

## System optimisation of ground-coupled heat- and cold supply for office buildings

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### ABSTRACT

In modern office buildings geothermal heating and cooling technology is used increasingly, replacing conventional systems with reversible heat pumps (heating and cooling) and/or direct cooling. In past monitoring projects it became evident that for ground-coupled systems there often is a large discrepancy between efficiency as to the design and according to real-life, monitored operational data.

The objective of this project “geo:build – system optimisation of ground-coupled heat- and cold supply for office buildings”, was to identify energetically and economically suitable combinations of geothermal technology and building HVAC equipment. Based upon simulation, monitoring and documentation, the behaviour of the systems, and in particular of the interface between geothermal technology and the building installation, was studied. System optimisation and operational strategies for transition from mechanical to direct cooling and back were discussed, in order to best use the underground as a seasonal thermal storage.

Basic preconditions were set by guaranteeing the internal comfort requirements in the rooms, and ensuring a long-term equilibrium with the thermal balance in the underground. Several combinations were tested upon data and behaviour of these building using TRNSYS. For the geothermal part, EED was used as a main tool for ground thermal calculations, with 3D-simulations using FEFLOW being done for comparison at two of the buildings.

Results of the system simulations show that the energy cost for electric power can be reduced through optimised use of direct cooling. The geothermal simulations prove the adequacy of the temperature predictions by both EED and FEFLOW; however, due to deviations of the actual heat extraction and injection from the design values, the temperature development

is different from that intended during the design stage. For one of the buildings, extrapolations of temperature development in the ground under various scenarios are made by simulation, proving the need for a long-term thermal balance and allowing for measures to adjust this balance.

The paper presents three of the buildings and geothermal systems investigated, summarises the monitoring results, and explains the ground temperature simulations.

### 1. INTRODUCTION

Within the scope of the R&D-project “geo:build - Optimization of ground coupled heating and cooling supply systems in office buildings - reversible heat pump and free cooling”, running from 2011-2014 and funded by the Federal Ministry of Economics and Technology (BMW, FKZ 03ET1024A), ground coupled supply systems for heating and cooling are being analysed both in theory and practice. The project was 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 was to study an adjustment of the cooling modes and switching between free cooling and chiller.

### 2. SUMMARY OF MONITORING RESULTS

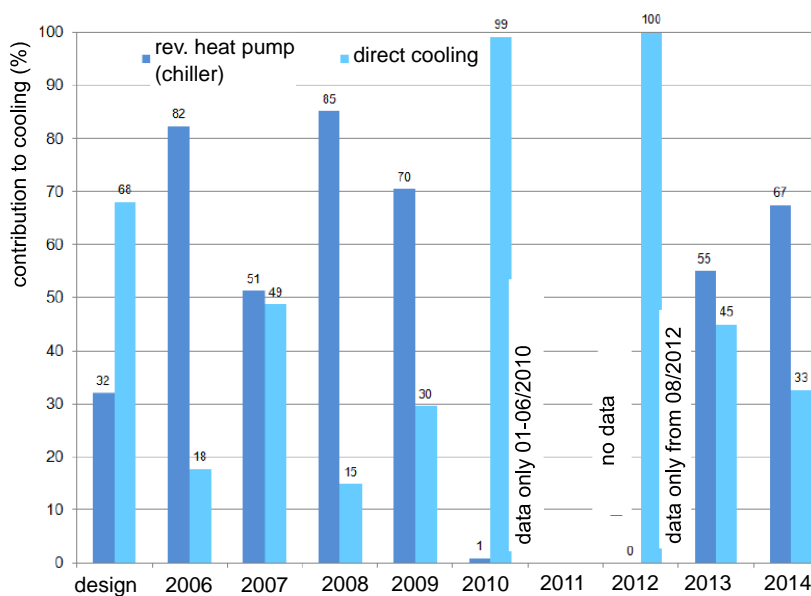
Three buildings monitored within the project are described in this paper; the basic data are listed in table 1. Some key findings from monitoring are given here for the individual buildings.

#### 2.1 GEW building

According to the planning documents for GEW, a ratio of 68 / 32 for cooling supply by passive cooling mode as compared to chiller operation was designed. However, until to date, the best ration that could be achieved was of 49 to 51 in 2007 (see Figure 1); the value for 2013 was 45 / 55, and the share of direct cooling decreased even back to 33 / 77 in 2014.

