Visualization of energy storage in boreholes

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Publication date: 2016

Document Version
Other version

Link to publication

Citation for published version (APA):

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Visualization of energy storage in boreholes

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Finance: Thanks to Engell Frils Fund for the 100,000,- kr in support of this project.

Date: 10.10.2016

Version: 1.1
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1 Introduction

Saving energy is a prerequisite for the Danish energy plan for 2020 focused on the transition to renewable energy sources to be implemented. In the years after 2020, the need to offset variations in the production and consumption will just become even more urgent, and it is therefore a key challenge in good time to prepare the community of this transition [see for example. (Petersen, 2013)]. The development of relevant technologies is obviously necessary, but also objective information on these should be high on the priority list, so that the publics support and participation is encouraged.

There are a number of different types of energy storage that are useful now and which will become indispensable in the future. Systems that can store electrical energy in the period of the order of hours, can help even out fluctuating production from wind turbines and solar panels. However, there is also a large potential for saving heat in the summer, so it can be retrieved in the winter when it is inherently far more valuable. Such seasonal storage is challenging to achieve, not least because large storage volumes are necessary. One promising possibility is the so-called borehole storages where, in the summer hot water is circulated 20-30 meters into the ground via vertical boreholes. The circulated borehole water heat to the ground in the summer and this heat can then be brought up in winter by instead pumping cold water through the system.

Boreholes for energy storage is a technology with a special connection to the Horsens area and VIA University College has worked intensively with the topic over the years, e.g. by establishing a testing and demonstrations drillings in the Energy Park Laboratory at Chr. Østergaardsvej in Horsens (Poulsen, 2015; Geoenergi.org, 2014; VIA, 2014). At the same time “Brædstup Fjernvarmeværk” established a borehole storage with a capacity of over 200 MWh, giving VIA unique opportunities to contribute to the integration of technology in the district heating network.

2 The project

The expected end product was described as follows in the original project description:

The end product of the project will be a compelling, modern presentation material for energy storage in soil borings. There should be conveyed a deep insight into a boreholes units and it’s functions, with real results from actual (real-time) and historic energy storage measurements. The requested Equipment must be able to collect- and visualize data showing the energy supplied borehole and the temperature changes the leads in the surrounding soil layers. The challenge to visualize equipment and processes underground makes the project particularly interesting.

As stated, the purpose of this project has been to extend VIA's unique knowledge of energy storage in soil borings, but more importantly to make this knowledge more accessible and useful through at set of powerful visualizations. Both the education internally at VIA University College and visits to the Energy Park...
Laboratory for elementary school classes, school classes and other interested people are expected to benefit from such a project. Although the borehole storage technology is in many ways spectacular, it suffers sadly from taking place underground and has thus traditionally been difficult to show. It is difficult to convince people that the energy storage in boreholes is a really good idea, despite very promising research results. With this project we have aimed at a huge step towards optimizing the presentation of the equipment and results from the Energy Park Laboratory, and to develop techniques for compelling and informative visualization of the mechanism behind heat storage in general. In a longer perspective, it is expected that this project create a basis for further work on the visualization of energy systems. It can be both internally at VIA, for example for the rest of VIA Energy Park or in cooperation with Civil Engineering, and externally, so we can help the local industry and supply companies- entirety to communicate technical issues in a more accessible way.

2.1 Project Plan:

In the planning and start-up phase of the project, some the thoughts from the project description were made more concrete. In particular, it was decided that a key element of the project was to make measurements on the existing boreholes in the Energy Park laboratory. VIA University College already has access to large-scale data from Brædstrup District Heating an-calf, but it was judged essential to be able to present concrete data from the local boring when there are visitors in the Energy Park. Field trials project were planned to run non-stop for at least 4 months in order to gather enough valid data. Such measurement results would also of great scientific value and were intended to be made available to Ph.D. students, businesses and other interested.

The visualization of the data and of the equipment's operation was planned to involve the latest techniques. The starting point would be build 3D models of soil drilling and the surrounding strata. Such models can then be used for Virtual/Augmented Reality visualization, where the user can select different perspectives, cuts, etc. and thus get an interactive experience system. In addition to the static elements such as soil conditions and bore dimensions, simulations should also provide more dynamic data such as the flow rate of the water that transports the heat into the ground in summer and up in winter, as well as the central point: temperature relation and energy flows in and around the borehole. Animations would be able to show how, for example, temperature evolves over a year.

