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Optimization of ground coupled heating and cooling supply systems in office buildings – reversible heat pump and free cooling

Franziska Bockelmann[1], M. Norbert Fisch[1], Lars Kühl[2], Tim Petruszek[2], Fritz Nüßle[3], Burkhard Sanner[4]

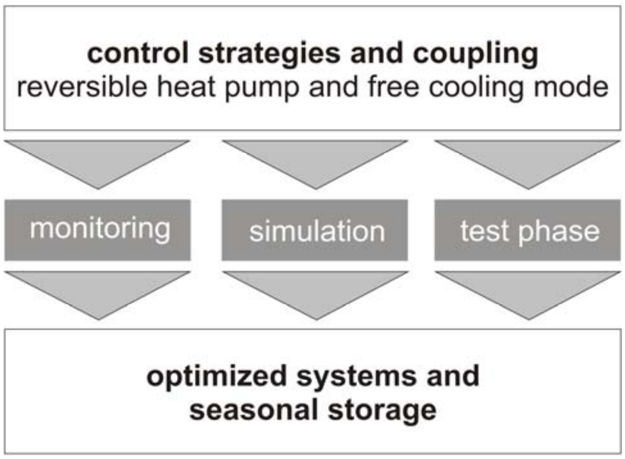
[1)] Technical University of Braunschweig IGS – Institute of Building Services and Energy Design, Mühlenpfordtstraße 23, 38106 Braunschweig, Germany, Phone: 49-531-3913557, Fax: 49-531-3918125, e-mail: bockelmann@igs.bau.tu-bs.de
[2)] Ostfalia University - Fakultät Versorgungstechnik, Wolfenbüttel
[3)] Zent-Frenger GmbH, Heppenheim
[4)] UBeG GbR, Wetzlar

1. Introduction

The use of near-surface geothermal energy and the potentials of the ground as a seasonal heat storage help to conserve fossil fuels. To ensure this in the future, further complex researches in this field are required. Special focus should be given on the interaction between heat extraction and heat injection. Moreover an investigation of the integration into the overall energy concept in building as well as the implementation of hydraulic and control technologies regard to the local conditions are indispensable for optimal operation.

Within the scope of the ongoing R&D-project "*geo*:**build** - Optimization of ground coupled heating and cooling supply systems in office buildings - reversible heat pump and free cooling", funded by the Federal Ministry of Economics and Technology (BMWi, FKZ 03ET1024A), ground coupled supply systems for heating and cooling are being analyzed both in theory and practice. The project is conducted by the IGS - Institute of Building Services and Energy Design at the Technical University of Braunschweig in cooperation with a scientific partner and the two industrial partners. The major focus of the 3-years project is to study an adjustment of the cooling modes and switching between free cooling and chiller. In a further phase of the project a development of energetic and economical sensible combinations of these technologies is predicted (Figure 1).

Figure 1 Proceeding



2. Underground thermal energy storage systems and principle of seasonal thermal energy storage

Drilling a borehole heat exchanger system in the immediate surrounding area of or below the building is one of the ways to use heat and cold storage capacity of the ground. Borehole heat exchanger storages consist of a single or a network of boreholes. The achievable depth of boreholes is practically unlimited, but a length between 50 m and 150 m, has proven to be economically feasible (Figure 2, left).

Taking advantage of synergy effects from pile foundations or foundation boards, including workload and cost reduction, the use of the thermal potential of the ground for heating and cooling should be taken into account in the design-/ construction-phase of the building. Typically, foundation piles or foundation slabs are turned into heat exchanger so-called "energy piles" or "foundation / floor absorbers" for storing thermal energy in the ground. In these cases the static calculation limited the heat transfer surface.

In the energy piles the probes are part of the foundation piles of the building. The production of energy piles differs only in the implementation of the necessary piping system into the usual production (Figure 2, middle).

For both closed geothermal systems, the heat transfer medium normally consists of a brine (water-antifreeze mixture e.g. glycol).

