Shallow geothermal energy use in industry in Germany

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ABSTRACT

Use of shallow geothermal energy for industrial purposes goes back to the 1960s, when large aquifer thermal energy storage (ATES) plants were built for cooling within the textile industry in the Shanghai area, China. It took rather long to convince industry in Europe to try shallow geothermal technologies. While the economics looked promising, performance and, most important, reliability was questioned. Meanwhile a good number of successful applications can prove that such worries are unfounded, provided the geothermal systems are thoroughly designed and properly installed.

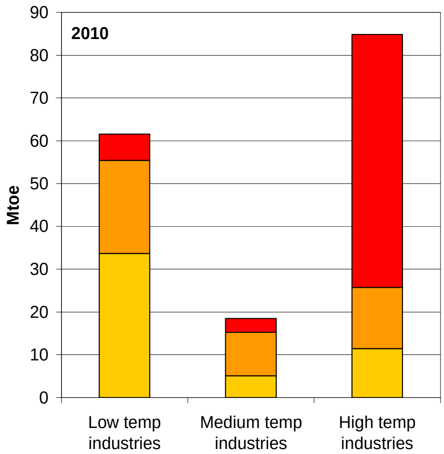
In this paper, an overview of the development of shallow geo thermal energy use for industrial purposes is given, focussing mainly on Germany, but touching some development in other European countries (starting with the EU-project IGEIA, Integration of Geothermal Energy in Industrial Applications, in 2006-2009). System concepts and experiences are presented, both for closed systems (borehole heat exchangers / BTES) and open systems (groundwater wells / ATES), respectively.

Some recent examples are highlighted, like the new headquarters of Leica Camera AG in Wetzlar, Germany, where two borehole heat exchanger fields serve as the central heat source and sink for a rather complex system providing space heating and cooling, and cooling for the machinery of the optics factory. At EGC 2013, the simulations for optimising the design of another project (a borehole heat exchanger field for cooling of a robotics factory) had been presented; now the completion of this project is described. Also a project using groundwater wells is included.

1. INTRODUCTION

The statistics on industrial heat use are not very detailed. Weiss et al. (2009) estimate that the needs of industrial heat users represent up to 44 % of the heat market. Industrial heat demand varies by temperature levels, sectors, countries, and energy supply, since many different industrial processes appear. OECD/IEA uses a distinction as can be seen in fig. 1, while in RHC-Platform (2013), three different temperature levels are used for describing the quality of the demand for heat to be used in various industries:

- Low temperature level up to 95 °C
- Medium temperatures between 95 ºC and 250 ºC
- High temperatures over 250 ºC



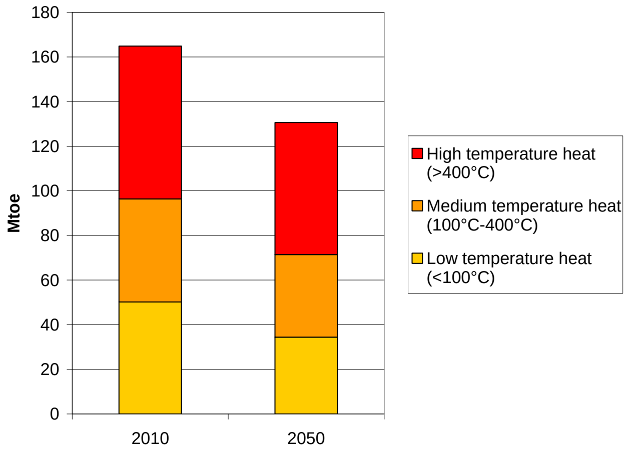


Figure 1: Industrial heat demand by temperature level in the EU in 2010 (left) and industrial heat demand in the EU in 2010 and expected demand in 2050 (right), from RHC-Platform (2013); original data source OECD/IEA, 2012

The low temperature level (<95°C) corresponds to the typical heat demands for space heating. According to Ecoheatcool (2006), around 30 % of the total industrial heat demand is required at temperatures below 100 °C. As can be seen in fig. 1, there is a certain demand for heat at this level even in the high-temperature industries (manufacturing metals, ceramics, glass etc.). With the advance of energy efficiency also in industry, driven by growing energy cost and increasingly strict environmental regulation, the total heat demand in industry is expected to decrease (fig. 1, right); however, the share for low temperature heat will remain substantial.

Low temperature heat is needed for industrial processes like washing, rinsing, and food preparation. Some heat is also used for space heating and on-site hot water preparation. This temperature level is suitable for being covered by shallow geothermal technologies. Typically there is also a certain need for cooling in such installations, providing good opportunities for using the ground as heat source and sink.

