of renewable energy in the energy supply.

Thus for the design first the site conditions and heat- and cold demand, including the respective temperature levels, have to be examined. In case the underground is intended as a thermal inertia in the system, alternative storage technologies (like large water tanks, Fig. 3) have to be considered in regard to the cost/benefit ratio. Where applicable, storage systems can be used to complement the geothermal part, with adaptation of loading/unloading cycles to the required capacities and heat transfer velocities. Monitoring such integrated energy supply systems with shallow geothermal energy in industrial environment, under scientific support, is an important contribution to proven functionalities and acceptance of this approach.

Figure 3: Placing of a 100 m^3 low-temperature storage tank at oeding print GmbH (photo Ostfalia).

4. PROJECT OBJECTIVES AND GOALS

In the frame of project geo:base complex energy systems based on shallow geothermal energy for heating and cooling at selected production sites in different industry sectors are investigated. The results shall elucidate, both for design and operation, the geothermal share in heat at low and cold at (relatively) high temperature level. The results will be transferrable to production sites of other sectors with similar temperature levels and demands, allowing for a wide use of the results from the project (i.e. in machinery construction, electric tools and devices, textiles etc.).

An essential part of the project is the monitoring and analysis of the energy systems at two production facilities, where heat and cold supply is partly provided by shallow geothermal installations. Two further facilities where short-term storages are integrated into complex systems are investigated for comparison (see chapter 5). The scientific and technical goals of the project are following from the overall goal to reduce primary energy consumption and the related emissions:

- Documentation of design and of control strategies of the installations considered, with emphasis on the integration of the shallow geothermal components and the thermal storages.
- Setup of monitoring, optimisation of operation and validation of optimisation measures.
- Evaluation of cost and benefit of the system concept and the optimisation measures.
- Development of simulation models for the complex energy systems investigated, including shallow geothermal components, thermal storages, other components for energy supply, buildings and demand patterns from production; validation of the models with measured values, and parameter studies.
- Coupling of simulation models for the geothermal part, the building and the production technology.
- Preparation of design recommendations and operation and control strategies for complex energy systems for production facilities with shallow geothermal energy supply and thermal storage.

The approach used in this project is a complete system analysis and holistic optimisation to achieve operation with optimum use of energy and resources, with and through shallow geothermal energy. A central issue in this respect is the adaptation of such components that each are meant to achieve high operating hours and thus are competing against each other. A control strategy considering this behaviour is a prerequisite for economic operation.

In the frame of the scientific monitoring of the installations in production facilities questions related to design, sizing and realisation of such installations will be treated, like:

- Operation- and control strategies for heating and cooling of buildings and processes, and regeneration of the underground.
- Balance of shares of heat and cold supply.
- Determination and analysis of the individual performances.
- Determination of suitable temperature levels for operation of the individual system components, in order to optimise the efficiency of the overall system.
- Evaluation of the suitability of different storage technologies in complex energy systems and their transferability to other sites.
- Determination of the potential for saving and optimisation in relation to overall control and control of individual energy sources and loading/unloading of storage elements.
- Investigation of the transferability of results and control strategies to other types of buildings and industry sectors with similar demand patterns (heating, cooling, electric power).

5. INDUSTRIAL PARTNERS AND FACILITIES INVESTIGATED

The individual plants investigated within project geo:base are described below. In addition, values from a facility of Technical University of Aachen (RWTH Aachen), the E.ON Energy Research Center built in 2006 (Fig. 4), will be used for testing and validating the geothermal simulations.

Figure 4: E.ON Energy Research Center at RWTH Aachen; the 40 BHE are grouped in 3 fields around the building (photo E.ON-ERC).

Heating and cooling of this building is assisted by 40 BHE each 100 m deep, each equipped with temperature sensors at inlet and outlet, and with DTS cables (glass fibre) to determine the ground temperature development. More info on this building at https://www.eonerc.rwth-aachen.de . The data on building and underground, collected over more than 10 years, allow for validation of simulation tools for various aspects.