Beside closed systems there is a well, which is used as an open system with groundwater as heat transfer medium The groundwater is pumped out of the extraction well, thermally used and then returned back into the ground through the injection well. An important aspect for keeping the operation of a well system upright is the water quality. A high concentration of iron or manganese in the groundwater can cause sedimentation of iron ochre in the heat source system. In order to avoid a thermal short circuit between the wells, it is important to keep enough distance between extraction and the injection well in the groundwater downstream region. (Figure 2, right)

A significant advantage of a well system compared to a closed system is the relatively simple and cheap feasibility. The groundwater is directly used as the heat transfer medium. A loss of efficiency or reduced output power due to heat transfer processes is clearly reduced. On the other hand these systems consume more electrical pump power for the extraction and injection well.

Figure 2 Coil with borehole heat exchanger pipes (left), energy pile / foundation pile (middle) and well [source: IGS, TU Darmstadt and IEK University Hannover]



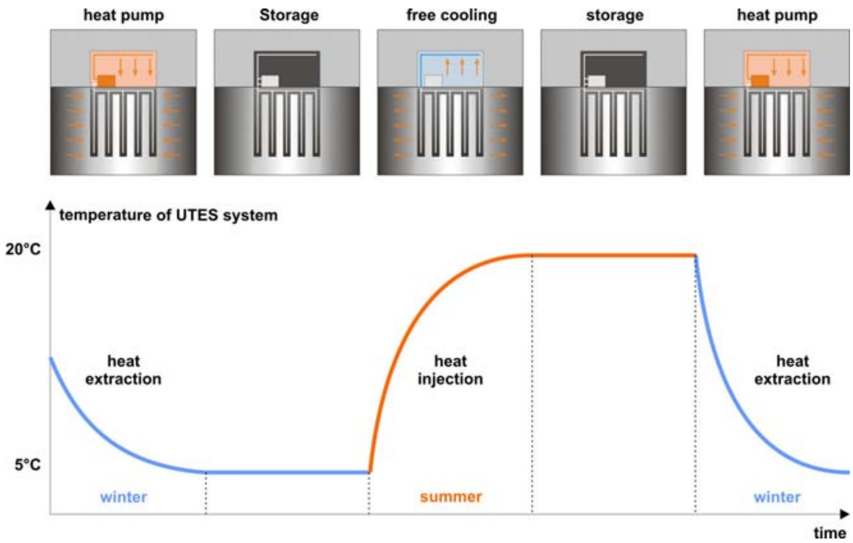
Using the ground for heating and cooling purposes in buildings, the heat will be injected and extracted into/ out of the ground in a seasonal change.

An advantage of using the ground for heating and cooling buildings is the relatively constant temperature level of the ground over the year. Thus, the soil, for example, can be used for the efficient free cooling mode, without the use of chillers, even at high outside temperatures in the summer.

A requirement for long-term functionality of the system is an active cooling of the soil during the winter and heating the soil in the summer, to reach a thermal energy balance in the ground.

During the winter the heat extraction will occur by using a heat pump, which raises the temperature level by the required amount to heat the building. In the summer, the heat transfer fluid is heated in the building and will be cooled down in the ground. (Figure 3)

Figure 3 Model of seasonal thermal energy storage in the ground



3. Methodology of the research and development project

The R&D-project is divided into six work packages (see Figure 4). The focus is on the monitoring of five office buildings (see Table 1) with a reversible heat pump and free cooling mode as well as the analysis of their operation strategies, operating system functions and energy performance.

Additionally building and plant simulations as well as simulations of heat extraction and heat injection into the soil and its thermal behavior will be carried out for two or three of them. The knowledge acquired from the simulations will be implemented and tested.

Figure 4 Work packages

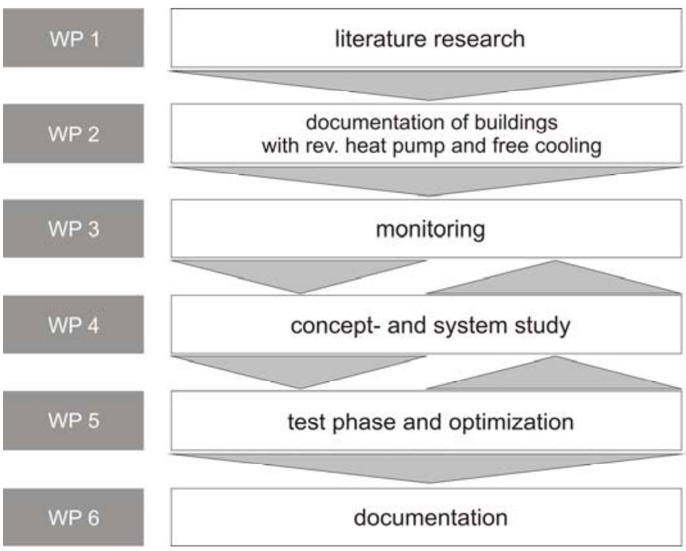


Table 1: Data of building, geothermal systems and heating-/cooling concepts of the monitored buildings