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

Building GEW (Gelsenkirchen)		
	building data	office building NFA 6'189 m <sup>2</sup> year of construction 2004
	geothermal system	36 borehole heat exchanger à 150 m
	design heating load	total building 207 kW / 43.6 W/m <sup>2</sup> <sub>NFA</sub> heat pump 326 kW
	design cooling load	total building 305 kW / 9.3 W/m <sup>2</sup> <sub>NFA</sub> free cooling 200 kW rev. heat pump 320 kW
Building FAS (Dortmund)		
	building data	office building NFA 2'930 m <sup>2</sup> year of construction 2010/11
	geothermal system	12 borehole heat exchanger à 144 m
	design heating load	total building 125 kW / 42.7 W/m <sup>2</sup> <sub>NFA</sub> heat pump 87.6 kW
	design cooling load	total building 95 kW / 32.5 W/m <sup>2</sup> <sub>NFA</sub> free cooling 60 kW rev. heat pump 68.4 kW
Building HSZ (Salzgitter)		
	building data	lecture hall building NFA 3.296 m <sup>2</sup> year of construction 2012
	geothermal system	15 borehole heat exchanger à 95 m
	design heating load	total building 92 kW / 28 W/m <sup>2</sup> <sub>NFA</sub> heat pump 60 kW
	design cooling load	total building 152 W / 46 W/m <sup>2</sup> <sub>NFA</sub> free cooling 60 kW rev. heat pump 45 kW



**Figure 1: Relative distribution of cold supply by direct cooling (light blue) and chiller operation (blue) in building GEW, 2006-2014**

During 2006 to 2009 significantly more heat was injected into the soil than extracted (about two to three times). 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 unfavourable temperature level for passive cooling mode, so that during the cooling mode mainly the chiller was operated.

As a part of the existing monitoring, measures and optimisation were carried out to minimise the heat injection, in particular the combined heating and cooling mode and to reduce the high fraction of chiller operation. The following measures for optimisation were suggested:

- Optimised ventilation strategy:  
No cold supply during office hours at low outside temperatures.
- Use of self cooling through the building envelope and the supply air flaps  
No space cooling during the night when the outside temperatures are less than the room temperature.
- Priority for free cooling at night.
- Changing the control strategy of the geothermal system:  
Increase of the temperature limit (outlet temperature from the ground heat storage) for unblocking chiller operation.

The overall measured SPF in 2013-14 was below the threshold of 3. It could not yet be verified if the proposed optimisation measures had the desired effect in increasing this value.

## 2.2 FAS building

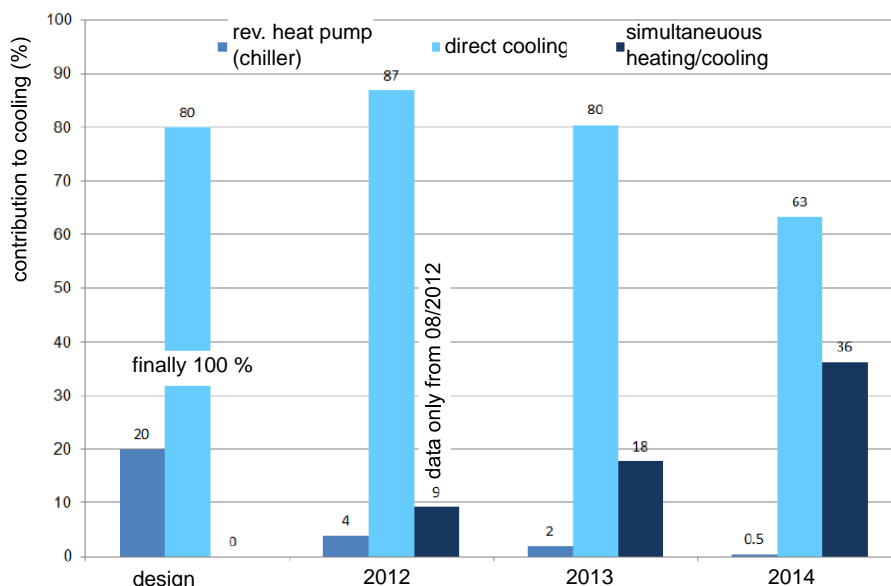
A speciality in this building is the simultaneous heating and cooling, with the heat pump still supplying heat to parts of the building while extracting heat from other parts (i.e. cooling); this is a third mode of cold supply in addition to direct cooling and cooling with the heat pump acting as chiller. Here the monitoring results for the first years of operation match quite well the design values, also in the distribution of cold supply, with 80% or more direct cooling in 2012 and 2013 (fig. 2). This proves that operation as designed can be achieved from the beginning, if design, construction, and use are consistent.

Measured SPF (SPF 2, i.e. including the ground-side circulation pumps) was:

- Heating: 5.2 in 2013 and 5.4 in 2014
- Cooling: 7.9 in 2013 and 11.4 in 2014

In cooling, all modes are combined for SPF calculation.

No suggestions for optimisation were made.



**Figure 2: Relative distribution of cold supply by direct cooling (light blue), chiller operation (blue) and dual heating/cooling (dark blue) in building FAS, 2012-2014**

## 2.3 HSZ building

Since March 2013 the full monitoring of the building HSZ has been active, with the start of operation. In planning, a ratio of 54% operation of the reversible heat pump to 10% direct cooling was defined, based on thermal simulations. In order to cover peak loads, two additional compression chillers (air-cooled) are

integrated to cover the remaining 36% of the total cooling energy demand.