2.2 Data collection ability

In the VIA Energy Park is a series of boreholes, which can all be connected to a heat pump. This makes it possible to study both heat storage and recovery. With the support from Engell Friis Foundation, we have worked over the last year to develop visualization tools to display data from the Energy Park in a comprehensible way. We will describe this work and our preliminary results in the following.
The project schedule is followed, and we can now do a manual data collection on the commissioned system. These data we use to demo of visual / augmented reality presentations of energy storage in soil borings VIA13 (Extracting energy from ground) and VIA14 (Storing energy in the ground). An automatic data collection takes considerably more time / money than we have the budget, which is why this task part is put into an ICT Engineering graduation as 3 departure students will be working with throughout the fall 2016th.

We have contacted businesses people to push the project into commercial use, or at least give us valuable input to the final form.

2.3 The achieved results:

1) Solve the problem why system automatically stops after 10 min. test.

To make the VIA Energy Park borehole system work we have used time to analyze why the system only could run for 10 minutes before it automatically stopped. The problem solution was concurred by raising the fluids pressure to 2 bar and the amount of Brine-Water was adjusted to avoid system freezing (permafrost).

2) Establish data communication (PUTTY) command prompt to Liab and make a File Transfer Protocol (FTP) connection to upload the modified configuration file to the Linux in a box (Liab) system controlling the VIA Energy storage system

3) Added automatic test run sequence to the system:

We have added the sequence automation functionality (loop sequence of one hour) as a new feature to the system. Before this project began, the operator needed to start/stop the system manually. The

4) Find the optimal energy storage parameters:
To optimize the amount of energy storage in the borehole the start-stop sequence was adjusted several times until we reached an optimal sequence of 15 minutes test run and 45 minutes standby (The saturation limit for storing energy at VIA 14).

5) Added outdoor temperature PT1000 sensor
Because the outdoor temperature have influence on the first meter in the boreholes we have added a PT1000 sensor outside the VIA Energy Park and integrated into the Liab system to measuring the outdoor temperature.

![PT1000 temperature sensor](image)

*Figure 2: PT 1000 temperature sensor.*

Because of the first 10 meters of ground is dependent of season temperature we need to measure the outdoor temperature.

![Season temperature influence on vertical ground temperature](image)

*Figure 3: Season temperature influence on vertical ground temperature.*

6) The borehole layers of material
The different kind of soil is shown with the deepness of the different kind of soil. The lambda values is used for energy storage efficiency (see e.g. Banks, 2012).
**Figure 4:** Via borehole soil structure incl. lambda value.

**Figure 5:** Thermal conductivity of various materials.

### Thermal Conductivity of Various Materials at R1

<table>
<thead>
<tr>
<th>Material</th>
<th>$k$ (W/m·K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>247</td>
</tr>
<tr>
<td>Copper</td>
<td>390</td>
</tr>
<tr>
<td>Gold</td>
<td>315</td>
</tr>
<tr>
<td>Iron</td>
<td>80</td>
</tr>
<tr>
<td>Nickel</td>
<td>90</td>
</tr>
<tr>
<td>Silver</td>
<td>425</td>
</tr>
<tr>
<td>Tungsten</td>
<td>175</td>
</tr>
<tr>
<td>1025 Steel</td>
<td>51.8</td>
</tr>
<tr>
<td>316 Stainless steel</td>
<td>15.9</td>
</tr>
<tr>
<td>Brass (70Cu-30Zn)</td>
<td>120</td>
</tr>
<tr>
<td>Kovar (54Fe-25Ni-17Co)</td>
<td>17</td>
</tr>
<tr>
<td>Invar (69Fe-36Ni)</td>
<td>10</td>
</tr>
<tr>
<td>Supex Invar (63Fe-32Ni-5Co)</td>
<td>10</td>
</tr>
<tr>
<td>Alumina (Al$_2$O$_3$)</td>
<td>39</td>
</tr>
<tr>
<td>Magnesia (MgO)</td>
<td>27.7</td>
</tr>
<tr>
<td>Spinel (MgAl$_2$O$_4$)</td>
<td>15.6$^a$</td>
</tr>
<tr>
<td>Fused silica (SiO$_2$)</td>
<td>1.4</td>
</tr>
<tr>
<td>Soda-lime glass</td>
<td>1.7</td>
</tr>
<tr>
<td>Boro-silicate (Pyrex) glass</td>
<td>1.4</td>
</tr>
<tr>
<td>Polyethylene (high density)</td>
<td>0.40–0.50</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>0.12</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>0.13</td>
</tr>
<tr>
<td>Polytetrafluoroethylene (Teflon)</td>
<td>0.25</td>
</tr>
<tr>
<td>Phenol-formaldehyde, phenolic</td>
<td>0.15</td>
</tr>
<tr>
<td>Nylon 6.6</td>
<td>0.24</td>
</tr>
<tr>
<td>Polymoprene</td>
<td>0.14</td>
</tr>
</tbody>
</table>

