Geothermal Information System for Potential Studies in Subsurface Soil Layers

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Abstract

The exploitation of shallow geothermal energy is challenging with respect to planning, dimensioning and approval procedures. All of these processes, as well as the achievable prediction accuracy, significantly depend on the data consistency. To reduce the complexity, all necessary data should be gathered in one database, serving as a tool in which the prementioned processes can be performed. This paper presents the geothermal information system GeTIS. It provides geothermal-related information that is needed by house owners, engineers and public authorities. Furthermore, it provides 3D subsurface and building performance simulations up to city district scale as well as plug-ins for the simulation tool FEFLOW. The used methods and standards are described and preliminary results of a practice-orientated dimensioning of a geothermal plant are presented.

Introduction

Geothermal energy systems are able to cover building heating and cooling loads and to store energy in the ground. In 2015, the percentage of end energy consumption in Germany providing space heating and domestic hot water adds up to 32 % (2400 PJ, (BMWI, 2016)). Still, geothermal energy covers only 0.072 % of the primary energy consumption. High investment costs are one of the reasons for the low utilisation, although geothermal systems redeem quickly due to small operational charges. These costs are caused by the exploitation of the energy source (e.g. drilling, purchase of heat pump and plant system) as well as by planning the geothermal system and lowering initial risks (e.g. via soil expertise, engineering consulting, economical and technical feasibility analysis). Moreover, long time efficiency of geothermal plants is only given if a good replenishment of geothermal energy is ensured. Therefore, processes in the subsurface such as groundwater flow and interaction of neighbouring ground source heat exchangers (GSHE) have to be considered. Spatial and legal limits restrict the utilisation or complicate the planning process.

In respect of the high potential (8000 GWh heating energy by shallow ground source heat pumps in 2013 in Germany[1]) and the German energy policy (German Energiewende, Renewable Energy Heat Act) geothermal energy provides a sustainable energy source. The research project Geothermal Information System[2] (GeTIS) presented in this paper, aims to simplify planning and approval procedures as well as system operation processes. The combination of long term subsurface and building performance simulations at a scale up to city districts with a geothermal information system increses the prediction accuracy.
The first step in the process of planning geothermal systems is the analysis of local conditions. Hydrogeological properties are crucial for the estimation of productivity. Unfortunately, a consistent data set providing all necessary information is not available. Some information can only be obtained in non-digital form for example in libraries or repositories of geological, research and university institutes. Other data are offered in digital form by service-providing institutions, often in various format types and accessible by different methods. Therefore, acquiring and collecting data can be time and cost consuming. Based on these data, an evaluation by geothermal aspects can be done.
However, especially for borehole heat exchangers (BHE) with high performance, a thermal response test and a simulation are recommended. Engineering offices offer those subsurface simulations using analytical, semi-numerical or fully-numerical methods. The latter two are used especially for complex situations occurring for example at distinct groundwater flow, neighbouring plants, thermal storage, well installations and long-term simulations. Semi-numerical models based on the work of Eskilson (1987), coupling 1D thermal resistance models of the geothermal devices and the 3D subsurface model, are already implemented successfully in expert tools like FEFLOW (DHI-WASY, 2010) and SHEMAT (Mottaghy and Dijkshoorn, 2012). This approach

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[1]www.geothermie.de/wissenswelt/geothermie/in-deutschland.html, retrieved 15.11.2016
[2]www.getis.rwth-aachen.de

represents a compromise between the level of detail and the computing time and allows implementing different geothermal plant models. Thus, it is used in this paper.

To simulate building performances, high and low order models can be used. In case of a single building model, programs simulating with a high temporal resolution and detailed system engineering like IDA ICE, EnergyPlus and Tas are available. However, they are not suitable for simulations at city district scale due to the high calculation effort. Hence, low order approaches have to be adapted.

Sagerschnig et al. (2014) presented a dynamic coupling between a building model in EnergyPlus and a subsurface model in FEFLOW, where BHE mass flow rate and temperatures were used as interface values. Results of an office building and a probe field showed a gain of information for both models and therefore more realistic predictions. Still, for areas with small groundwater flow an uncoupled model, where heat demand was imprinted, showed good results, too. However, detailed simulations with multiple buildings clearly extend computing time. The dynamic interconnection between GSHE and building performance simulation at urban scales is challenging and subject of current research.

Spatial Data Infrastructures (SDI) are set up to improve the access to and exchange of geospatial information (Groot, 2003; Bocher and Neteler, 2012; Harvey et al., 2012). SDIs offer consistent access to many different geospatial data sets (Schleyer et al., 2014). The European Union issued the INSPIRE directive to establish a consistent data infrastructure for spatial information in Europe to support community environmental policies, and policies or activities with a possible impact on the environment[3] (INSPIRE, 2007). This specified data infrastructure utilise the Open Geospatial Consortium[4] (OGC) standards, especially the OGC web service interface standards (Benedict, 2005), for example Web Map Service (WMS) and Web Feature Service (WFS), and the OGC data encoding standards such as Geography Markup Language, GML and CityGML. Presently, SDIs are introduced by the EU member states for diverse purposes (Craglia and Annoni, 2006; Thomas, 2013).