Gelsenwasser AG, Gelsenkirchen		
	building data	office building NFA 6.189 m² year of construction 2004
	geothermal system	36 borehole heat exchanger à 150 m
	design heating load	total building 207 kW / 43,6 W/m²$_{NFA}$ heat pump 326 kW
	design cooling load	total building 305 kW / 9,3 W/m²$_{NFA}$ free cooling 200 kW rev. heat pump 320 kW
VGH Regionaldirektion, Lüneburg		
	building data	office building NFA 3.957 m² year of construction 2002
	geothermal system	101 energy piles à 20 m
	design heating load	total building 350 kW / 88,5 W/m²$_{NFA}$ heat pump 85 kW
	design cooling load	total building 120 kW/ 30,3 W/m²$_{NFA}$ free cooling 80 kW rev. heat pump 89 kW
Office Freundlieb am See		
	building data	office building NFA N/A m² year of construction N/A
	geothermal system	24 borehole heat exchanger à 100 m
	design heating load	total building N/A kW / N/A W/m²$_{NFA}$ heat pump 90 kW
	design cooling load	total building N/A kW / N/A W/m²$_{NFA}$ free cooling N/A kW rev. heat pump N/A kW
Lecture hall, Salzgitter		
 [agn Niederberghaus & Partner GmbH]	building data	lecture hall building NFA 3.296 m² year of construction 2012
	geothermal system	12 borehole heat exchanger à 95 m
	design heating load	total building 180 kW / 55 W/m²$_{NFA}$ heat pump 60 kW
	design cooling load	total building 225 kW / 68 W/m²$_{NFA}$ free cooling 60 kW rev. heat pump 45 kW
Bonner Bogen - Kameha Grand Hotel		
 [BonnVisio/Bonner Bogen]	building data	hotel NFA 21.000 m² year of construction 2012
	geothermal system	Well system à 28 m (3 production and 3 injection wells, seasonal reversal)
	design heating load	total building N/A kW / N/A W/m²$_{NFA}$ heat pump 919 kW
	design cooling load	total building N/A kW / N/A W/m²$_{NFA}$ free cooling ca. 900 kW rev. heat pump 625 kW

4. First monitoring results - fundamentals

The collected experiences from the preliminary project WKSP - heat and cold storage in the foundation area of office buildings (BMWi, FKZ 0327364A) are the basis of carried out monitoring and further optimizations in the research project *geo*:**buid**.

First optimizations and bug fixes are implemented in the buildings VGH and Gelsenwasser AG regarding the performance of the systems, heat injection and heat extraction to achieve an even balance in the soil (

Figure 5 and Figure 7) as well as the implementation of the designed operation.

The design goals concerning more efficient use of the free cooling mode compared to the chiller operation was still not yet been adequately implemented. This is where ***geo***:**build** starts.

VGH Regionaldirektion, Lüneburg

Based on the heat injection and heat extraction (

Figure 5) it becomes clear that until 2007 no planned heating or cooling operation of the geothermal system has been scheduled.

To increase the extraction of heat from the soil and to establish a systematic heating and cooling mode, the following measures and optimizations have been implemented as part of the first monitoring:

- Elimination of design errors in the concrete core activation system (e.g. improperly installed valve)
- Elimination of control errors in the building management system (BMS)
  - Modification of the calculation of the mean ambient temperature
  - Adaption of heating and cooling boundary set point temperatures
  - Adjustment of the heating and cooling curves of concrete core activation and ventilation systems
- Localization of errors in the internal controller of the geothermal heat system
- Implementation of the heating operation in spring 2007
- partial realization of the cooling operation in summer 2009

Through the carried out optimization measures and the implementation of the designed cooling operation the ratio of cooling supply by chiller to free cooling in the year 2007 was from 89% to 11% and will be reduced in 2009 from 55% to 45% (see Figure 6). There is no information on the designed proportion of compression chiller/ free cooling.