RHC-Platform (2013) states on low temperature industrial heat (and cold): "*Geothermal energy can provide heat in the low temperature range […]. Because geothermal energy has definite base-load characteristics, and is always available when required, it matches perfectly with stable demand patterns of most industrial processes. […] Another geothermal technology useful for industrial applications is underground thermal energy storage (UTES). In particular UTES at 40-90 °C can directly supply heat for low temperature industrial needs such as batch processes or seasonal industries (e.g. sugar refineries), where periods of heat (and/or cold) demand are followed by phases of inactivity. […] Geothermal heat can also be used as operating energy for absorption chillers, to supply cooling to industrial processes*." It should be added that UTES for cooling purposes has a proven record of reliability and economy. The first ATES plants in China in the 1960s as well as the first Dutch ATES for a newspaper printer in Amsterdam in 1987 were of industrial cooling character.

1. PROJECT IGEIA

The project "Integration of Geothermal Energy into Industrial Application" (short IGEIA) was supported through the Intelligent Energy Europe program under EC EIE/06/001 and ran from 12/2006 to 5/2009. The coordinator was the French consulting company Saunier & Associés, partners were from Estonia (Enpro), Germany (UBeG), Portugal (EST Setubal) and Sweden (Sweco). The project website is no longer online, however, the main reports are available for download from the UBeG website (www.ubeg.de).

From the project proposal, the objectives were stated as follows: "*Industrial applications constitute the smallest sector of direct geothermal energy use. The industrial sector, at least in theory, offers a very attractive target for geothermal use. Historically this has not translated into extensive use however. The project aims at helping the development of geothermal heating and cooling into industrial sites. We plan to develop geothermal applications in the industrial sector in some countries. We want to convince the industry that the geothermal energy could offer solutions to its energy problems.*"

The project partners worked towards these objectives by identifying energy needs from the industrial sector, investigating industrial sites that permit the use of geothermal application, evaluating the related energy usage, and providing feasibility studies for sample applications in France, Germany and Sweden. The work was complemented by reports on the markets and on incentive schemes in the partner countries. The available deliverables are listed in the references to this paper.

An important part of the project was to prepare three feasibility studies on concrete examples. Two of these, have resulted in actual installations: A supermarket with "total heating and cooling" concept using geothermal as a buffer in Germany, and a borehole thermal energy storage (BTES) system for a foundry in Sweden.

The basic concept of the German project is shown in fig. 2. All heat sources (refrigeration, cooling, air conditioning) and heat users (space heating) are connected to one intermediate circuit, which is connected to the borehole heat exchangers (BHE). As more heat is produced than consumed annually, a fan coil is used to dissipate excess heat into the ambient air.

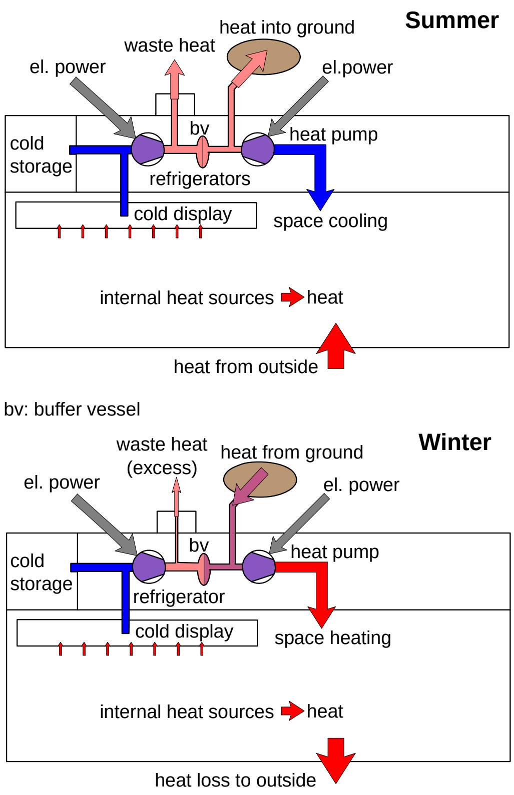


Figure 2: Schematic of a "total heating and cooling" geothermal system for standardized supermarket (from IGEIA D10-DE, 2008)

Three alternative scenarios have been investigated, with coverage of the heat rejection of the central refrigeration system ranging from 15-65 %. The lowest pay-back time could be achieved with 30 % geothermal coverage, i.e. rejecting 70 % of waste heat from refrigeration to the ambient air. However, the straight payback time was calculated to 16 years in 2008, a value that probably will not have improved until today under current German electricity prices. For the final energy consumption a reduction of 45 % and for the related CO_2 emissions a decrease of 28 % could be expected (under German electric power production values of 2008).