Visualisations, accesses and queries for geospatial data from SDIs are often enabled by using web geoportals through the internet (Bernard et al., 2005). Such geoportals are i.e. Geothermie in NRW[5], GEOportal.NRW[6] and the geoportal used for the SDI of EarlyDike (Becker et al., 2016). Increasingly, they are implemented in an INSPIRE compliant manner.

The objective of GeTIS is the development of a national open web-based geo information system. It supplies bundled information about geothermal-related data. Among them are 2D and 3D hydrogeological and cadastral data sets, protection areas and local regulations as well as application forms and informative literature. For this purpose, an SDI provides cartographic visualisation and data analysis based on the prementioned exchange standards.

GeTIS enables an evaluation of the geothermal potential by the connection of building performance and urban district simulation models with subsurface models. The focus lies on shallow geothermal systems up to 100 m of depth. Subsurface simulations can be done either directly on the platform or by downloading 3D models for integration in the program FEFLOW. In summary, GeTIS shall simplify and optimise geothermal-related planning processes.

Methodology

For processing control, user interaction and presentation of simulation results, an SDI including a web-based geoportal is applied (see figure 1). Using the international OGC Web Processing Service (WPS) standard, the subsurface and building models are connected to the web portal, the so called GeoPortal. WPS enables the start of simulation programs triggered by the user and forwards the required parameters to the respective tools. In turn, the WPS transfers results for visualisation into the GeoPortal. Furthermore, WPS allows carrying out analytical simulation approaches, geo-processing operations (e.g. Inverse Distance Weighting) and calculation of subsurface grids. The necessary data are accessed using WMS and WFS from databases of external providers, which are mostly consisting of national, federal or local public authorities. Accessing data by means of the OGC Web Services (OWS) has the advantage using only the latest data. Unfortunately, some third party data, for example subsurface geological information, borehole information and the digital elevation surface model, are currently not accessible by web services. These data as well as input parameters and processing results of the simulations have to be stored in the GeTIS database. This allows the users to access information of preceding sessions. Stored data can be used in the GeoPortal by both WMS and WFS for visualisation or WPS for processing purposes.

GeTIS database

As briefly described, simulation results and third party data not provided by OWS must be imported and managed by the GeTIS database. Therefore, an integrated data model is in development that fits the different requirements of subsurface and building models, external data and international standards. The model has to consider dependencies, such as the linkage between the results of the building simulation and the subsurface simulations or the third party data such as building data.

[3] http://inspire.jrc.ec.europa.eu, retrieved 15.11.2016
[4] www.opengeospatial.org, retrieved 15.11.2016
[5] www.geothermie.nrw.de, retrieved 15.11.2016
[6] www.geoportal.nrw, retrieved 15.11.2016