Due to the high heat extraction and the resulting unbalanced energy balance in the soil (

Figure 5), the temperature level in the soil is very low. Thus, a further reduction of the chiller operation and implementation of the efficient free cooling mode should be possible.

Figure 5 Monthly heating extraction and injection as well as ambient temperature (VGH), 2005 – 2009

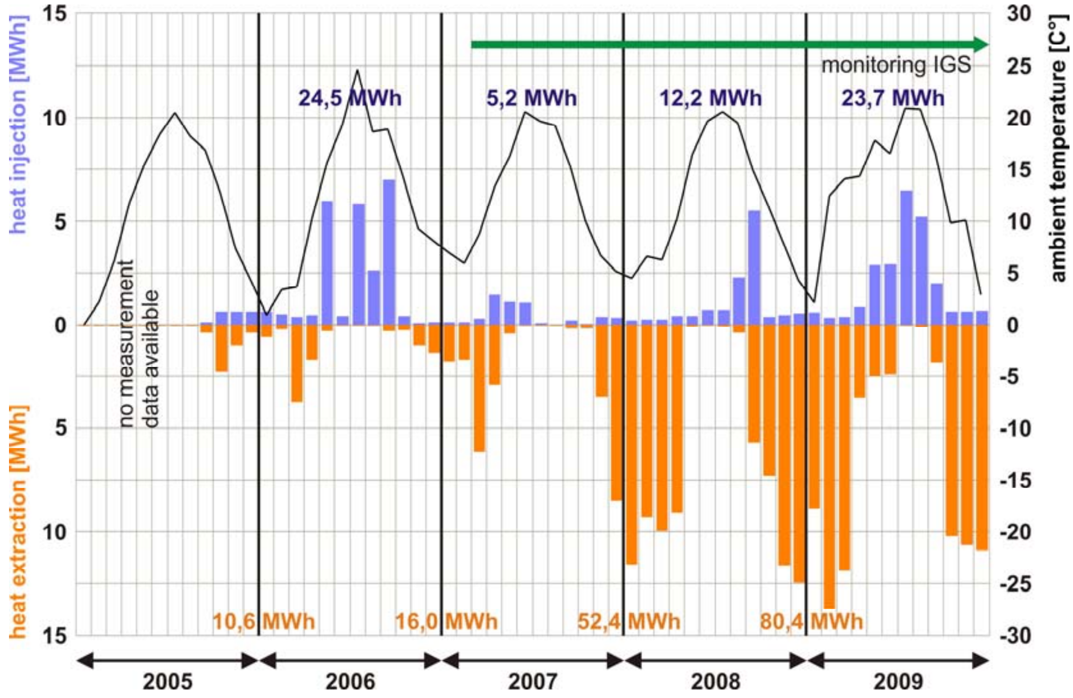
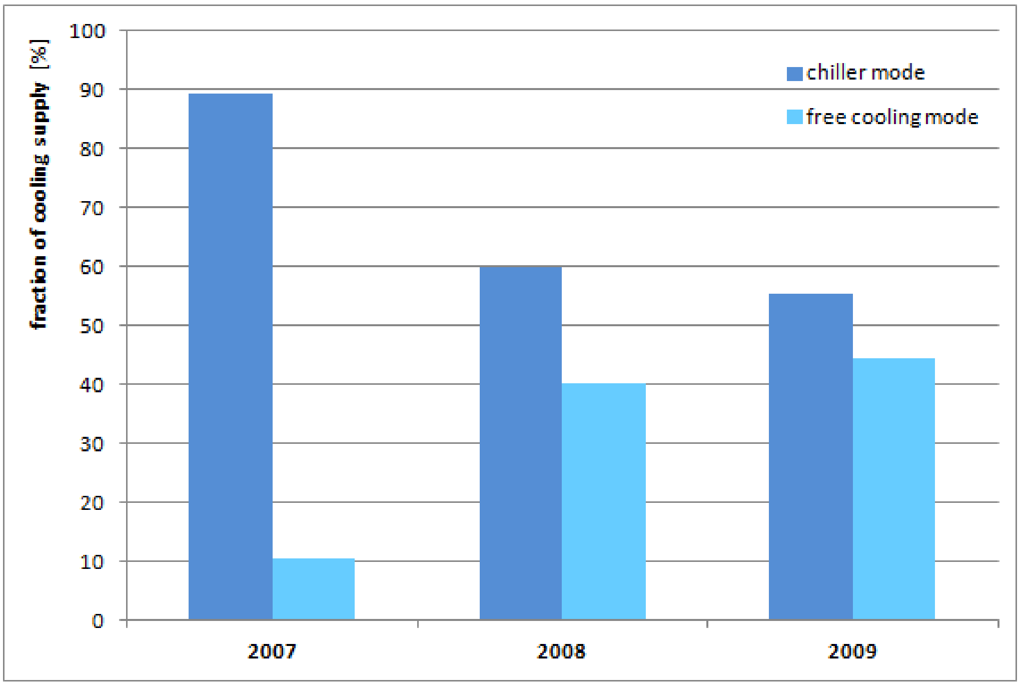