The feasibility study resulted in a pilot plant with 16 BHE each 100 m deep installed South of Frankfurt, Germany; fig. 3 shows the drilling for BHE on the construction site. The ground thermal conductivity fro the site as determined by TRT (fig, 3) was only 2.0 W/(m·K), a less than average value. Detailed design, construction and monitoring of that plant were not part of the project and financed privately, so results are proprietary and cannot be released. The basic concept meanwhile can be found in several variations in Germany and neighbour countries.

Figure 3: Drilling for BHE on supermarket construction site (top) and TRT on the same site (bottom), 2008

In the Swedish feasibility study, the objective was to make the recovery of waste heat from a foundry more efficient by using BTES and by using heat pumps in the system. In the storage, waste heat is seasonally stored from the summer to the winter season. The storage is heated to approx. +60 °C at the end of summer and recovered again during winter. The temperature of the storage will then be approximately +40 °C.

The storage was also planned to be used for short term storage of heat during part of the winter. In this case, recharge of heat takes place when the foundry is in operation and recovery is at nights and week-ends. Based on measured data from two years it has been calculated that 3800 MWh of waste heat could be stored. By using a simulation model, Earth Energy Design (EED), it is estimated that at least 2600 MWh (68 %) can be recovered. The rest are heat losses from the storage. In addition, the system comprises two heat pumps, to increase the temperature of waste heat that is not warm enough for a direct utilization. The heat pumps will add another 2200 MWh to the recovery. All together, the system can replace approximately 4800 MWh of bought district heat annually. The pay-back was calculated at 5.5 years.

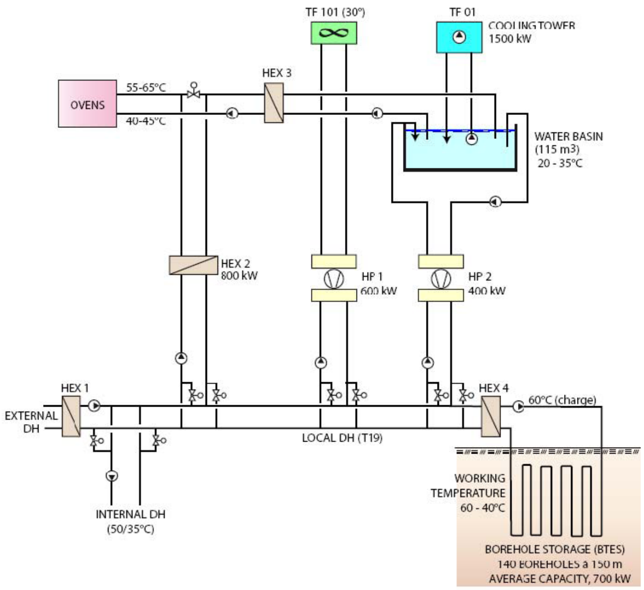


Figure 4: Schematic of BTES plant in Swedish feasibility study (from IGEIA D10-SE, 2008)

The plant based on this feasibility study was constructed in Emmaboda, Sweden, in a factory for pumps (Andersson et al., 2009). A foundry for pump casings (fig. 5) is the source of waste heat.

Figure 5: Foundry in Emmaboda, Sweden, 2007

The BTES system consists of 140 BHE of 150 m depth each. The boreholes act as a heat exchanger to a rock mass of some 600’000 m^3. Heat storage began in late summer of 2010, and until March 2014 the bedrock temperature had increased from 8 °C to about 37 °C. In 2013, about 40 MWh of energy was successfully extracted. When the storage is fully up and running, the plant will be able to cut the amount of district heating it purchases by around 2600 MWh annually. This will allow for avoiding the emission of 8.8 tons of CO_2 per year.

The experiences meanwhile are very good (Andersson and Rydell, 2012; Nordell et al., 2015), and in 2014 the plant (under its new company name Xylem) was in the competition for the EUSEW annual award. The related documentation is still available at:
www.xylemwatersolutions.com/sites/EUSustainableEnergyAward

2. INSTALLATIONS IN GERMANY

2.1 Cooling in industry

Process cooling is a common need in many industries. Targets may be equipment (machine tools, mills, extruders), products from smelters, casting and injection molding, re-cooling in food processing, etc. Some examples are highlighted here.