5.1 Volkswagen AG, Emden

Volkswagen AG had erected a new production hall (Halle 18) with 64'000 m^2 floor area (ca. 530 x 120 m) at its Emden factory. The ground at the building site in vicinity to the river Ems, with poor load bearing properties, made a pile foundation necessary. About 5000 piles of 17.5 m depth were installed, 3000 of which have been equipped with heat exchanger pipes. The heat produced by the welding robots is stored in the underground and can be used for heating via a heat pump (Fig. 5). Central air-handling units are installed for heating the hall, with 45 °C water supply temperature at design conditions. The energy piles contain a double-U-pipe made from PE 100 with 25 x 2.3 mm pipe dimensions. A further component is a stratified water storage, providing different temperature levels at different heights. The energetic optimisation in this installation is planned in the areas of balancing heating and cooling work and in regard to the loading and unloading strategies for the ground storage. Geothermal cooling assisted by night-time ventilation and cold storage is also investigated.

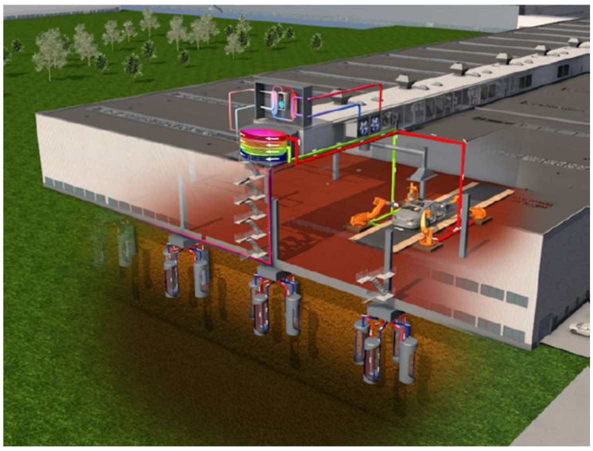

Figure 5: Schematic of one of the sections of the Halle 18 plant; from top: heat pump and air-handling units, layered storage, production hall, energy piles (graph Volkswagen AG).

5.2 Leica Camera AG, Wetzlar

In 2014, the new headquarters and production facilities of Leica Camera AG, situated in the Leitz-Park in Wetzlar, have been inaugurated. The energy installation is particularly suited for the planned optimisation in this project, as it comprises innovative technology with various heat, cold and electricity producers. The facility sits on an area of ca. 35'000 m^2 (Fig. 6). The base load for heating and cooling can be provided by two hydraulically and locally separated BHE fields with 50 and 30 BHE, respectively, and a general BHE depth of 110 m. For cold production these fields are coupled to an electric compression heat pump, a sprinkler tank doubling as cold water storage, and an absorption heat pump, and can also be used for direct cooling, individually or together. An additional conventional chiller is installed as a peak and backup system. Heat production on a high-temperature level is mainly done by two heat and power co-generation units and a condensing gas boiler. The heat produced by the co-generation units can be used for operating the absorption heat pump, and the electric power to operate the compression heat pump.

Figure 6: The Leica Camera AG offices and factory in Wetzlar, shortly after inauguration in 2014; the two BHE fields are located under the parking to the left (photo Leica Camera AG).

The system, operational since spring 2014, has been adjusted initially, but still is in a state that is expected to offer good opportunities for optimisation. In the production part of the facilities, energetic optimisation always has to keep a focus on the guarantee of stable boundary conditions for the delicate production processes. These requirements are dictated by the different manufacturing divisions, including clean rooms and coating machines. Besides the optimum interaction of the individual components in the building the cost-effective energetic management of the two separate BHE fields has to be investigated.