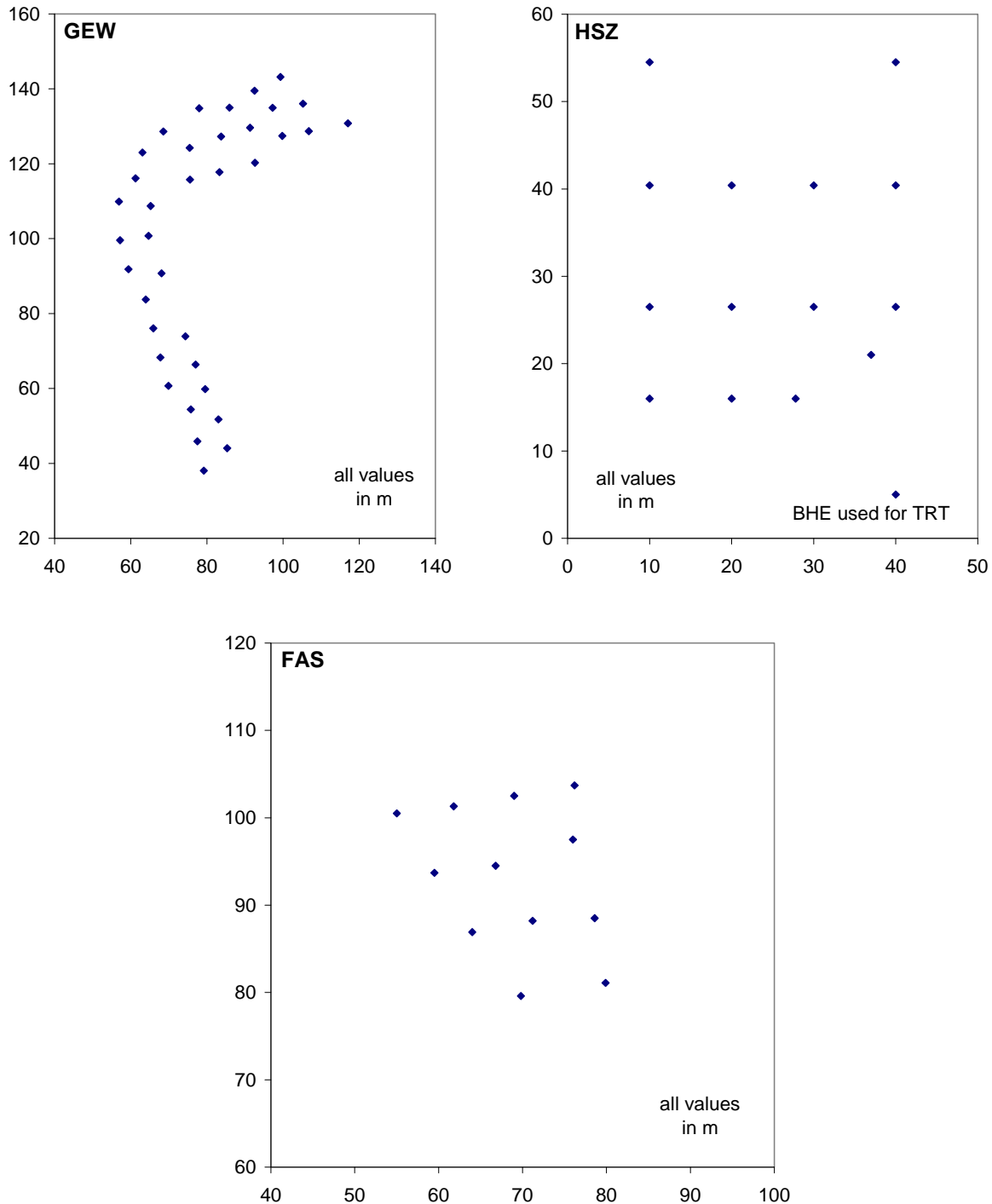
In 2013 and 2014, the cold was mainly provided by the heat pump in cooling mode, with the air-cooled chillers providing less than one third of the cold. The potential of direct cooling is generally limited at the end of the cooling period due to rising temperature in

the soil; in fact, no direct cooling was recorded in these two years. The SPF in 2014 was 4.4 in heating mode and 5.5 in cooling mode (heat pump).

Control optimisation was necessary to raise the proportion of direct cooling, and in 2015 a share of 20 % was achieved (monitoring period January-September), more than the 10 % from design.

### 3. VALIDATION OF EED-CALCULATIONS AND FEFLOW-SIMULATION WITH MONITORED DATA

The data from the monitoring could (and can further) be used for validation of design software. EED-calculations have been made for all buildings in table 1, FEFLOW-simulation only for one of the objects. The layout of the BHE fields is shown in figure 3.



**Figure 3: BHE-Layout for GEW (top left), HSZ (top right) and FAS (bottom); further data in table 1**

With EED, the measured loads for the two years 2013-2014 were used as input for calculating the fluid temperatures in the BHE. With the current version of

EED, this is only possible if the annual thermal balance is somehow in equilibrium, and no long-term cooling down or heating up of the ground occurs. The

results of these calculations for GEW and FAS are shown in fig. 4 and 5; they show a pretty good prediction of the real temperatures.

