1. BACKGROUND

The R&D-project “Thermal Energy Storage in Office Buildings Foundations” analyses foundation absorbers, energy piles and borehole heat exchangers (max. depth 150 m) for seasonal heat and cold supply of office buildings. The R&D-project has a duration of three years and ends in June 2007. It is supported by the Federal Ministry of Economics and Technology (BMWi) and coordinated by the Project Management Organisation Jülich (PTJ).

Since the late nineties office buildings in Germany are being constructed using the surrounding ground of their foundations for heat exchange and seasonal thermal energy storage. Via a heat pump those seasonal UTES-systems extract heat from the surrounding ground during the cold period. The backflow of the heat pump cools down the foundation and surrounding ground. The volume cooled down beneath the building can be used afterwards as a heat sink during summer time.

The planning of those UTES-systems implies a closer look on the surrounding geological conditions, physics, heat and cold demand of the building. During planning process complex planning software like TRNSYS or FEM software is often applied. Simple planning tools are not available. To develop those easy to use tools a systematic evaluation of those systems is being elaborated by our R&D-project.

The evaluation includes nine low energy office buildings and one library constructed between 2002 and 2004. Those office buildings have a gross floor area varying from 3 500 m² to 73 500 m². All buildings are using the UTES in connection with low temperature heating systems (22° to 27°C with ground coupled heat pump) and high temperature cooling systems in a direct cooling mode (17°C to 22°C). These ranges are ideal for an efficient ground coupled energy supply. Most of those buildings are equipped with concrete core activation (CCA). Here the concrete core of the ceiling is fitted out with closed circuits of water filled hoses. Depending on temperature gradient, water flow as well as position and distance of the tubes in the activated ceiling, the cooling or heating power achieves a value between 25 and 40 W/m².

The specific heating energy demand of the evaluated buildings differs from 55 kWh/(m²·a) to 200 kWh/(m²·a). The UTESs cover only a certain part of their heating/cooling demand. Only a few buildings additionally use the UTES for air conditioning.

The buildings show a great difference of planning and design effort put into the evaluated UTES. Our monitoring also reveals that fitting out and constructing those systems is not a today problem. The performance of those UTESs depend in a great matter on a sophisticated controlling ability of the facility management in charge.

An overview of the participating buildings and their implemented systems is given in table #1.

<table>
<thead>
<tr>
<th>VW University Library of the Technical University of Berlin</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Usage / Floor area</td>
<td>Library building / 34,000 m² (completion 2004)</td>
</tr>
<tr>
<td>UTES type</td>
<td>8,000 m² horizontal foundation heat exchanger supplying a concrete core activation system for cooling and heating</td>
</tr>
<tr>
<td>Heating capacity</td>
<td>80 kW by HP (basic heat load supply)</td>
</tr>
<tr>
<td>Cooling capacity</td>
<td>100 kW free cooling (basic cooling load supply)</td>
</tr>
</tbody>
</table>
### 3. METHODOLOGY OF THE RESEARCH AND DEVELOPMENT PROJECT

The R&D Project is structured in two parts. On one hand all ten buildings are being analyzed regarding to geological conditions, system configuration, energy performance as well as investment and operating costs. An important component of this analysis is the comparison of estimated and predicted values with the real values in operation. This comparison should help to detect inaccuracy and failures of the design and simulation tools.

Furthermore monitoring five of the buildings is main part of the project. In those five buildings measuring equipment has been installed to analyze operation, energy performance and ground temperatures. Cold/heat meters are installed to log the energy output of the UTESs as well as its quota of total heating and cooling energy consumption. Furthermore the electric energy consumption of heat pumps and UTES-system-pumps is monitored to enable a complete evaluation.

In order to optimize their efficiency and control algorithms the building will be simulated with dynamic thermal building and system simulation tools (TRNSYS). In order to gain sophisticated simulation data resource about 250 values are simultaneously logged every 15 minutes in each building. The data is then collected from our institute via internet and automatically visualized. This can be done at reasonable cost by using existing building control system infrastructures.