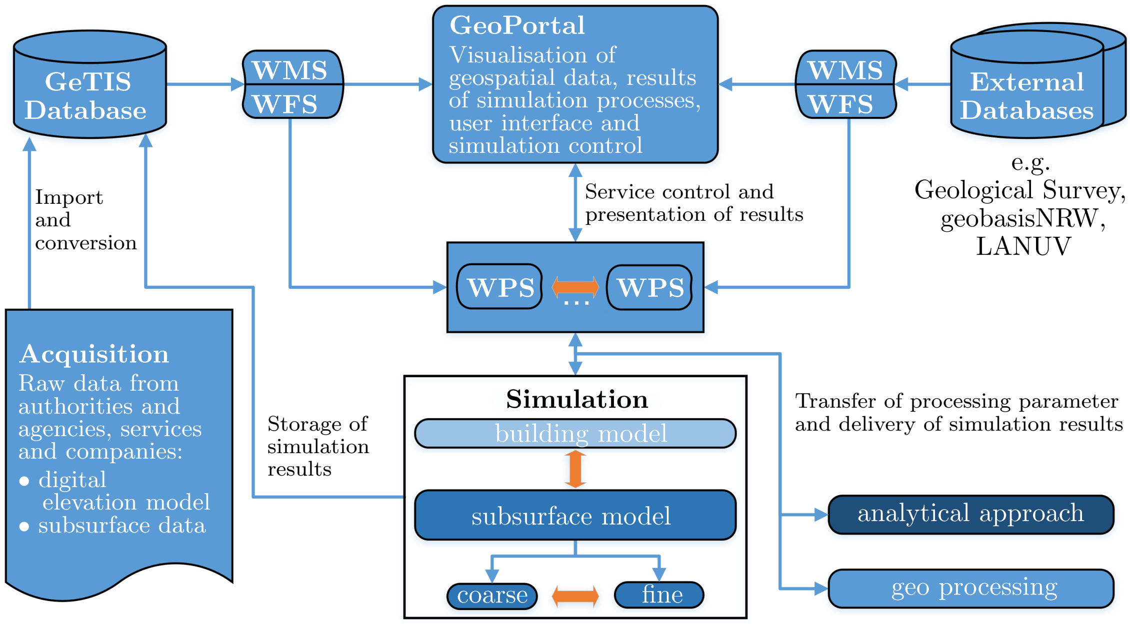


Figure 1: Process and communication structure of GeTIS

As first step for implementing the database, the open source database PostgreSQL[7] is used. The spatial extension PostGIS enables operating with geospatial data. A raster database (e.g. rasdaman[8]) is planned for storing raster data sets and providing them to the GeoPortal.
All acquired data are stored in their own schemas. The geological subsurface data require a relational scheme, which consists of two main tables, one for geometry (horizontal position and depth) and one for semantic data (e.g. name, condition and hydrological status for each geological layer). Initially, the horizontal resolution is resolved using a 50 m mesh width.

Test regions

Test runs of GeTIS are based on two model regions located between Cologne and Aachen in North Rhine-Westphalia (NRW, Germany). These test regions TR1 and TR2 differ significantly from each other in terms of quality and quantity of data.
The first test region TR1 covers an area of 169 km^2 in the Lower Rhine Bay close to the Rhenish lignite mining district. Its geology is characterised by soil and loose rock formations. A high data density is available because of the comprehensive monitoring of the draining system by the mining operator RWE Power AG.
The second and smaller region TR2 (10.5 km^2) is located in the North Eifel as part of the Rhenish Slate Mountains. The geology consists of solid rock formations in which no hydrogeological changes are expected during the relevant observation period for geothermal plants.

[7]www.postgresql.org, retrieved 15.11.2016
[8]www.rasdaman.org, retrieved 15.11.2016

Information base

The GeoPortal combines a wide range of data necessary to construct suitable models below and above the ground. Data are obtained from public authorities, agencies, services and companies. The subsurface model merges geological and hydrological data to a hydrogeological layer model, whereas the building model assembles cadastral and building information. As GeTIS presents an information system for shallow GSHE, the subsurface model only needs data for the relevant subsurface soil layers up to a maximum depth of approximately 100 m. The geological data are provided by the Geological Service NRW and contain information about average thickness, occurrence and soil type of the geological sections. Based on this, geological and hydraulic properties (e.g. porosity, permeability) and thermal attributes (e.g. thermal conductivity, specific heat capacity) can be defined from literature. Soil temperatures are derived from air temperature measurements of the Meteorological Service of Germany (test reference year data set, TRY), assuming a correlation of mean air temperature and soil temperature in the neutral depth. Temperature rises with increasing depth according to the geothermal gradient. The surface level of the ground is described using the digital terrain model DGM1 of geobasisNRW in a resolution of 1 m. A geological layer model in raster format is generated by combining ground surface and geological layer information, which leads to the geo-referenced position of the layer boundaries.
As major association of the water board in TR1, the Erft water authority releases groundwater level and dry surface plans. Thus, information about groundwater level and flow direction is available for the rel-

evant hydrogeological horizons. These data complete the hydrogeological layer model. Due to thermal disturbance in the measurements, groundwater temperature data are currently not used. In addition to the mentioned data, restriction zones such as water protection areas, nature conservation areas and communal restricted areas are taken into account in the models.

The building model primarily requires five key parameters. Some of them can be derived from CityGML LoD2 data provided by the federal state of NRW. Additional parameters cannot be extracted from the available data yet and have to be added manually. Cadastral data can be used, containing information about building types and parcels. Development plans provided by the authorities for urban planning allow for the estimation of the year of construction.

In order to handle raw data from various sources, it is necessary to process and reorganise data sets into consistent structures and formats in the GeTIS database. According to data security and privacy, the GeoPortal publishes interpreted and anonymised data depending on the authorisation level of the user (private or authority user).

Process of planning, request and approval

The process of planning, request and approval of geothermal systems is controlled by specific, technical and legal aspects and regulations. First, the legal framework of the German Federal Water Act (WHG) of the government ensures the prevention of contamination and adverse change of the groundwater quality and quantity by water law permits. Permissions for GSHEs are regularly given for a period of 25 years. Additionally, a process according to the mining law has to be carried out for boreholes exceeding a depth of 100 m. Special treatment is necessary if the heated building and the geothermal device are located on different properties. Guidelines like the VDI 4640 and DVGW W-120-1 regulate technical aspects. In general, boreholes have to be constructed by technically qualified and certified drilling companies. The GeoPortal gathers necessary information and documents such as German basic map, cadastre register and site plans with location of buildings and planned boreholes for the selected area of interest.