$^a$ Converted from J/m·K.

- **Diamond:** 2310
- **Graphite:**
  - Along c-axis: 2000
  - Along a-axis: 9.5

- **SiO$_2$**
  - Crystalline
    - Along c-axis: 10.4
    - Along a-axis: 6.2
  - Amorphous: 1.38
7) The borehole identification at VIA using 2D VIA Tags
To be sure we are handling the correct borehole the respective borehole tag (2D image) is used

Figure 6: Three versions of VIA Tags to identify different boreholes.

8) The visualization of energy storage in boreholes
The energy storage in clay, sand, rubles, granite etc. is visualized by use of the modern presentation on SmartPhone (Samsung S5). In the summer, the energy is stored/spread in the soil and in the winter, the energy is extracted from the soil.

Figure 7: General overview of the Visualization.

The energy (heat) storage compression/extraction in boreholes:

Figure 8: Pre-version of animation of the VIA Energy Park heat storage/extraction.
The animation of VIA Energy Park energy storage system can be presented in a Visualization demo. The VIA Energy Park’s 100 meter deep soil borings (VIA 13 and VIA14) as an Android app on a Samsung Smartphone or Sony Tablet.

The energy storage system fluid flow, temperature changes and power consumption is working fine and makes the wanted visualization of the energy storage in boreholes on Smartphone / Tablet.

Along with a few students, I present an animation of energy storage in soil borings, propagation of heat in VIA’s Energy Parks soil with layers and a Smartphone visualization.

9) The “Visualization of energy storage has been presented on VIA FOU energy conference. Many interested quested was offered by the audience.
10) Test results

The test results on VIA Energy Park System Equipment
The test run sequence was calibrated several times to find the saturation point for VIA energy parks borehole.

The test results on Visualisation on SmartPhone
At the VIA Engineering FOU-conference 10 people tested the Smartphone visualization of energy storage in boreholes. They all agreed that this application really helped understanding how the VIA Energy Park stores the energy in boreholes. Also the animation of how the energy extraction/contraction helped a lot to the understanding of how the energy is stored in the soil and the latency for this kind of energy storage.

11) Project interview for VIA local paper.
To make publicity of the article “Visualization of energy storage in boreholes” was published in the local VIA paper on web. The Engell Friis foundation was mentioned as the sponsor of the project (see Appendix).
2.4 Deviations:

1) Data visualization presentations are based on historical data, not real time data. Based on the reduced budget and time spent on basic working functionality we did only have time to make a proof of concept project.

2) Temperature sensor in parallel to boreholes does not work
   The temperature sensors dug into the ground near by the tested in steps of 5 meter in the boreholes are found not usable, because they have not been placed accurate in parallel to the test boreholes. The temperature measurements behavior is unpredictable and very strange to expected results.

   The soil layers with temperature sensors are shown in Figure 12.