5.3 oeding print GmbH, Braunschweig

The company oeding print GmbH has a newly built facility in the Braunschweig suburb of Rautheim, where it produces printed materials in offset and digital technology. The building from 2013 houses production, storage and administration (Fig. 7). The building was planned following the “Plusenergiestandard”, meaning that the energy for the building (excluding energy for the production) is provided at the site directly. Measures for insulation and shading (in summer) have been combined with the installations for providing heat, cold, electricity and compressed air, adjusted to the production and driven by the “Plusenergie” target. The insulation was carried out according the the “Passivhaus-Standard” (Near Zero Energy Building). The concept is optimised by integrating renewable energies (use of passive-solar gains, maximised use of daylight with light-directing elements, installation of active solar components on the roof). Main components of the energy system are co-generation units and absorption heat pumps, and the use of residual heat from the printing machines. Three water tanks provide storage on high- and medium temperature levels for heating and on low temperature level for cooling.

Figure 7: Facilities of oeding print GmbH in Braunschweig-Rautheim (photo oeding print).

5.4 SOLVIS GmbH, Braunschweig

SOLVIS GmbH is a manufacturer of solar heating systems based in Braunschweig, residing in a zero-emission factory built already in 2002 and planned for about 150 employees (Fig. 8). Several awards were granted for this building, including the European Solar Award 2002 and the Energy Globe 2003. The compact building shape is surrounded by a tight envelope of high thermal insulation, reducing heat demand to a minimum. Good quality glass and targeted locations of windows allow for daylight use and thus reduce electric power demand. The building and an extension from 2009 are supplied by 100 % renewable energy produced on site. 2000 m^3 of roof-mounted PV-panels with 220 kWp installed electric output provide electricity for building and production, about 24 kWp are installed on the roof of the bicycle parking, and 20 kWp are tracking the sun. The missing electric power is produced in a co-generation unit together with heat, which can be stored in three water storage tanks of ca. 100 m^3 in total.

Figure 8: Zero-emission factory of SOLVIS GmbH in Braunschweig, with solar energy and water storage (photo SOLVIS).

6. FIRST PROJECT WORK STEPS

After the kick-off discussions before the summer break 2018, research and collection of documents and data started. Subsequently the individual installations have been visited and current situation and operation could be discussed with the local operators. Concepts for intensive monitoring are now developed for each case. All installations investigated consist of complex energy system, comprising several energy sources and supply units, and numerous consuming points of heat and cold. Hence a systematisation of the systems is required for monitoring, comparison and simulation. This is shown at the example of Leica Camera AG in Fig. 9.

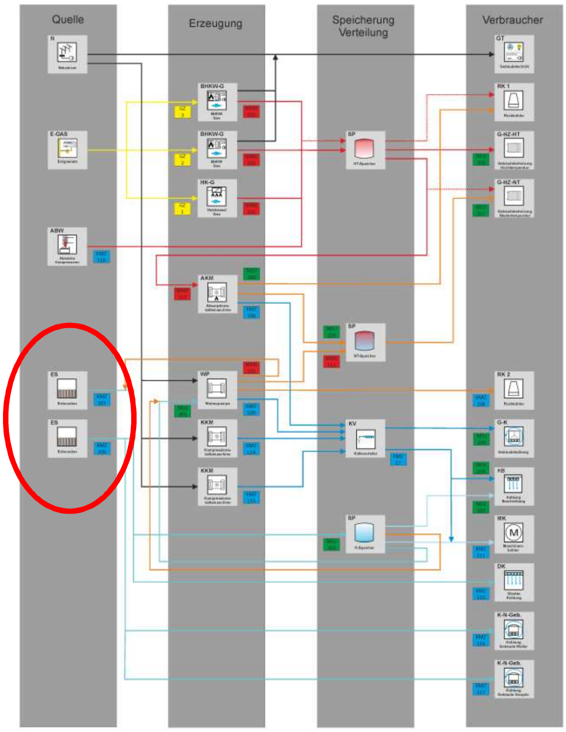

Figure 9: Systematisation of the energy supply system for Leica Camera AG, as basis for monitoring and simulation; columns from left: Energy source (incl. ground storage, encircled in red), energy conversion/transformation, energy storage and distribution, energy consumers.