For the new building HSZ, a comparison with 3-dimensional numerical simulation using the FEM-software FEFLOW was made. The match with both methods (EED shown in figure 6) is not as good as with the two other examples, while the numerical simulation and the EED-calculation match quite good (figure 7). In figure 8, the temperature distribution in the ground at half the BHE depth is shown for end of May, i.e. when heating (with some cooling) changes to cooling exclusively, and for end of October, after the end of the cooling season.

A new version of EED (V 4) is currently under development. In this version, hourly input values are possible (the current version 3.21, as used for the calculations during the project, allows only monthly values and one peak per month in hourly resolution). The match of the calculated fluid temperatures with the temperature data for the first part of year 2013 (until a gap in available data from end of August on) is almost perfect (fig. 9).

For HSZ, the calculation with hourly data in EED was compared to the results of FEFLOW simulation and the monthly base-load temperatures as to EED 3.21 (fig. 10). Beside the fact that FEFLOW can give the temperatures for inlet and outlet of each individual BHE (in fig. 10 only the average for inlet and outlet is shown, for clarity), no additional information can be derived; the calculation with EED even with hourly input data was done in less than a minute, while 3-D numerical simulation required several hours of computing time.

#### 4. CONCLUSIONS

The monitoring results show that the post commissioning monitoring of operation is important in order to identify and resolve problems at an early stage. The results for heat pump performance are mostly encouraging. The amount of direct cooling, allowing for very high SPF, was satisfactory only in building FAS. For the other buildings, suggestions for improvement have been made, which showed first positive effect in building HSZ.

The validity of BHE design software could be verified by using the monitored data for temperature and

thermal loads. EED proved capable of good prediction of fluid temperatures, while FEFLOW in addition allowed for determining the area of thermal influence around the BHE field. A new version of EED, not yet released, could match the accuracy of FEFLOW for fluid temperature calculation in the conductive environment given, with calculation times only a fraction of those with numerical simulation. In cases where groundwater flow has to be considered and the spatial distribution of temperatures in the ground are required, software like FEFLOW is required; in the other cases, the new EED version might become the method of choice.