3) We did not compare the VIA Energy Park results with results from other boreholes like Brædstrup Fjernvarme, because the main interest was the Visualization of energy storage in boreholes.
3  Target fulfillment: Technical

3.1 Energy park Operation:

It was a prerequisite for doing visualizations of real operational data for the system to be able to run it in a controlled and preferably automated way. The VIA Energy Park heat pump and borehole system is configured such that a small computer, the LIAB Box, is the central controller. This computer can turn on and off both the two pumps circulating water and brine respectively to boreholes 13 and 14, as well as the heat pump itself. The LIAB Box runs a small webserver and provides a web interface to turn on and off the pumps. This way of control is essentially like a traditional panel of switches with added possibility of remote control. It does not provide any simple way of scheduled operation. It was therefore a priority to figure out how to get a more direct, low-level access to the LIAB Box and set up a scheduled control sequence.

We sought the help of Steen Kramer Jensen and Esben Okkels Larsen from Insero who were involved in the project “Styr din varmepumpe” (Control Your Heat Pump) for which the LIAB Box was developed. With their assistance we were quickly able to access the system and figure out how we could schedule on/off signals to the pumps. The LIAB Box has Linux as operating system and the actual control and data acquisition is handled by a daemon called `contdaem`. The daemon is in turn controlled by an XML-formatted configuration file. In order to transfer a new configuration file to the box, a FTP program must be used and in order to activate it, it is necessary to log on to the box via Telnet.

Although the `contdaem` has no direct scheduling functionality (i.e. an option to send control signal at given date and time), it does have sequencing functionality. We initially set up sequences where the circulation pumps and the heat pump itself were all on for 30 minutes and then the system was allowed to rest for 30 minutes. However, as the heat pump is actually quite powerful it was not possible to repeat this cycle for a longer period of time without risk of freezing the ground around the source borehole. The majority of our data collection has therefore been done with a one-hour sequence consisting of 15 minutes of heat transport followed by 45 minutes of rest. The practical knowledge we have gained in the project is currently being disseminated to staff and students at VIA. Before this project, only simple control via the web interface was used, but now more advanced and longer-running experiments are feasible.
3.2 Data Acquisition

As mentioned above, the data acquisition in the VIA Energy Park heat pump installation is handled by the LIAB box. The control daemon condaem collects sensor data, does appropriate averaging, and then dumps the data in a SQLite database on the box. This database is then periodically read and transferred to centralized server where all the data from the Energy Park can be accessed via a web interface. Our first concern regarding this system was to add the outdoor temperature from the newly mounted sensor. This turned out to be surprisingly difficult and no fully satisfactory solution has yet been found. A second desired improvement was a better time-resolution. By default, condaem averages the data over 5 minute periods. Although this is clearly enough for a continuously running system, it falls short when we want to track the response of the system during a sequence where some phases last perhaps only 15 minutes. At a 5 minute resolution, the data collected will be very dependent on the exact timing between the averaging periods and the control signals. We therefore opted to introduce data with only 30 seconds averaging into the database.

Initially, we had hoped to measure soil temperatures directly using a set of sensors which were actually installed to monitor a different borehole. The sensors are, however, just a few meters away from one of the active boreholes. Unfortunately, due to the very large storage volumes, the temperature differences that we can realistically induce turn out to be too small to see even at these short distances. We have therefore started experimenting with “probe sequences”, where the pump circulating fluid in a borehole is turned on at its own. The fluid temperature will then reflect the temperature conditions in the borehole, possibly even with some spatial resolution. An example of data from such a probing sequence is shown in Figure 13. We intend to pursue this idea further after the completion of the current project.

3.3 Visualization

3.3.1 Previous visualization display

In an internal VIA University College Research and Development Conference, we presented the preliminary results, which gave rise to a good constructive dialogue with VIA's other teaching staff. Uffe presented a test sequence comprising a graphical presentation of data from the heat pump, flow / temperature of the brine and heating as well as system power consumption.
3.3.2 New visualization display:

The data used for demos are based on historical data from the Liab, but with the new Bachelor project team the server will be configured to extract the data real time from Liab using PC server and send the data for presentation on the Platform.

1) Before the system can work, a 3D model of the borehole must be created in UNITY and uploaded to the AUGMENT server.
2) The Tablet and the Smartphones install the AUGMENT application.
3) Go to destination and place the VIA Tag on the top of the borehole you want to visualize
4) Activate the AUGMENT application and try to make VIA Tag fit into UNITY frame on Tablet or Smartphone display. The VIA Tag identification is a 2D A4 paper showing pebbles (stones).
5) The VIA Tag is recognized and the “VIA Enegi Storage Horsens” image is downloaded to the application and shown at the display.