Some monitoring data of Leica Camera AG from the time before the project start could be used for setting up first simulations for the underground, with a purely conductive model (EED), and with FEM (FEFLOW), Figure 10 shows the temperature development for the first year of operation as calculated with EED 4, based on monthly data for heat injection and extraction (not yet balanced, obviously). In this current version the software is also able to calculate on the basis of hourly, measured data and thus will be suitable for application in this project. The accuracy of temperature calculation with EED 4 has been shown by validation with measured data in another project (Sanner et al., 2016). Also a first FEFLOW model was set up already in the design phase for the Leica project, in order to determine the area of thermal influence in the underground (Fig. 11).

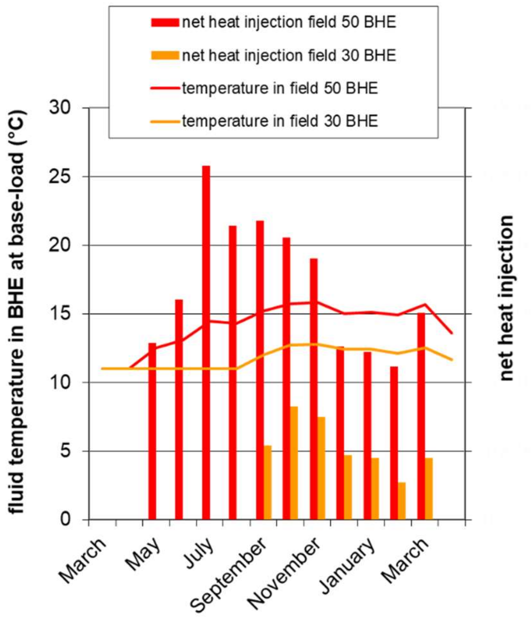

Figure 10: Net heat injection (values suppressed) and resulting temperatures in the BHE field in the first year of operation (2014/15), calculated with EED.

Both geothermal installations are equipped with numerous sensor and measuring points, thus only minor supplements or changes are required in addition to the existing setup. As the project duration is 4 years, monitoring should be operational in spring 2019, to allow for more than two years of monitoring and testing of optimisation measures, and for sufficient time for evaluation.

A further activity in the project is the evaluation of cost and benefits of design and installation of shallow geothermal installations. Finally, the monitoring shall lead to improved efficiency, functionality and reliability of complex energy supply systems based on shallow geothermal technologies for production facilities, and to enhanced accuracy in design and increased efficiency in operation of such installations. The goal is also to improve the possibilities for making use of residual heat and integrating renewable energy sources into the energy supply of production facilities. A substantial contribution to the reduction of CO_2-emissions in the industrial sector is envisaged altogether.

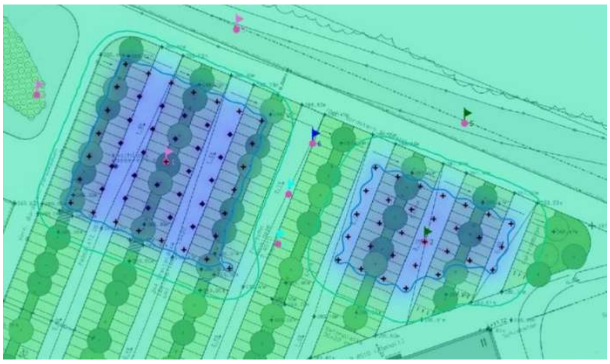

Figure 11: Numerical simulation of temperature influence of the Leica BHE fields, situation after 10 years at the end of the heating season

The project lifetime is May 2018 to April 2022; it is coordinated by the Institute of Optimized Energy Systems (EOS) of Ostfalia University of Applied Sciences, Wolfenbüttel, in cooperation with the Institute for Energy Efficient Buildings and Indoor Climate (EBC) of RWTH Aachen. UBeG GbR, Wetzlar, works on the simulation of the geothermal systems in the framework of the project. Project geo:base is funded by the Germany Federal Ministry for Economic Affairs and Energy (BMWi) under contract 03ET1552.

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