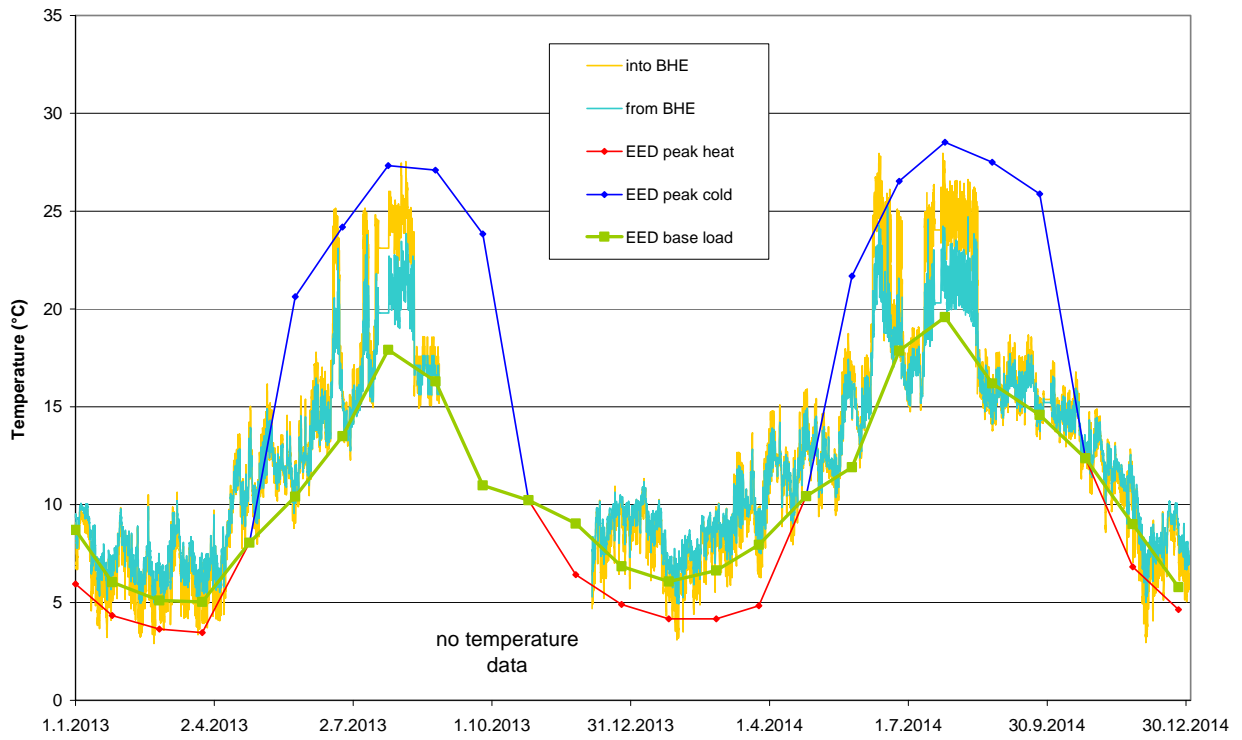
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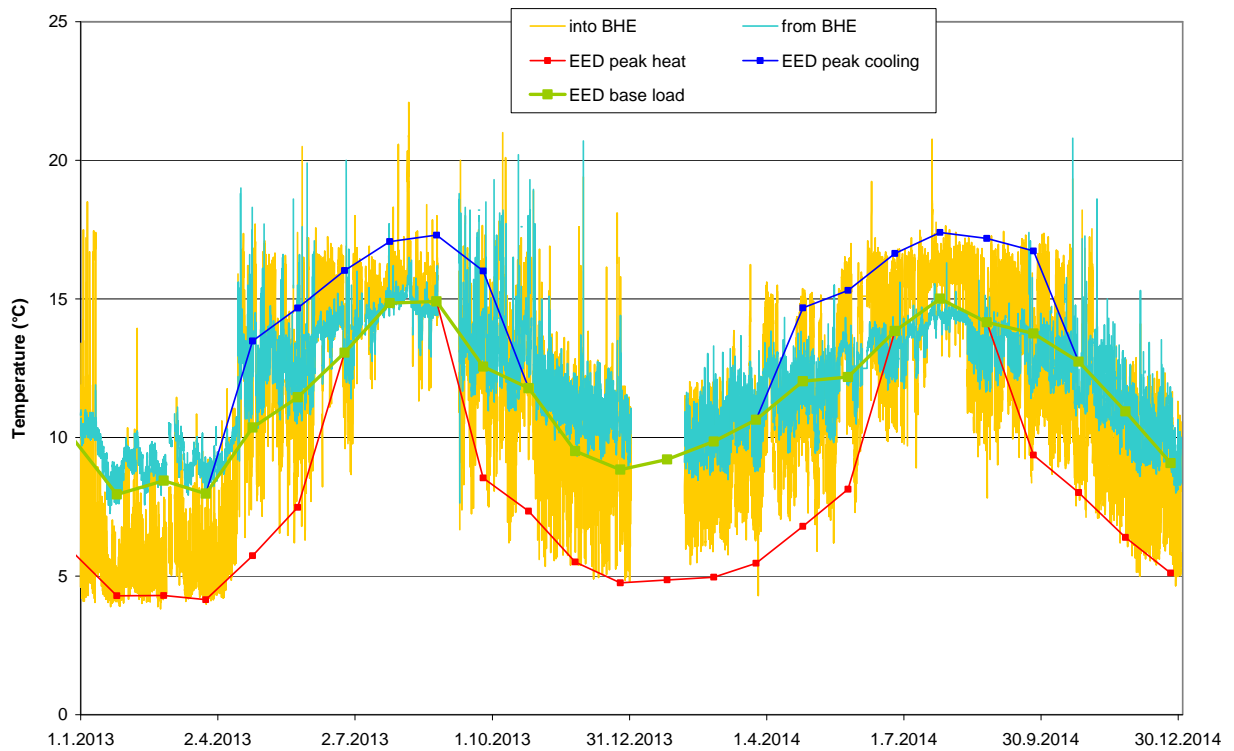
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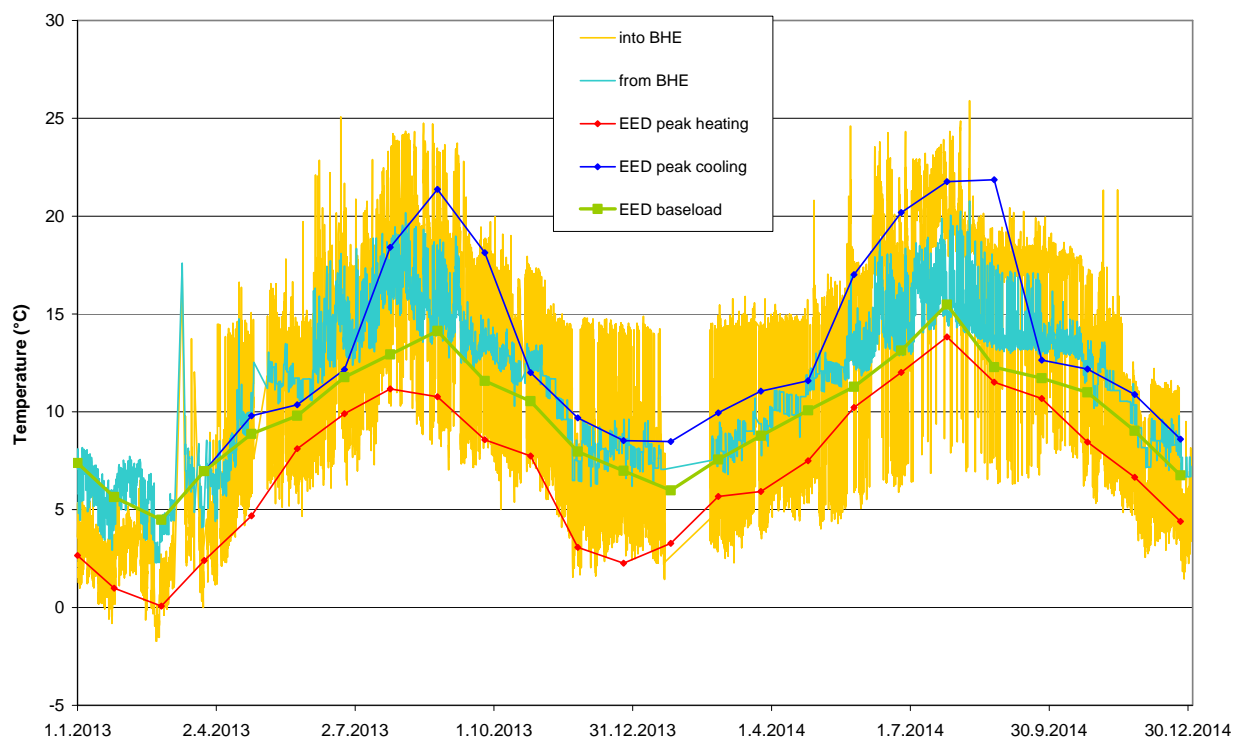
The authors also wish to acknowledge the assistance given by Thomas Blomberg, Blocon, in performing the calculations with not yet released EED V 4.