Building performance simulation

The open source program TEASER (Tool for Energy Analysis and Simulation for Efficient Retrofit) is used for transient building performance simulation and aims for the calculation of the heating loads. TEASER is suitable for dynamic simulation with a large number of buildings, especially in city districts. The program includes a dedicated workflow automation tool and parameterisation algorithms in the programming language Python (Müller et al., 2016). TEASER creates Modelica based models with dynamic template models from the Modelica AixLib and Annex60 libraries (Müller et al., 2016). Based on these models, typical buildings for corresponding building types (e.g. residential building, office or institute) are generated based on statistical information with respect to the German building stock. The AixLib and Annex60 libraries contain HVAC equipment and distribution networks to enable integrated analysis of energy systems at multiple scales ranging from single buildings to city districts (Müller et al., 2016).

AixLib provides a low order building model archetype that permits reduced computing times (Lauster et al., 2014). Despite its low order, it reaches sufficient accuracy and performs well in city district simulations with sparse information density (Müller et al., 2016). The median average deviation between a low order simulation of a German campus district (Jülich Research Center) and measurement was determined to 14.4 % (Müller et al., 2015). Nevertheless, accuracy highly depends on the investigated buildings and the quality of used statistical data (Lauster et al., 2016). Lauster et al. (2013) and Lauster et al. (2014) give more detail about the low order model.

Each building model is customised by five main input parameters for simulation: building type, year of construction, number of storeys, height of storeys and net floor area. Moreover, the model archetype allows a detailed specification of further building information like residential layout, air handling units, neighbouring buildings, attic, dormers, cellar type and construction type. These properties influence wall constructions, material properties, geometric dimensions and boundary conditions of the building. Internal gains and weather conditions are usually given in hourly time steps (Müller et al., 2016).

The generated Modelica models are simulated within the graphical development environment Dymola, often with a simulation time step of one hour. The produced performance curves are the benchmark for geothermal systems. At the scale of urban district simulations, dynamic effects caused by simultaneous heating demands and superposition of various heating loads, have to be taken into account. To handle these complex effects, a dynamic model of a compression heat pump is used to connect the building systems with the subsurface model. It is based on an object-oriented programming language and considers influences of building systems, current heating loads and GSHEs on the coefficient of performance (COP). The subsurface simulations respectively the GSHEs are controlled by imprinting operating parameters, for example brine inlet temperatures or volume flow rates, to ensure a sufficiency of geothermal energy for building needs.

Nomenclature			
λ	Thermal conductivity, W/mK	M	Mass source/sink, 1/s
ϱ	Density, kg/m^3	S	Storage coefficient, 1/m
c	Specific heat capacity, J/(kgK)	T	Temperature, K
D	Thermal dispersion coefficient, m^2/s	t	Time, s
eff	Efficient	u	Velocity, m/s
h	Pressure head, m	Q	Heat source/sink, W/m^3
K	Hydraulic conductivity, m/s	w	Water

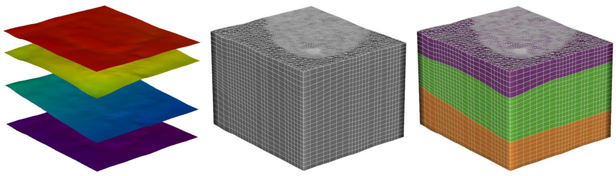
Hydrogeological models for coarse and fine simulation

GeTIS targets different groups of users, for example house owners, drilling companies, consulting engineers and public authorities. All of them have different interests in complexity, accuracy and extent of data. Expertise and capability of using software differ a lot. Thus, two different tools are used in this project, executing coarse simulations on the one hand and fine simulations on the other hand.

A coarse simulation is a batch-controlled, fully automatic subsurface simulation triggered by the user of the GeoPortal. After providing initial conditions by the user, e.g. via choosing heat pump and a building type, the simulation is executed without additional checks by experts. This approach limits the accuracy and, therefore, results can be seen as approximation of the geothermal potential or geothermal-specific values. A fine simulation allows for a detailed dimensioning of heat exchangers and heat pumps. The fine simulation is not executed on the GeTIS servers but on the local computer of the user, running the program FEFLOW. Hence, the GeoPortal provides an automatic preparation of geospatial bounded data, e.g. 3D subsurface models, which are directly accessible via a FEFLOW plug-in.