Figure 6 Percental distribution of cooling supply by free cooling and chiller mode (VGH), 2007 – 2009



Gelsenwasser AG, Gelsenkirchen

In Figure 7, the heat injection and the heat extraction for the years 2006 to 2009 are presented. During the four years significantly more heat was injected into the soil than extracted. The heat came e.g. from the building itself (combined operation mode) and the high fraction of the chiller. The result is a warming of the soil to an unfavorable temperature level for free cooling mode, so that during the cooling mode mainly the chiller was operating.

According to the planning documents for the Gelsenwasser AG, a ratio for cooling supply by the free cooling mode and chiller provided by 68% to 32%. However, to date, it was only possible to achieve a ratio of 30% to 70% (see Figure 8).

As part of the existing monitoring, measures and optimization were carried out to minimize the heat injection, in particular the combined heating and cooling mode and to reduce the high fraction of chiller operation.

Measures and optimization:

- optimized ventilation strategy:
  - No cold supply during office hours at low outside temperatures
    - ➔ use of self cooling through the building envelope and the supply air gills
  - No space cooling during the night when the outside temperatures are less than the room temperature
    - ➔ use the free night cooling
- Changing the control strategy of the geothermal system:
  - Increasing the temperature limit (outlet temperature from the ground heat storage) for approval of operating chillers

Figure 7 monthly heating extraction and injection as well as ambient temperature (Gelsenwasser AG), 2005 - 2009