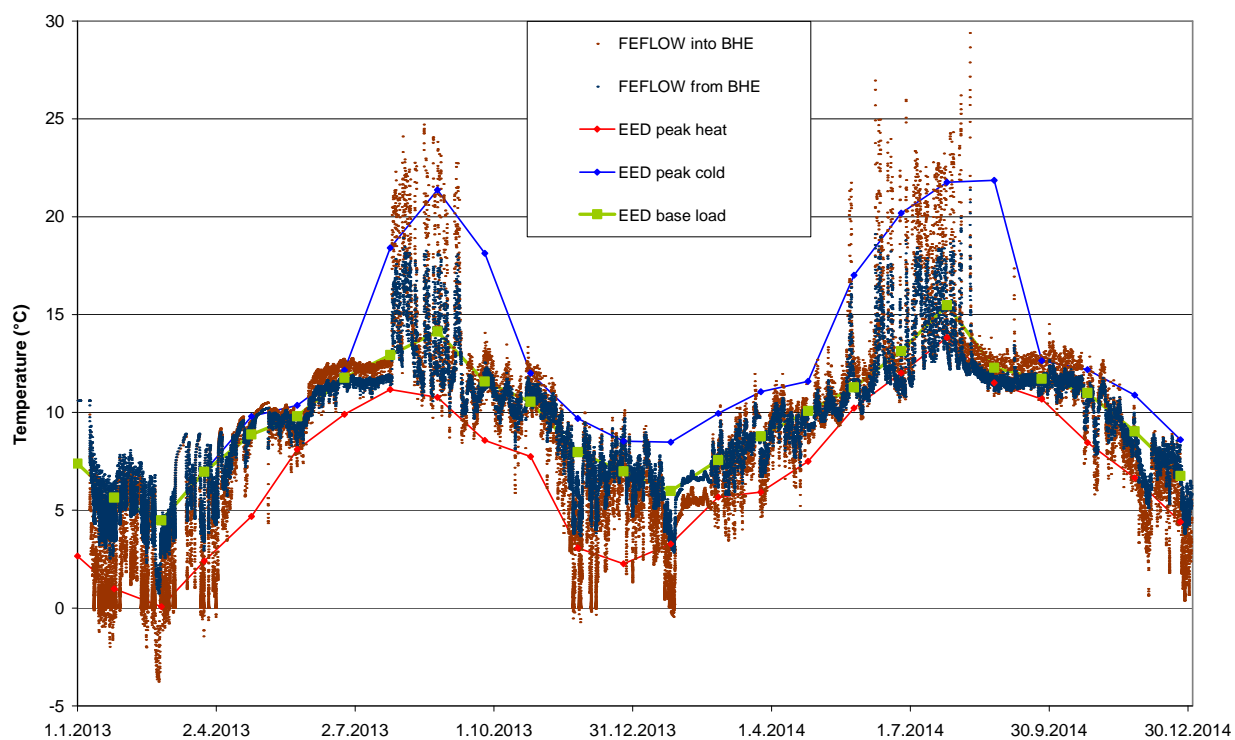
**Figure 4: Measured data for building GEW in 2013 and 2014, compared with EED calculations using measured loads as input**



**Figure 5: Measured data for building FAS in 2013 and 2014, compared with EED calculations using measured loads as input**



**Figure 6: Measured data for building HSZ in 2013 and 2014, compared with EED calculations using measured loads as input**



**Figure 7: Measured loads from building HSZ in 2013 and 2014 used as input data for FEFLOW-Simulation and EED calculations**