Verolum Schwalbach

In 1981, Helmut Hund GmbH in Wetzlar, Germany, built a new facility for production of optical glass fibres in Schöffengrund-Schwalbach, For the relatively small building (fig. 6) with glass smelter and extruding equipment 8 BHE of 50 m depth each were drilled as a heat source. This plant, one of the very early GSHP installations in Germany, already had the option to reject heat from the process cooling into the ground via a heat exchanger to the ground circuit. The heat pump was operated only in the heating mode, the main purpose of the BHE installation.

Figure 6: Glass-fibre factory Verolum in Schöffengrund-Schwalbach, Germany; 8 BHE along the left and front side of the building, built 1981, photo from 1995

Feig Electronic, Weilburg

A new, large building for production and testing laboratories was added to the buildings of Feig Electronic GmbH, Weilburg, Germany, in 2009. The limitations in area required to locate the BHE underneath the new building (fig. 7), and to use relatively deep drilling of 250 m. BHE such deep are more common in Sweden and Switzerland, but still not found often in Germany. They are currently restricted to areas with hard rocks, like in the Black Forest or in the Rhenish Massif, as is the case for Weilburg (fig. 8). The low annual mean temperature and a geothermal gradient at or below average allow for efficient cooling also with deep BHE (the UBeG offices in Wetzlar are heated and cooled using even deeper BHE of 300 m depth).

Figure 7: Drilling of 250-m-boreholes from the planum of the construction pit for the new building, 2008

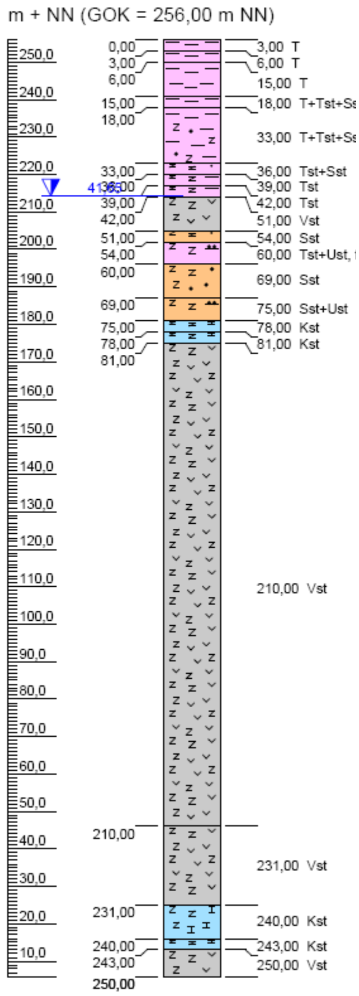


Figure 8: Lithological cross-section of 250-m-borehole for BHE in Weilburg: Devonian shale (Tst), sandstone (Sst), and conglomerate (Vst, local name “Schalstein”), with few limestone banks (Kst)

The BHE installation in Weilburg consists of 15 boreholes, each 250 m deep, with double-U-BHE made of PE-pipes with 40 mm diameter. The heat pumps supply up to 250 kW of heat to the building, and about 100 kW of cold can be used for cooling in the production processes (and for space cooling in summertime).

Automotive supply manufacturer, Regensburg

The triangle Munich-Ingolstadt-Regensburg in Bavaria is not only know for good beer (the Hallertau region, in the centre of that triangle, is the main hops-growing area in Germany), but is also a major centre for car manufacturing and home of BMW and Audi. Beside the main car manufacturers with several plants in the region, numerous suppliers for the automotive industry are located nearby. One of the major suppliers operates a large facility in Regensburg, in the wide valley of river Danube.

The site is located in an area of Cretaceous sandstones with thin Tertiary cover. The calcareous sandstone banks are fractured and form a suitable aquifer. The shallow aquifer within the gravel deposits at the edge of the Danube valley is not thick enough to yield the necessary water, so wells were drilled into the sandstone layers down to a depth of 50-70 m (table 1).