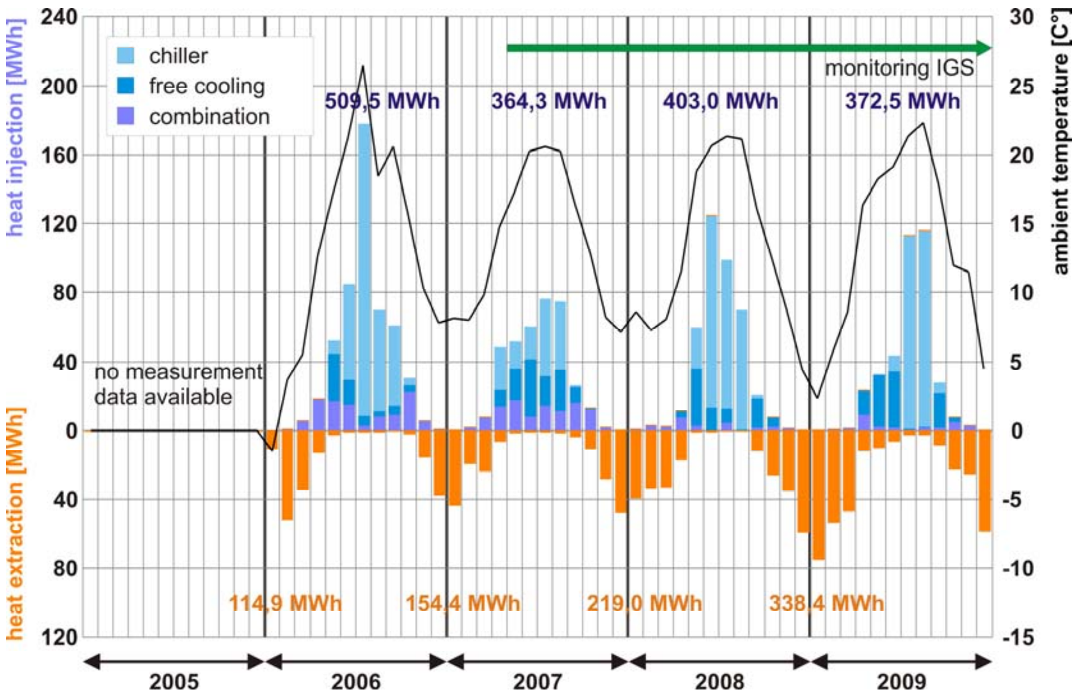
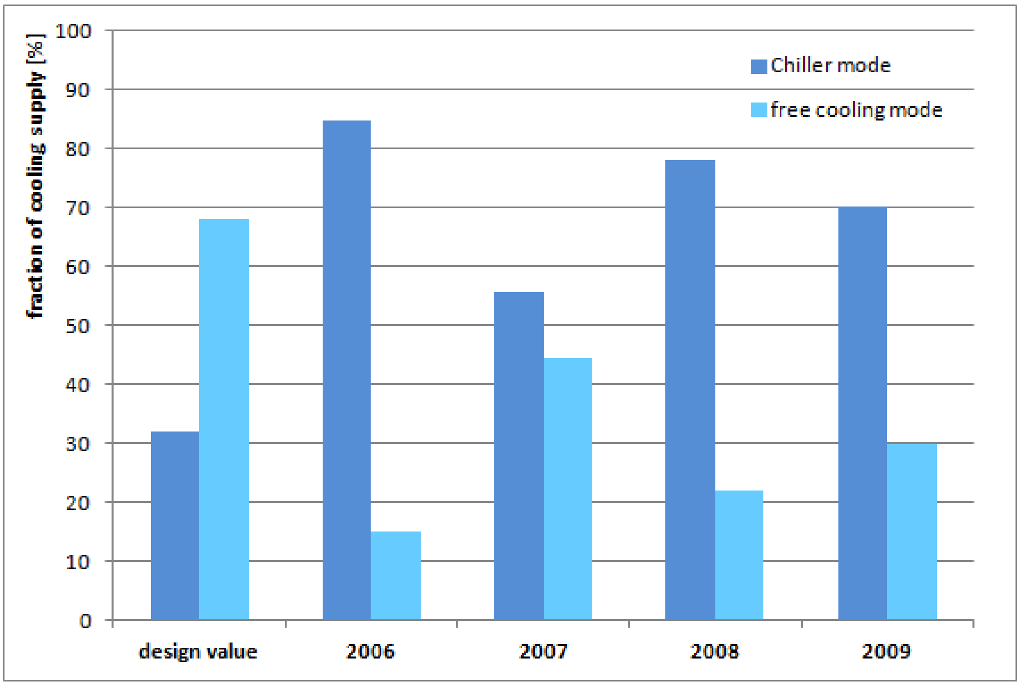


Figure 8 Percental distribution of cooling supply by free cooling and chiller mode (Gelsenwasser AG), 2006 – 2009



5. Aims of the project

The aim of the R&D-project *geo*:**build** is to optimize the implementation of geothermal heat and cold storages as well as to develop and test more efficient use of these storages. To achieve an improved storage efficiency ratio, optimized operation strategies and application-oriented storage concepts should be further developed and evaluated in particular with ground coupled chiller and the operation of switching between chiller and free cooling mode. Approaches to regulation and interpretation of the investments in terms of

- operation and control concepts enabling an immediate switching between chiller and free cooling mode,
- potentials of an intermittent operation of the probe field,
- the regeneration phase between chillers operation and free cooling mode,
- a constant thermal conditions in the soil as well as a realizable heat extraction and heat injection, the available load to the building and the relationship between heat extraction and heat injection

should be processed.

Furthermore, it should be clarified, if it is possible to achieve first reliable estimations of dimensioning at an early stage of planning based on building designs (A/V ratio, orientation, thermal protection standards, ...) as well as the proposed usage or the operation of ground coupled systems for heating and cooling.

6. References

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