![Image](image1.png)

Figure 15: In the right corner of application display select the animation or the borehole layers heat absorption/extraction.

6) User selects 1 of the 2 scenarios:
   a) VIA Energy Park Liab System Animation
   b) Show borehole layers heat absorption/extraction

![Image](image2.png)

Figure 16: VIA energy storage animation presentation.

a) The VIA Energy Park Liab System Animation shows the warm down/up, the brine down/up, flow speed for warm and brine and the weather outdoor temperature.
b) The VIA Energy Park’s Show borehole layers with short intervals, Lambda values for the different soil layers, heat absorption/extraction during winter (heat extraction) and during summer (heat storage).

4 Target fulfilment: Project

Informative 3D graphics will be a big step forward in presentation, both for visitors in the Energy Park laboratory and in connection with lectures as VIA’s employees hold around the country and at international conferences. In order to illustrate the example the depth of the wells and associate experiments close to the physical environment can go further with Augmented Reality visualized rings. Here visitors using, for example, the camera on their mobile phone “see” through the soil surface and onto the otherwise hidden installations, soil conditions, temperature distributions and so on. The technique is not yet at a stage where it can replace technical drawings connection for construction work, but to teaching target and for display for visitors will be particularly suitable. Further information on Augmented and Virtual Reality and the main units that we want to visualize are described in separate documents for the project contributes VIA University College with soil drilling, heat pump, circulation pump, pressure gauges, valves, water tank, temperature and flow sensors, data is collected-processing equipment and database facilities.

4.1 Project timetable:

The project has run over a 12-month period with starting 1 October 2015. The development of the software part took place before data collection for the 3D model visualization and tests. The publication was make on VIA FOU conference and VIA local web page. The main points for the project time table was as follows

<table>
<thead>
<tr>
<th>Date</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 / 10-2015 - 1 / 4-2016:</td>
<td>Developing software with simulated data</td>
</tr>
<tr>
<td>1 / 4-2016 - 1 / 10-2016:</td>
<td>Data acquisition from the VIA Energy Park</td>
</tr>
<tr>
<td>1 / 8-2016 - 1 / 9-2016:</td>
<td>Import of real data in the software, optimizing the presentation and documentation</td>
</tr>
<tr>
<td>1 / 9-2016 - 1/10-2016:</td>
<td>Publication of the project: VIA website, local newspapers, trade journals, conferences.</td>
</tr>
</tbody>
</table>
5 Tips and hints for future projects

1) (Prio 1) Data must be collected real time.

2) (Prio 2) Database
The project can be extended with database to continuously collect data from Liab to prevent not being able to show data from borehole. The Augment Reality glasses makes it easier for operators to work hands free on the system and still follow the system behavior.

Figure 16 Extension possibilities for this project

3) (Prio 3) Make use of 3D tracking of the boreholes instead of the 2D icon used.

4) (Prio 4) Make use of the GPS location to extract information's from database: sewer lines, power cables, water pipes, telephone cables, fiber optic cables

5) (Prio 5) Make real end user scenarios (household) for the borehole system, not only the proof of concept scenarios.

5.1 Project consolidation

The project is based on VIA's Center for Research and Development in Construction, Energy and Environment.
In the process we have involvement of Insero companies And VIA FOU both in terms of getting qualified input to work, to make scar-operation practice-oriented as well as a qualification of the results obtained.
5.2 Company relations

Engell Friss
Insero

6 References

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Poulsen, Søren Erbs and Pagola, Maria Alberdi. Interpretation of ongoing thermal response tests of vertical (BHE) borehole heat exchangers with predictive uncertainty based stopping criterion, Energy, 88, 157, 2015

VIA BYGGERI, ENERGI & MILJØ, Center for Forskning og Udvikling, Årsrapport, [Online], 2014

Geoenergi.org, [Online], 2014.


7 Appendix:

Artikel from VIA’s “Medarbejderportalen”