Table 1: Wells for the Regensburg plant

	Injection		Production	
	VB1	VB5	VB2	VB3
Depth (m)	72	55	63	49
Inner diameter (mm)	250	350	250	350
Top of screen (m)	26.2	25.0	32.5	25.0

In addition monitoring well VB4, approximately 50 m deep

The wells required thorough de-sanding and in few cases acidification in order to achieve the necessary yield and injection rates. After well tests at individual wells, a joint pumping test using all wells as planned for the final installation was done in 2006 (fig. 9). This test proved that:

- An amount of 60 l/s (216 m³/h) can be produced and re-injected without problems
- The hydraulic impact is limited to the factory site
- Groundwater wells for drinking water supply in a neighbouring village are not affected

Figure 9: A production well at the Regensburg site with measuring device, during the pumping test with all wells coupled, February 2006

The original estimation of the thermal impact area of the aquifer system was done with the CONFLOW software (Probert, 1995). This easy-to-use program provided quite reliable predictions of the thermal front (fig. 10), as was confirmed during the monitoring phase (see below). Today, most thermo-hydraulic simulations for thermal uses in aquifers are performed with numerical simulation, and the FEFLOW software is the one used primarily in UBeG. However, the perceived accuracy of numerical simulation can be misleading; depending on the quality of input data, even lengthy simulations cannot achieve higher rate of accuracy than the simple design programs.

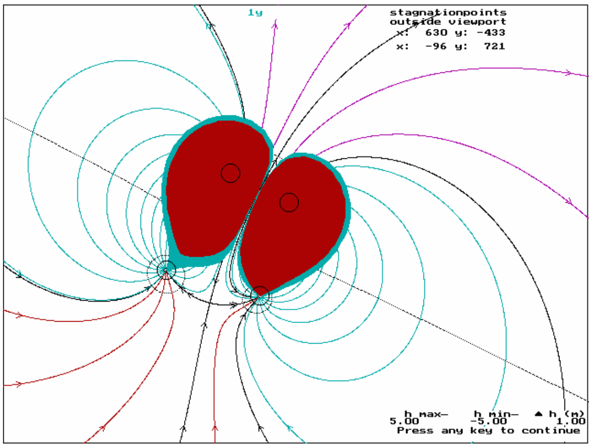


Figure 10: Thermal front prediction of 2005 using CONFLOW, with well VB4 intended as injection well; the width of the graph represents 800 m

The wells are part of the system supplying thermal energy to building with offices, laboratories and production facilities. The heat is distributed within the buildings by water loops to radiators and to structural concrete slabs (floor/ceiling) with pipes inside. Thus the building structure serves for thermal storage and for release of heat or cold, depending on the temperature within the rooms. Heat and cold is also provided for machinery and for process cooling. The energy supply is secured by the wells via heat pumps (heat or cold), directly by the wells (cold), and by a district heat connection (fig. 11); conventional chillers serve as backup for process cooling.

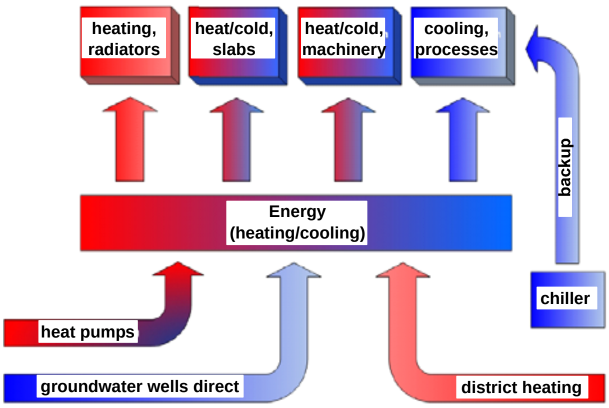


Figure 11: Schematic of thermal energy supply for Regensburg plant

The design values of the system are:

Heating capacity heat pumps	1014 kW
Evaporator capacity (heat extraction)	840 kW
Δt groundwater circuit for heating	4 K
Groundwater pumping for heating	180 m^3/h
Cooling capacity direct cooling	1500 kW
Δt groundwater circuit for cooling	6 K
Groundwater pumping for cooling	216 m^3/h

The system is thoroughly monitored on order of the water authorities, and also was part of a scientific monitoring carried out by the University of Hannover in cooperation with UBeG (plant 3 in Bohne et al., 2012) The measured overall annual performance factor of 4.0 is not fully satisfactory, and several reasons could be identified and suggestions for mitigation were made. These include a better de-coupling of the higher temperature level in the radiator circuit from the lower level required for the circuit in the concrete slabs (fig. 11), and a better control of the well pumps.

The temperature measurements allowed for reconstruction of travelling time of the thermal front. Of the 5 wells drilled only 3 were actually used during the period considered; VB5 is the injection well, while production is done in wells VB2 and VB3. Injection well VB1 had serious clogging problems and thus was isolated. Because of the good performance of VB5, no second injection well was required at the given level of operation. VB4 is a monitoring well. The travel times of thermal signals from injection well VB5 to the production wells are shown in figure 12.