<table>
<thead>
<tr>
<th>Building</th>
<th>Usage / Floor area</th>
<th>UTES type</th>
<th>Heating capacity</th>
<th>Cooling capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORD-LB, Hanover</td>
<td>Office Building / 1.400 workplaces / 73.334 m²</td>
<td>122 energy-piles supplying a concrete core activation system for cooling and heating</td>
<td>155 kW by HP(basic heat load supply)</td>
<td>128 kW free cooling (peak cooling load supply)</td>
</tr>
<tr>
<td>VGH Inc., Lüneburg</td>
<td>Office building / 3.500 m² (completion 2002)</td>
<td>98 energy piles for cooling and heating of a concrete core activation system and ventilation</td>
<td>90 kW by HP</td>
<td>60 kW free cooling (basic cooling load supply)</td>
</tr>
<tr>
<td>Rickmers, Hamburg</td>
<td>260 workplaces / 9920 m² (completion 2002)</td>
<td>17 BHE (depth: 100 m) for cooling and heating of concrete core act. and ventilation</td>
<td>90 kW by HP (basic heat load supply)</td>
<td>60 kW free cooling (for basic cooling load supply)</td>
</tr>
<tr>
<td>EnergyForum Berlin, Berlin</td>
<td>Office Building / 21.200 m² (completion 2003)</td>
<td>198 energy piles 8.50 m deep for a concrete core activation system for cooling and heating</td>
<td>107 kW by HP (partial basic heat load supply)</td>
<td>60 kW free cooling (partial basic cooling load supply)</td>
</tr>
<tr>
<td>Gelsenwasser Inc., Gelsenkirchen</td>
<td>Office building / 20.000 m² (completion 2003)</td>
<td>48 BHE (depth: 150 m) for supplying cooling/heating panels and ventilation</td>
<td>320 kW by 2 HP (basic heating load supply)</td>
<td>260 kW free cooling (basic cooling load supply)</td>
</tr>
</tbody>
</table>
4. RESULTS AND EXPERIENCES AT VOLKSWAGEN LIBRARY OF THE TECHNICAL UNIVERSITY AND UNIVERSITY OF ARTS OF BERLIN

The VW-Library of the Technical University and University of Arts of Berlin has been in service since fall 2004. Constructor has been the Federal State of Berlin itself, represented by the Senate Department of Urban Development. (see Fig # 1)

![Fig. # 1: The VW-Library of the Technical University and University of Arts of Berlin (source: Prof. Walter A Nobel)](image)

**Building Concept**

Main part of the realized energy design is an 8,000 m² horizontal absorber placed below the base of the library. The absorber containing 126 parallel circuits with a tube diameter of 0.025 m and a tube distance of about 0.45 m is placed 1 m below groundwater table. The complete length of the implemented tubes is about 21,300 m. The UTES is used for seasonal heat and cold supply of concrete core activation implemented in 7,700 m² of ceiling area of offices and reading space. Just like in most buildings the cold is used for direct cooling. For heating in winter the system is coupled with an 80 kW heat pump.

In addition to the concrete core activation covering the basic heat and cold supply, the offices and reading space are equipped with radiators using long-distance heating. In the reading space HVAC-systems (DCS-systems) are also implemented and the offices are realized with natural ventilation. (see Fig. # 2)

![Fig. # 2: Energy concept – VW-Library of the Technical University and University of Arts](image)
Energy performance

During system design an equalized energy balance was estimated for horizontal absorber with a maximum charging and discharging energy amount of 142 MWh/a (see Fig. # 3). Contrary to those planning preferences– the heating and cooling energy earnings by the foundation absorber were about 50 MWh/a and 178 MWh/a from March 2005 until March 2006.

This uneven energy balance is due to higher internal heat loads than estimated caused by more technical equipment fitted into the library.

A second reason is the faster reacting space heating compared to the slower reacting concrete core activation during the heating period. In general the thermostatic valves of the space heating are operated by the office occupants themselves. Keeping them running on a high level, the room temperature increases above the intended temperature. Because of this the CCA reaches its activation point less often and the heat pump is running rarely and not at full load mode. In other words the slower concrete core activation is not able to supply the rooms with heat because the space heating preliminarily heats up the office section. (see Fig. # 4) Even though the heat demand is low, the SPF of the heat pump is about 3.

![Fig. # 3: Predicted energy-output of the foundation absorber beneath the VW-Library](image)

![Fig. # 4: Heat quantity of concrete core activation in comparison to heat quantity of space heating at the VW-Library, October 2005 till April 2006](image)
In addition an undesired ‘injection’ of heating energy into the UTES during winter months is caused by the rarely working system. Due to this the fluid in the heat pump circuit stands still and warms up in the pipes and has to be cooled down again while being pumped through the ground.

Another reason for the uneven energy balance was a fault in the controlling strategy. In the past the system was controlled by the present outdoor temperature. So during transit time the system was permanently changing between heating and cooling. At night the building was heated and had to be cooled down at daytime because of internal gains.

In order to optimize the foundation absorbers performance the energy charging has to be reduced and the discharging has to be increased. Therefore an additional compression chiller will be implemented to the cooling circuit to cover the higher than accepted heat load and realize a recovery of the overcharged UTES.

To increase the heat supply quota the concrete core activation the space heating has to be turned down to a temperature below the intended room temperature.