The coarse simulation is based on the program MPFluid (Frisch, 2014). MPFluid is an in-house C++ code using a finite volume approach that allows simulations on massive-parallel systems. Therefore, it is suitable for fast simulations, even at a large scale for example in city districts. MPFluid is released under open-source license and can be applied without restrictions in GeTIS. After setting the area of interest, MPFluid determines groundwater flow. In case of sparse data density (e.g. single groundwater isohypse), the bounding box is extended until sufficient information is ensured. Results can be set as boundary condition (BC) in the coarse and fine simulation. The simulation geometry is generated using all available data from the database, for example layer models and groundwater levels. As MPFluid uses equidistant grids, the meshing process can be automatised easily. However, the user is able to choose the level of detail.

FEFLOW is an expert tool often used by engineering offices and agencies. It allows a detailed simulation of BHEs by numerical or semi-analytical approaches (Diersch et al., 2010). To reduce the effort for setting up the necessary 3D model, GeTIS aims for an export of hydrogeological boundary conditions and material parameters for a user-specified area. Geological layer boundaries that build up the geometry of the finite element model are imported from the database (figure 2). The mesh has to be discretised manually by the user. This allows fitting to the individual purposes and needs of the simulated scenario. After meshing, GeTIS provides mapping packages of material properties and boundary conditions by a downloadable FEFLOW plug-in. The mapping is performed in a geo-referenced way and is therefore independent from the meshing process. The fine simulation procedure targets a significant reduction of time and cost for setting up scenarios while retaining the freedom of customised mesh discretisation.



(a) *(b)* *(c)*

Figure 2: (a) Geometric boundaries exported from GeTIS (b) Mesh Discretisation in FEFLOW (c) Parameter and BC mapping

Besides the now available options for modelling BHEs within FEFLOW, GeTIS develops approaches for the simulation of various other geothermal systems such as thermally activated construction elements or thermal collectors, which will be available in the GeoPortal.

The physics in the subsurface is treated independent of the applied simulation program. Two partial differential conservation equations describe the relevant transport mechanisms, which represent groundwater flow and heat transport in porous media. An incompressible laminar groundwater flow is calculated using the mass balance equation, in which the flow velocity is expressed by means of Darcy's law as product of hydraulic conductivity and gradient of hydraulic head, eq. (1)[9]. Currently, the information base only pro-

[9] for declaration of symbols see nomenclature, p. 5

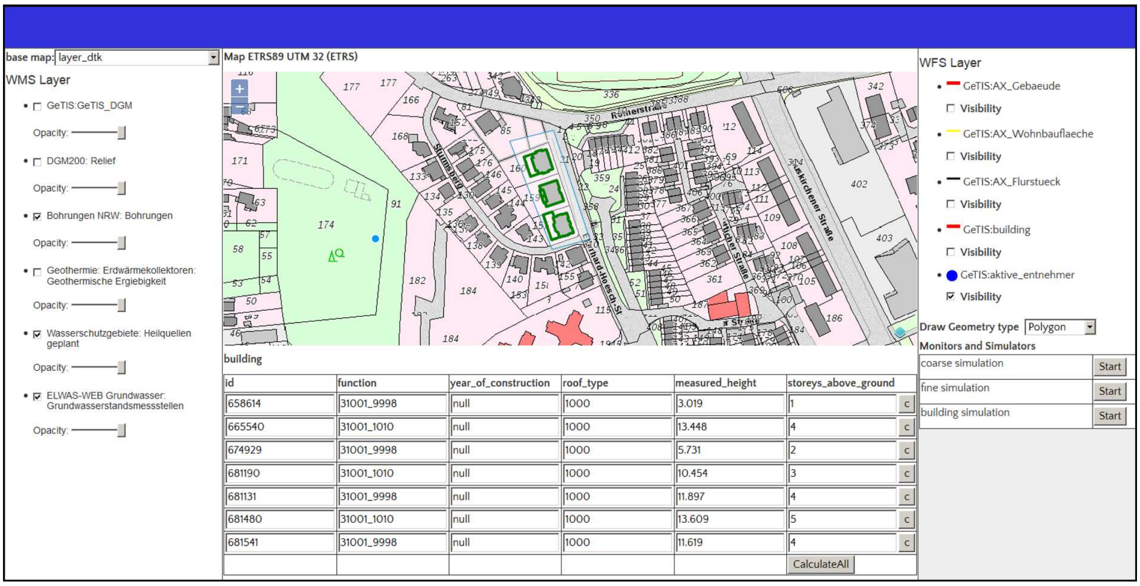


Figure 3: Draft of the GeTIS GeoPortal

vides stationary information about groundwater levels. Therefore, the transient storage term and mass sources are dropped. Using the calculated hydraulic heads, velocity is determined by Darcy's law.

$$S\frac{\partial h}{\partial t} = \boldsymbol{\nabla} \cdot (\mathbf{K}\boldsymbol{\nabla} h) + M \tag{1}$$