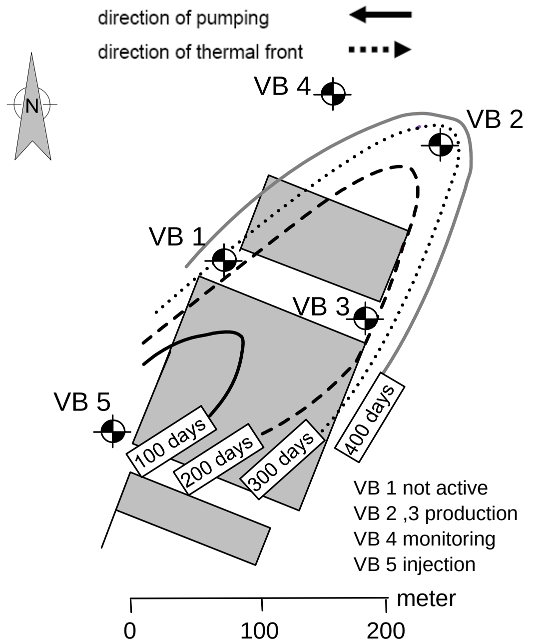


Figure 12: Travelling time of the thermal front from injection well VB5 after measurements in the period 2007-2011

As the aquifer consists of fractured calcareous sandstone, the groundwater flow is following a preferred direction, resulting in a narrow thermal front. The use of the wells originally was planned in the opposite direction and with VB4 as active well (later replaced by VB5), thus the CONFLOW results from the design phase as shown in figure 10 are reversed. However, the thermal front is in the same order of magnitude as predicted, considering the lower pumping rates in the project phase concerned, than in the design parameters

The only problem with the well system was with temporary clogging in injection well VB1 as mentioned before, due to improper filter functioning. Otherwise the system proved to be reliable, and the owner currently is investigating the possibility to enlarge the system for serving also planned new building additions.

<u>Robotic actuator manufacturer, Limburg</u>

A company for robotic drives and actuators near the city of Limburg, Hessen, erected a new production hall in immediate vicinity to the existing faciltiy. An existing gas boiler can be used for the peak-load heating of the new building. The high cooling demand for the machines and the air-conditioning of the new building should be covered by a BHE-installation. The design calculations had to secure the base load for heating of the new building, and as much cooling from the underground as possible. This was achieved by using the seasonal storage effect with additional diurnal storage of night-time cold.

The installation cools down (or re-cools) the underground with a conventional cooling tower during night time, and uses the cooled underground for cooling the building and machinery during day time. The cooling tower should be used for re-cooling the ground only with free cooling. Such a concept had been devised already by UBeG for a large retail store in the South of Spain (Fernandez et al., 2012). The determining factor in the Limburg project is the high industrial cooling demand. The engineering task was to determine the possible amount of cooling for the building that could be covered from the planned field of 50 BHE, comprising normal heat dissipation, seasonal storage of heat and cold, and diurnal storage with re-cooling at night. The simulation also did determine the optimum flow rate between cooling tower and underground, in order to achieve the most economic re-cooling, and identified the optimum setpoints for control of pumps and fans for high heat transport with low electric input.

The ground parameters as determined by TRT are:

Thermal conductivity λ	2.4 W/(m·K)
Undisturbed ground temperature T_0 (average for the depth 10-150 m)	10.8 °C

The design simulations to determine this optimum operation strategy are described in Mands et al. (2013). The basic design of the BHE field was done using EED calculation, and the determination of thermal impact area (requirement from authorities) and the operational strategy by numerical (FE) simulation (fig. 13). The optimisation of cold storage (seasonal and diurnal) resulted in a theoretical increase of the available energy for cooling from about 800 MWh/yr in the standard design case to more than 2000 MWh/yr in the final case, without enlarging the BHE field.

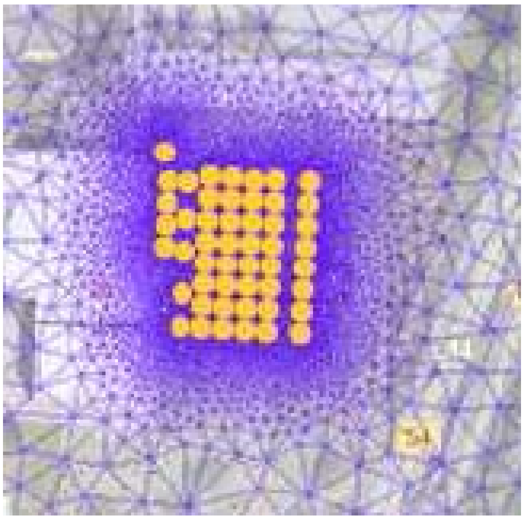


Figure 13: Central part of the FE-grid for simulation of the Limburg BHE installation, showing the pattern of the 50 BHE

The plant is operational since 2012, and the main parameters are:

50 BHE each 150 m deep	
Heat extraction from BHE	250 kW
Heat pump heating capacity	ca. 320 kW
Cooling capacity (heat injection into BHE)	250 kW

2.2 Complex system: the Leica headquarters

The new headquarters of Leica Camera AG in Wetzlar, Germany, have been inaugurated in May 2014. The office part evokes the aspect of old film rolls, the heritage of photography (fig.14).

