Down to earth

Lessons learned from putting ground source heat pumps into action in low carbon buildings
Interestingly, when the participants were asked whether GSHP would be the technology of choice if the project started over again, all said “Yes!”
Sharing our experience: About this booklet

*Down to earth* is part of the ‘Sharing our experience’ series. These booklets provide advice and tips to help you plan, build and manage cost-effective low carbon buildings that really work to save you money and carbon.

The insights are based on real data from 28 case studies from the Department of Energy and Climate Change’s Low Carbon Buildings Programme and our work on refurbishments. The projects cover many sectors including retail, education, offices and mixed use residential buildings.

Further information
To find out how we can help with your low carbon building project, contact us on 0800 085 2005 or visit [www.carbontrust.co.uk/buildings](http://www.carbontrust.co.uk/buildings)
What is a ground source heat pump?

Ground source heating and cooling systems exploit the stable temperature of the ground or groundwater beneath a site and use it as a source of heating and/or cooling. We look at three types.

**Open loop system**
- Groundwater is extracted from and returned to a suitable aquifer below the site
- Output is dependant on how much water can be extracted
- More efficient than closed loop systems, so less boreholes are needed
- Generally more cost efficient than a closed loop system
- Can use cooling effect of groundwater without running a heat pump.

**Closed loop vertical system**
- A heat exchange fluid is circulated through pipes laid vertically in boreholes in the ground
- Can be used in most ground types in the earth or in ground water
- Output is fairly predictable
- Less efficient than an open loop system so more boreholes are required (projects showed this was by a factor of around 40)
- Generally less cost efficient than open loop systems – but up-front investigations are less.

**Closed loop horizontal system**
- A heat exchange fluid is circulated through pipes laid horizontally in trenches in the ground
- A large area of ground is required – larger than vertical systems
- None of the case studies referenced in this report used this system – but one considered it.
Using heat pumps

A heat pump uses electricity to raise or lower the temperature of the heat exchange fluid, but can be three or four times more efficient than conventional electric heaters.

Low temperature heating systems (or equivalent cooling systems) such as underfloor heating or chilled beams most efficiently deliver heating or cooling.

Heat pumps can be used to heat domestic hot water, however efficiency is reduced and a supplementary heating system is usually required.

Boreholes can be located almost anywhere on the site providing ground conditions permit, and there is adequate spacing between them. They can also be built or landscaped over, providing access is maintained. Space inside a plant room is required for the heat pump equipment.

Conventional systems such as gas boilers are often installed for peak heating demands and to provide a back-up system.

The GSHP installations were predicted to contribute to average reductions in CO$_2$ of 25% compared to 2006 Building Regulations.
Low carbon technology is perceived as being relatively expensive, but actually we found it to be quite cost-effective. Certainly the running costs are very cost effective, and the capital cost to us was quite modest.

David Oldham, Director of Capital Investments, Edge Hill University
Why choose ground source heat pumps?

A well-insulated and adequately ventilated building is the ideal candidate to benefit from the low-carbon, low-cost benefits of ground source heat pumps (GSHPs).

Motivations
When we asked what motivated our case study project teams to opt for GSHP we received a variety of responses.

- They are easy to run once installed.
- They can provide low carbon cooling.
- Appropriate use reduces CO₂ emissions.
- They can reduce running costs.
- They work well alongside other low carbon technologies.
- They are becoming mainstream.

GSHPs can make a big contribution to carbon savings in new buildings, with most teams predicting GSHP would provide carbon savings of 10%-20% compared with 2006 building regulations.

Many teams were attracted to the operational simplicity of GSHP. One chose GSHP over biomass to eliminate uncertainty around future fuel supply and storage.

After visiting various low energy buildings, St Edmundsbury Borough Council concluded that GSHP would complement its design ambition – high occupant comfort combined with natural ventilation. Pipes fed by GSHP have been embedded in the concrete ceilings to provide radiant heating and cooling.

The bigger design picture
Good building design can improve the feasibility of GSHP by minimising the size and cost of the system needed. GSHP works well with:

- well-insulated and naturally ventilated buildings – because if less heating or cooling is needed, less ground area is required
- low temperature systems such as underfloor heating or radiant cooling
- low carbon electricity sources, such as photovoltaics and wind turbines, help balance the electricity used by the heat pumps.

Stoke Local Service Centre’s passive design measures worked with GSHP. Very good insulation keeps the building warm in the winter, and a natural ventilation system cools the building in the summer. Underfloor heating is used to provide a steady, even source of heating when required.
Costs

GSHP can offer the benefits of reduced energy bills, carbon savings and reduced maintenance costs. These will eventually offset the up-front capital investment.

Open loop systems tend to involve greater up-front cost and testing. However, overall they appear to be more cost effective than closed loop systems in the majority of situations.

The broad range of costs seen is due to the fact that conditions and solutions vary from site to site.