Eq. (2) shows the energy equation, containing some simplifying assumptions, for example one-phase fluid flow and thermal equilibrium of fluid and solid phase (Nield and Bejan, 2006).

$$(\varrho c)_{\text{eff}}\frac{\partial T}{\partial t} = \boldsymbol{\nabla} \cdot [(\lambda_{\text{eff}} + (\varrho c)_{\text{w}} D_{\lambda})\boldsymbol{\nabla} T - \vec{\mathbf{u}}(\varrho c)_{\text{w}} T] + Q \tag{2}$$

Efficient thermal properties are calculated using the geometric or arithmetic mean of solid and fluid property (Fuchs et al., 2013).

Interconnection of building and subsurface model

Heat pumps are the connection between buildings and subsurface and therefore, a dynamic heat pump model is necessary. Its task is the regulation of heat and circulation pumps in order to satisfy the actual building's heating load. This research project uses a fixed-speed heat pump model (constant compressor power). Brine mass flow rate and inlet temperature are forwarded from the heat pump to the subsurface simulation, dependent on the hourly updated heating load input. As a result, the brine outlet temperature is committed to the heat pump, which allows determining the transferred ground source heat flux. Using this heat flux and the electrical power consumption of the heat pump system, the heat flux provided to the building's heating system can be calculated and compared with the sufficient heating load of the last time step.

The heat pump model uses hourly time steps. Indeed, the reduction of the time steps to minutes or seconds reveals influences on the installation engineering more precisely, but highly increases the calculating time of the coupled simulation at city district scale. Moreover, the subsurface and heating loads do not provide a finer temporal resolution.
If the heating load differs from the calculated heat flux, the brine inlet temperature is adjusted. This adjustment is limited by a bottom temperature, to prevent the soil from freezing over (VDI 4650-1, 2014). If no coverage in this monovalent system can be reached, the dimension of the GSHE has to be increased.
The heat flux to the building's heating system, the electrical power of the compressor and the brine circulation pump as well as the influence of the control strategy are necessary information to calculate the current COP. The temperature difference between inlet and outlet of the BHE should be between 2 K and 3 K in order to provide an efficient operation of the brine circulation pump and a high COP of the heat pump system (VDI 4640-2, 2015). The COP is logged continuously to show the efficiency of the heat pump for different heat extraction rates.

GeoPortal

The GeoPortal (figure 3) is the web-based information access point and the central visualisation and control unit to the provided data and functions of GeTIS. It allows enabling or disabling different layers with different information in the map window. The user can navigate to certain areas and city districts. By the use of different tools e.g. a pointer or a bounding polygon, one or multiple buildings can be selected as input data for the simulation. The GeoPortal offers an option to enrich relevant data gathered from internal and external databases manually. The portal is developed using frameworks like HTML5 and JavaScript as well as free software libraries such as OpenLayers. These web techniques are used to implement the visualisation of the vector and raster data accessed by the OWSs. Raster maps are transferred by WMS, vector data by WFS. These standards are used by third party distributors as well as internally by the free map server Geoserver applied in GeTIS. The third used OWS method is WPS, which is suitable for starting numerical or analytical simulations and geo-processing operations. Results are transferred by WPS to the GeoPortal. Depending on the results, visualisation will be generated as overlay to the base map layer, as table, chart or 3D model. For the provision of bundled information to the user, an output in PDF format is intended.

Results

First results are presented by means of a test scenario, where heating loads, productivity of the ground source heat pump systems and temperature plumes of six residential buildings located in TR1 are investigated. These results are not used for validation but for demonstrating the output of GeTIS for the planning process.

Figure 4 shows a cadastral map of the simulation test area. With the exception of building B2, the buildings are single-family homes with different numbers of neighbouring buildings. B2 is a multi-family house covering two parcels. Maximum lengths of the double U-tube BHEs is limited to 80 m in this test region. The electrical power of the heat pump is estimated to 2 kW.

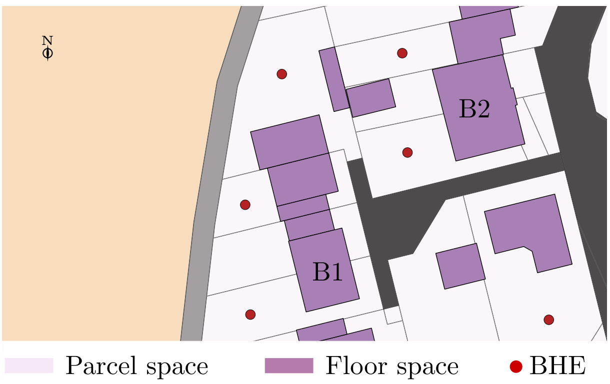


Figure 4: Cadastral map of simulated test area

Heating load

Figure 5 exhibits the annual heating load of building B1, with a maximum heating load of 13.7 kW. The amplitudes in summer are caused by low building insulation, due to the year of construction (1971) and building type, as well as by cold clear summer nights and the neglect of night set back in TEASER. The graph is created by means of the TRY data set 2010