Figure 14: Leica buildings with main entrance, exhibition and offices; the production facility is in the back

Prior to the concrete planning, 2 test BHE for TRT were installed in 2008. The resulting thermal conductivity of the underground was 3.2 and 3.5 W/(m·K), respectively, an excellent value for the area. The design calculations were performed with EED. It was clear from the beginning that BHE would only be able to deliver a part of the total heating and cooling load of the facility, and thus an optimisation along the following lines was attempted:

- Available ground area for BHE (under consideration of future building plans)
- Ground-side design for high COP and seasonal performance factors, both for heating and cooling
- Securing a substantial part of cooling in direct cooling mode (without heat pump operation)

As a result, a plant with 80 BHE of 120 m depth each was designed and installed (total 9.6 km of drilling). The maximum heating capacity is approx. 800 kW, a decent share of the total heat load. Cooling can be provided actively with a heat pump or direct via heat exchanger to the ground circuit, with a planned capacity of 560 kW. The installation should be operated in such a way that a thermal balance is kept on the underground side.

Active cooling with heat pump means that the temperatures in the BHE soon will exceed the level of 16-20 °C suitable for direct cooling. In order to be able to provide in summertime both active and direct cooling for different users, the BHE are divided into two hydraulically separated fields of 30 and 50 BHE, respectively (fig. 15). Numerical simulations were performed to check that there is no thermal interaction between the fields, and that there is no thermal influence outside the actual building lot (a requirement coming from mining legislation in Germany).

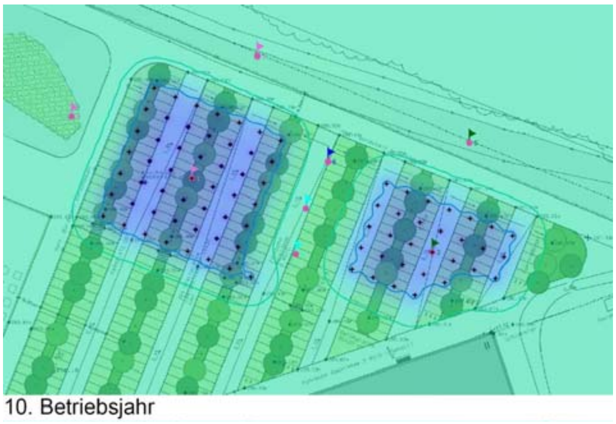


Figure 15: Numerical simulation of temperature influence of Leica BHE field, situation after 10 years at the end of the heating season

Drilling and BHE-installation was done early in 2012. In order to keep the time for this works short, 3 drilling rigs were in operation simultaneously all the time (fig. 16), and in peak times even 4. A central manifold was installed in each of the two BHE-fields, and separate pipe loops connect them to the mechanical room in the building.

The BHE installation and heat pump are only a part of the complex system for heat and cold supply. A simplified schematic is shown in fig. 17. The high importance of space conditioning for the demanding production processes requires sufficient redundancy. Buffer storages as well on the warm as on the cold side (the water tank of the fire sprinkler system acts as cold storage) secure steady supply also for peaks, and can bridge shorter gaps in heat or cold production.

Figure 16: Drilling for Leica BHE field with 3 rigs in parallel, February 2012 (top) and manifold for the field with 50 BHE (bottom)

Two units of different size for combined heat-and-power generation (CHP) and the geothermal heat pump provide the heat, with a condensing gas boiler for peaks and as backup. For high heat demand, power from the CHP drives the heat pump, and the heat from CHP and heat pump is supplied to the building. Economic optimisation allows for prioritising of the heat source with lowest momentary fuel cost. Several sources exist also for cold production, First is direct cooling from the BHE, then active cooling via heat pump and heat rejection into the BHE, and finally an absorption chiller rejecting heat to ambient air. For high cold demand, heat from CHP activates the absorption chiller, while the heat pump operates on electric power from CHP. The division into two the BHE-fields allows for simultaneous direct cooling and active cooling with heat pump. A separate, conventional, air-cooled chillers acts as backup.