Faults and potentials are being detected step by step. Our scientific monitoring in cooperation with the facility management will lead to an improvement of the performance of the foundation absorber and the thermal comfort of the library.

5. RESULTS AND EXPERIENCES AT THE EXAMPLE OF THE ENERGYFORUM BERLIN

Another monitored building is an office building standing on 198 energy-piles in the centre of Berlin, called ‘EnergyForum’. The approximately 21 000 m² large building was finished in 2003 and cost 55 million Euros. (see Fig. #5)

The EnergyForum reached its energetic goal of a primary energy consumption of 91 kWh/(m²a) for HVAC and lighting. Using ordinary Double-U Borehole piping material, the 8.50 m long energy-piles form a 6 732 m long heat exchanger below the building. The energy-piles are used for a seasonal base load supply of heat and cold for 4 100 m² of concrete core activation in the office ceilings. The 100 kW heat pump is covering about 17 % of the annual heating energy demand. About 83 % of the heating energy comes from a high efficient distance heating power plant.

The total investment cost of the UTES was 171 718 €. This is about 25 € per energy-pile. Since the operation started in June 2003 the UTES yearly saved about 11 517 €/a of heating and cooling energy cost (see Fig. #11). During operation the heat pump performed an average SPF of 5.6 which is a very good result for a heat pump which has not been running in full load mode often.
Fig. # 6 (left): Coverage of the total heating energy consumption in 2004 of the EnergyForum.

Fig. # 7 (right): Coverage of the total heating energy consumption in 2005 of the EnergyForum.

Fig. # 8 (left): Weekly averaged measured Seasonal Performance Factor (SPF) of the 100 kW ground source heat pump at the EnergyForum Berlin.

Fig. # 9 (right): Measured heating power of the installed convectors and the energy-pile heat pump from Sept. 2003 till April 2006.

Those kind of UTESs are planed as even balanced systems in which only the same amount of energy should be extracted as is brought into the storage. This way the UTESs remain a stable system over decades. Another aspect in Berlin is that the UTES of the EnergyForum would be shut down by the authorities in case the UTES warms up the groundwater in an undesired level. Here takes the protection of drinking water resources priority over UTES-usage. As shown in Fig. # 10 below, the charging and discharging of the UTES of the EnergyForum was very imbalanced during the first six months of operation. This was a result of malfunctions in the building control system. In August 2004 the building reached a ‘regular’ operation status. This ‘regular’ operation status still leaves enough aspects for optimization. Especially the control of the CCA is in constant modification in order to reach better heat pump operation times and to lower consumption of long-distance heating energy.
6. CONCLUSION

Our R&D-project shows that it is possible to fit UTES-systems into today’s office buildings energy concepts. They are ideal to be combined with low temperature heating or high temperature cooling systems like concrete core activation or heating/cooling ceilings. In this combination UTES coupled heat pumps reach high SPF’s. In order to implement a cost-effective seasonal UTES-system, it must be taken in consideration throughout the entire design of a building, that high temperature cooling systems (fluid temp. = 17 to 22°C) need modern façade-systems which keep the external load out of the offices.
The investment cost per meter energy-pile lies around 17 and 28 €/m. A borehole heat exchanger (BHE) costs about 45 to 75 €/m in Germany. One of the biggest parts of investment costs of the UTES are the heat pumps. About 30 to 40 % of the investment costs have to be spent here.

In day to day practice it shows that a relatively low experience level of the facility management might lead to long lasting underperformance of a seasonal UTES-system. Therefore the control strategies have to be double checked during commissioning phase. In case of starting operation of a seasonal UTES-system during cooling period it must be kept in mind that an overheating can easily occur due to a non pre cooled underground. The high storage capability of the ground prevents high temperatures from being lowered during just one heating period. Those circumstances might lead to an underperformance of cooling over years.

During spring and autumn malfunctioning controls often cool down an office building during daytime and heat it up at nighttime. As a result lots of energy is being wasted by running heat pump and circulation pumps. This demonstrates that a seasonal UTES performs the best if it is strictly operated during cooling and heating periods only.

Under hydro geological aspects we recognized a clear difference between the ground temperatures forecasted by planning simulation and the real ground temperatures at begin of operation. Here all influencing side effects have not yet been worked out.

In the next months we will combine our monitoring results with dynamic building and system simulations to elaborate optimizing strategies. In order to reach a more detailed simulation of groundwater flow induced temperature drift a coupled simulation with TRNSYS and ANSYS is in development.

The first results of the project show that operation of energy-piles, foundation absorbers and borehole heat exchangers used as seasonal UTESs are still in need of optimization as well as research work in order to reach full user acceptance and better cost-effectiveness.

7. REFERENCES