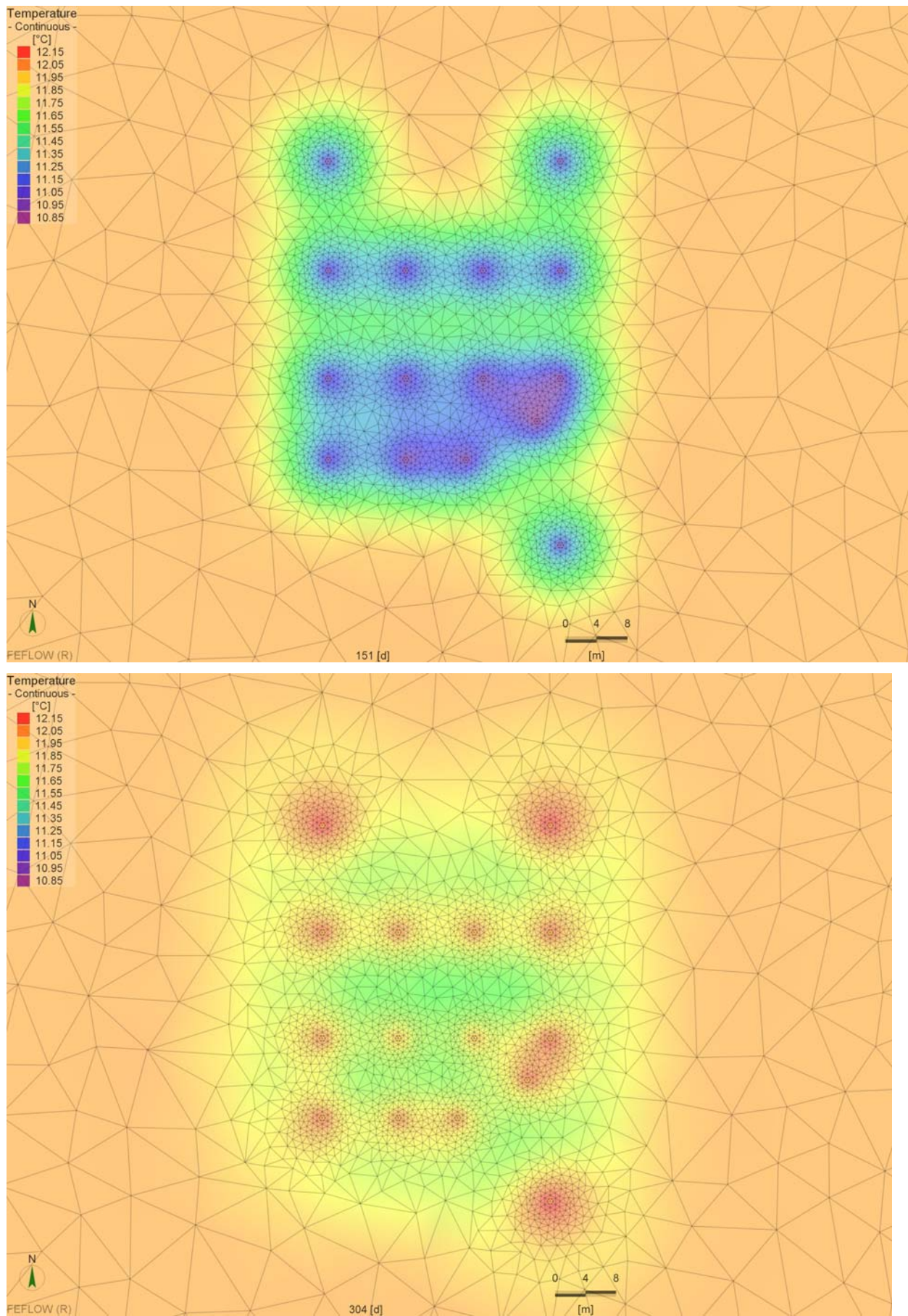
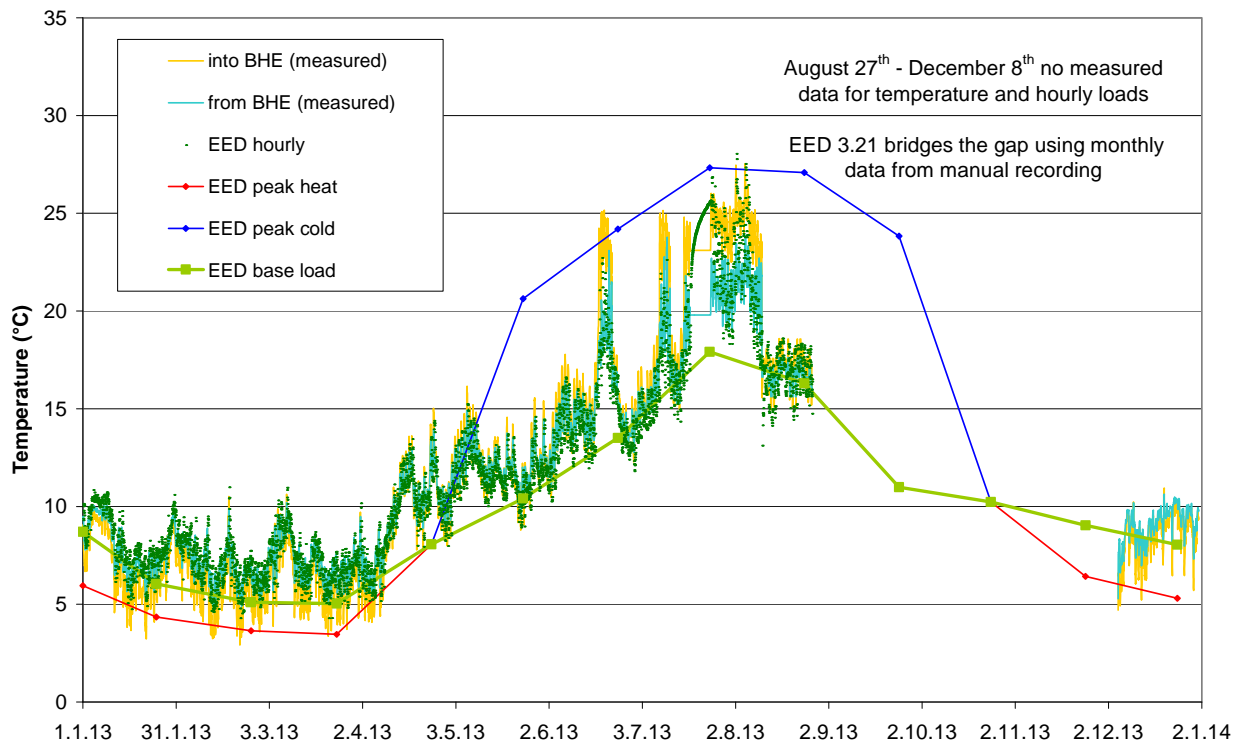
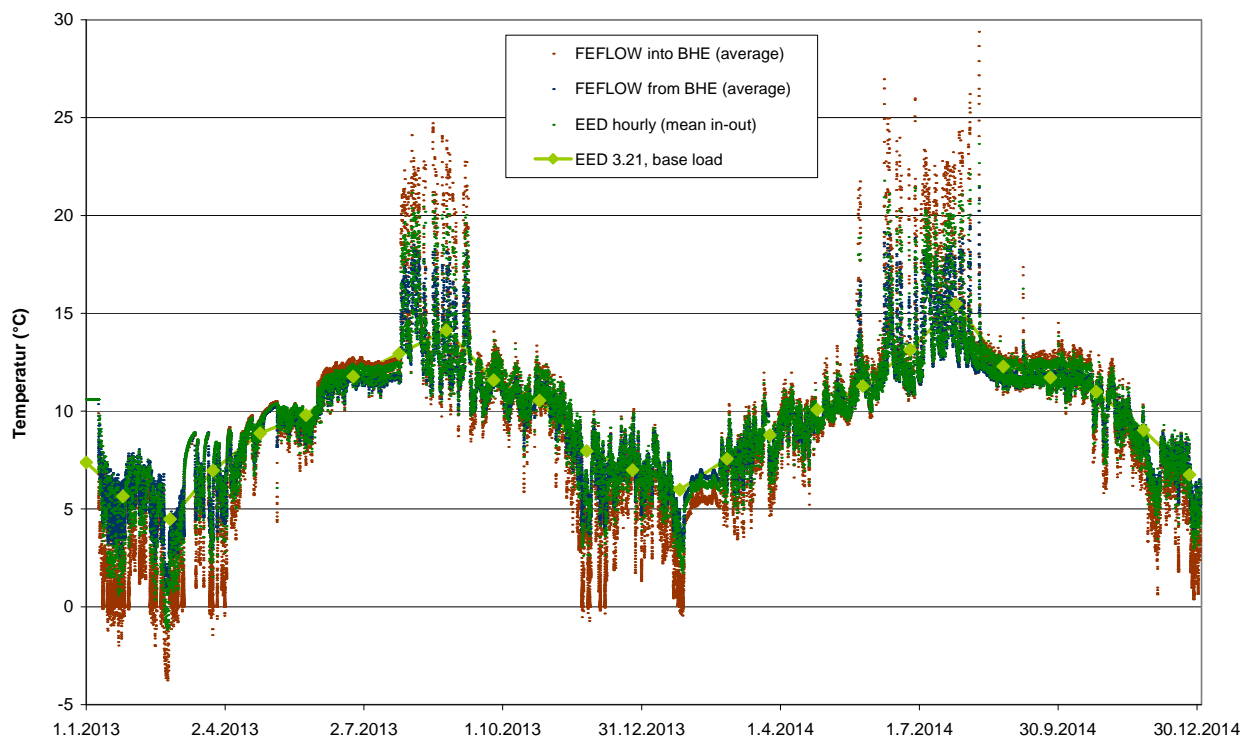


Figure 8: Temperature distribution in the ground at half the BHE depth for end of May (top) and end of October, (bottom) in the BHE-field for building HSZ, calculated with FEFLOW





**Figure 9: Measured data for building GEW in 2013, compared with EED calculations using measured loads as input, both for EED 3.21 (monthly values base load and peak load) and for the pre-release version of EED 4 (hourly values)**



**Figure 10: Measured loads from building HSZ in 2013 and 2014 used as input data for FEFLOW-Simulation and EED calculations, both for EED 3.21 (monthly values base load) and for the pre-release version of EED 4 (hourly values)**