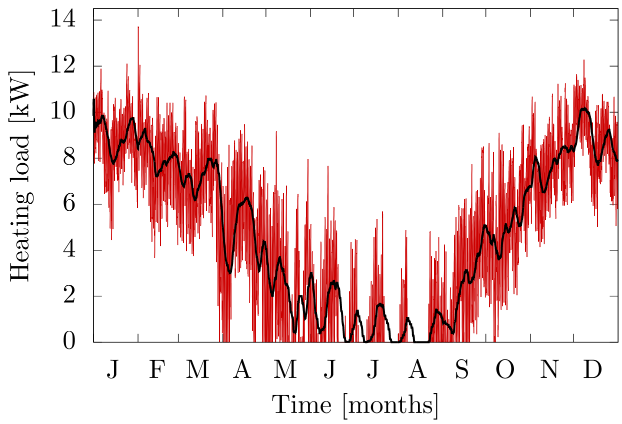


Figure 5: Annual heating load; black line: moving average of 5 days

of the city Essen and is used as an input for every year of simulation. Building B2 shows the highest heating load of all buildings (26.7 kW).

Groundwater flow

Additionally to the unconfined aquifers, the subsoil is segmented in eight different geological layers mainly consisting of sand, gravel, silt or coal. As figure 6 presents, permeable and nearly impermeable layers alternate with increasing depth. The layers are aquiferous. The simulated geometry has an area of 40.000 m^2 and a depth of 140 m. Groundwater flows from southeast to northwest with a maximum Darcy velocity of 0.53 m/d. Therefore, a constant flow of water with elevated temperature is ensured. Because of the flow direction, the BHEs in the test area are thermally series-connected.

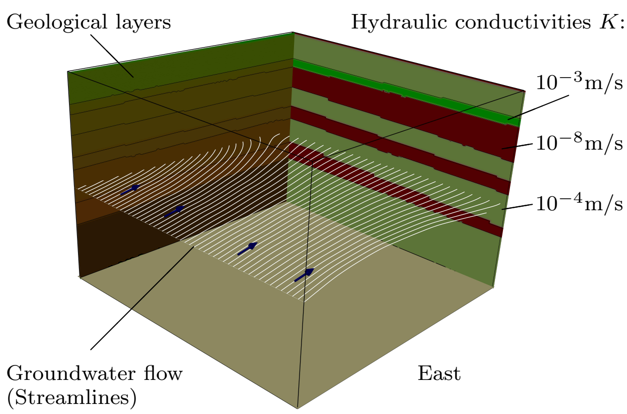


Figure 6: Groundwater flow in simulated test area at a depth of 70 m

Geothermal energy gain

In a first attempt, the heating load of the building B1 should be covered by one BHE. The blue curve in figure 7 shows the extraction rate of the BHE, while

the blue curve in figure 8 demonstrates the heating load coverage. Since one BHE could not cover the entire heating load, a technically identical BHE was added to supply building B1. Extraction rate and coverage of both BHEs are displayed as red curves in the mentioned figures.
The BHEs have a length of 80 m and are 6 m apart from each other. In order to minimise thermal interaction, they are located perpendicular to the groundwater flow. Each BHE is operated with a volume flow rate of 36 m^3/d to ensure low energy usage for pumping and turbulent flow in the tubes (diameter 32 mm). Due to the high Darcy velocity in the simulated region, the subsurface temperature recovers during periods of low energy demand. Therefore, no significant reduction in energy gain occurred during the simulated time span of 25 years.

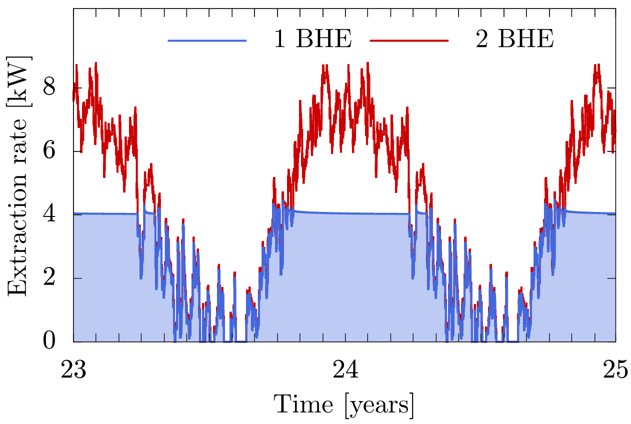


Figure 7: Progress of extraction rate of BHEs supplying B1 in the last two of 25 years