The control of such complex system requires some time for adaptation and optimisation. The direct cooling of production machinery worked very well; it was so efficient, that in the first year more heat from process cooling was rejected into the ground than was extracted for heating, as monitoring revealed. A short-term strategy for thermally balancing the BHE field was devised, and plans exist for further long-term optimisation. This will allow to keep the operation at the economic optimum while securing the building supply with heat, cold and electric power, and respecting the limitations set forth by authorities.

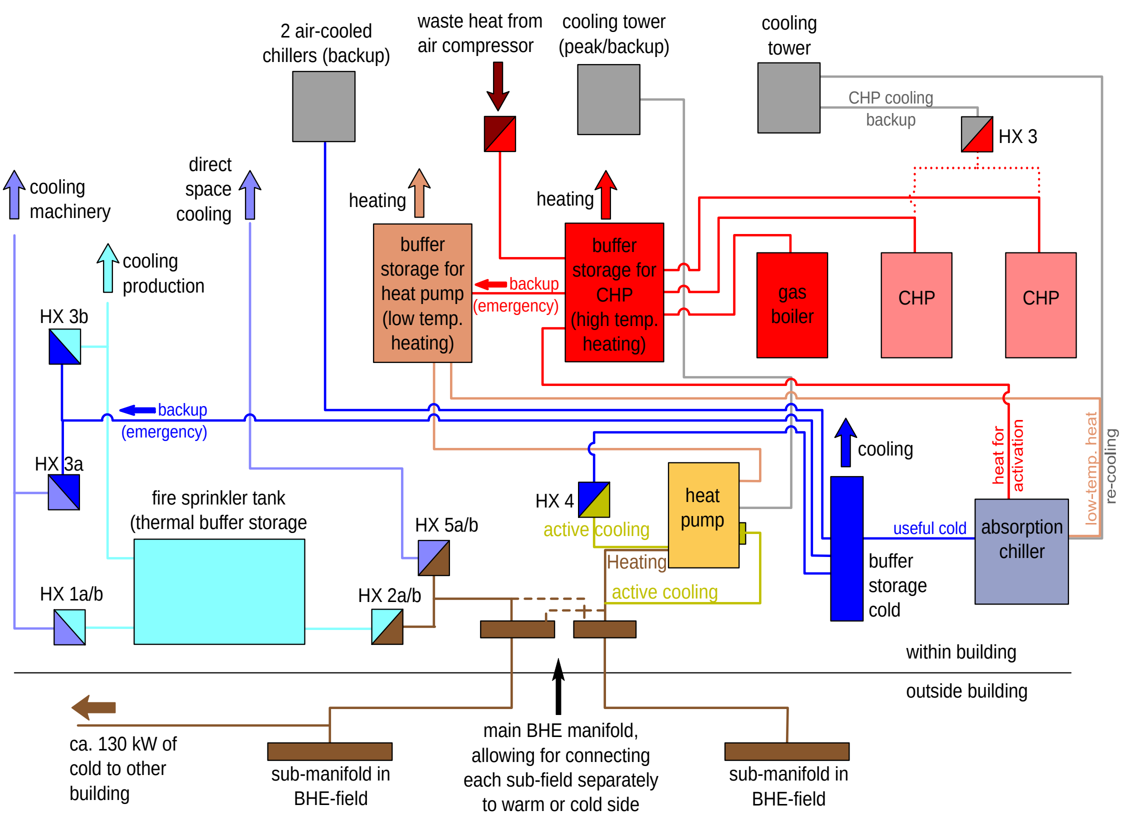


Figure 17: Simplified schematic of the Leica energy system

3. CONCLUSIONS

Shallow geothermal technology is highly suitable for industrial application, mainly in the form of thermal energy storage in the underground (UTES), with or without the use of heat pumps. Also classic geothermal heat pump systems when used in industrial environment usually make some use of underground storage effects, as the examples in this paper show.

The use for cooling purposes and for low-temperature heat (up to about 50 °C) is routinely done, with proven 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 Emmaboda example from the IGEIA project is one of few applications. Temperatures close to 100 °C or higher do not seem suitable for shallow geothermal technologies, as the French experiments in the 1990s showed (Caizergues, 1998). 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 inaugurated in Rittershoffen, France, in June 2016; more info at: http://egec.info/a-world-first-for-geothermal-deep-egs-heat-plant-for-industrial-use-inaugurated/ .

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