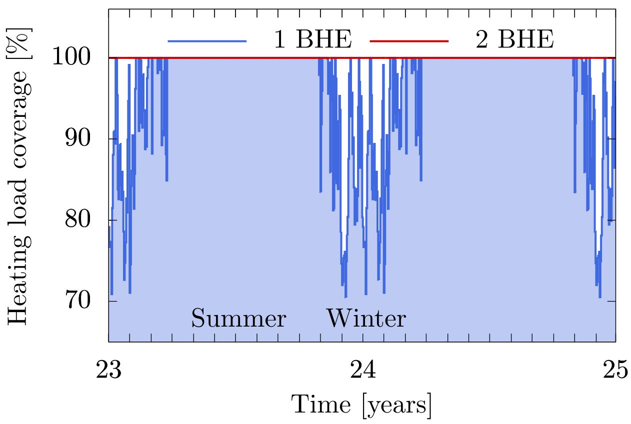


Figure 8: Progress of heating load coverage of BHEs supplying B1 in the last two of 25 years

As figure 8 illustrates, one BHE provides enough energy to cover the heating load during summer, but fails during winter period. Temporarily, the coverage drops to 70 %. As expected, an additional BHE leads to full coverage.

Temperature plumes

In figure 9 temperature plumes for the winter of the year 25 are presented using four isolines for each BHE in the range of 10 to 10.3 °C. The undisturbed soil temperature is around 10.5 °C. The BHEs cause temperature plumes that exceed the parcel boundaries and lower the temperature in the neighbour's property. In some German federal states this would impede the approval. Attention must be paid to the big plumes at the top of the area. In addition to the subsoil cooling by the BHEs, they are caused by local downwards flow of colder groundwater. Those effects have to be considered in approval procedures as well.

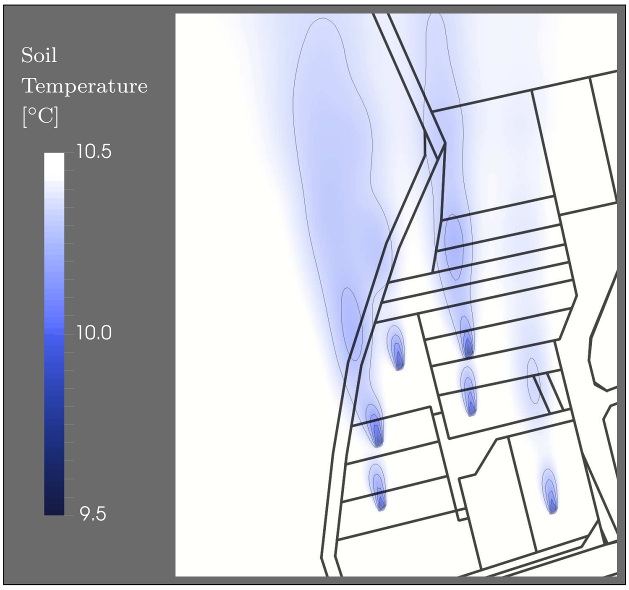


Figure 9: Temperature plumes in simulated test area at a depth of 70 m in winter of year 25

Conclusion

The planning of shallow geothermal systems is complicated by the effort for simulation and data acquisition, by data inconsistency and approval procedures. There are no tools for direct dynamic connection between building performance simulation and complex subsurface models up to city district scale. This paper described preliminary results of the research project GeTIS, which aims to simplify planning processes by the provision of information and simulation applications. The concepts of data acquiring, data flow and data storage as well as the GeoPortal were explained. The used simulation methods were shown and illustrated by an example scenario. All necessary geothermal-related information is gathered in one database. House owners, engineers and public authorities can use this open web-based geo-information system for building performance and 3D subsurface simulations. Users with a license for the commercial tool FEFLOW are able to download 3D hydrogeological models. A heat pump model is connected to the simulations.

The GeTIS tools will be continuously further developed. Main focus in future work lies on the validation of the coupled system with collected data from the test regions TR1 and TR2. The simulation scope will be extended to city district scales, cooling applications and fields of BHEs with modular heat pumps. GeTIS will be developed with the option to transfer and expand the system from initial test to Europe-wide regions. Based on the specifications of the INSPIRE directive, the database is extensible. Besides numerical simulations, analytical approaches will be implemented in order to provide a preliminary and direct potential estimation. Moreover, existing and newly developed semi-analytical approaches to model geothermal systems such as thermoactive components, ground heat collectors and open loop water-water heat pumps will be integrated in GeTIS. Additionally, storage processes, the influence of domestic hot water demand and different control algorithms will be implemented in the heat pump model.

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