<table>
<thead>
<tr>
<th>Type of system</th>
<th>Cost per kW of heat output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open loop</td>
<td>£1,000 to £2,000</td>
</tr>
<tr>
<td>Closed loop</td>
<td>£1,600 to £3,200</td>
</tr>
</tbody>
</table>

Performance in practice

At Stoke Local Service Centre, the GSHP system had a measured carbon saving of around 30% compared to a conventional gas boiler. However, energy use for heating was higher than expected as the control system still needed further tuning.
Low carbon cooling

GSHP’s versatility was part of its appeal for some clients and design teams, as it is able to provide low carbon cooling as well as heating.

This proved particularly useful for St Edmundsbury Borough Council and Edge Hill University, who might otherwise have resorted to air conditioning.

Using GSHP for cooling as well as heating improves the efficiency of a system over its lifetime, because it helps keep ground temperatures constant. Hackney Academy were advised to use cooling for this very reason.

The London School of Hygiene and Tropical Medicine (LSHTM) only required cooling since the building was already connected to a district heating system. So the design team decided to use an open-loop groundwater cooling system, omitting the heat pump element.

Lessons learned

- GSHP works best as part of an integrated low carbon design.
- Good building fabric is essential to minimising heating and cooling needs.
- Upfront costs are offset by lower whole life costs.
- GSHP can make a big contribution to carbon savings in new buildings, if operated correctly.
- Using GSHP for low carbon cooling improves efficiency.

Renewable Heat Incentive (RHI)

If you install a new GSHP you could get paid for the heat generated by the installation.

This RHI tariff will significantly improve the business case for heat pumps and support their broader roll-out to meet the UK’s 2020 renewable energy target.

- For more information visit the Department of Energy and Climate Change website.
Assessing site feasibility

The success of GSHP depends on ground conditions, which are highly variable. It is important to thoroughly research site feasibility and technology choices.
Assessing ground condition

The diagram above shows the stages of the fact-finding process. Each stage offers a more detailed level of information, reducing the risk of making the wrong choices.

Case study: Desktop only
A desktop study confirmed that there was not a great deal of local information available about the ground conditions at RHS Garden Harlow Carr. A closed loop system was therefore chosen as no ground water is needed, and output can be predicted fairly reliably.

Case study: Comparing locations
The LSHTM found that the ground water yields of boreholes in nearby locations weren’t indicative of the actual yields in practice.

Case study: Actual yields
Some projects, such as St Edmundsbury Borough Council, found the yields of their boreholes were better than tests predicted. Whereas Greenhouse in Leeds found the yields of the four different boreholes on their site varied to a significant extent.
Dealing with the unknown

Contractor costs
Contractors’ time can be expensive. As the LSHTM didn’t need many boreholes overall, it took a calculated gamble by asking the contractor to drill them all at once during test drilling.

Fixed price drilling
It can be difficult to control costs because you don’t know how many boreholes you need until you start drilling. The Royal Horticultural Society (RHS) managed the risk on Bramall Learning Centre by asking their contractor for a fixed price for a guaranteed output – passing the risk of the ‘unknown’ onto them.

Predicting yields
Calculating best- and worst-case scenarios before you have the full picture can help you decide whether it is viable to proceed. The team on Greenhouse project in Leeds worked out that it would need between two and five boreholes to meet its needs, which gave them confidence to go ahead. Actually, only four boreholes were needed.

On projects where we could measure GSHP performance there was often a small gap between predicted average performance and what was delivered in practice, as shown in Figure 2. This is worth accounting for in any feasibility assessment.

Figure 2 The gap between predicted and measured coefficients of performance (CoP) for three GSHP projects
Technology choices

Technology choice was influenced by:

- ground space available
- building characteristics
- likely ground conditions
- groundwater presence.

Three examples are shown above.

<table>
<thead>
<tr>
<th>Constraints</th>
<th>Bramall Learning Centre</th>
<th>City Academy, Hackney</th>
<th>Edge Hill University</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small, well-insulated building (700m²) with low heat demand</td>
<td>Large heat demand, 11,000m² building</td>
<td>Large heat demand in a 9,000m² building</td>
<td></td>
</tr>
<tr>
<td>Unknown ground and water conditions</td>
<td>Suitable aquifer not available</td>
<td>Very productive aquifer</td>
<td></td>
</tr>
<tr>
<td>Good ground space</td>
<td>Good ground space on sports pitch</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Solution</td>
<td>Five vertical closed loop boreholes</td>
<td>51 vertical closed loop boreholes 8m apart – using a large area</td>
<td>Two open loop boreholes – one extracting and one discharging water – with excess capacity to share with adjacent buildings</td>
</tr>
</tbody>
</table>

Lessons learned

- Desktop studies give an indication of what to expect from your site.
- Test boreholes may be expensive but they reduce risk and can be reused in the final installation.
- Ask for a fixed price for borehole drilling.
- Estimate the maximum and minimum number of boreholes needed.
- If an aquifer is available, consider an open loop system.
- Allow for a slightly reduced average CoP in operation in a feasibility assessment.
Design, procurement and installation
Finding experienced delivery partners, fostering good relationships and setting up collaborative work practices are all essential to project success.

Building successful teams

Experience
Contractor experience was given as a defining factor for success.

Citu was grateful that its construction contractors for Greenhouse were up-front about their limited experience. It bridged the knowledge gap by asking the building services consultant to design to a higher level of detail – an approach that worked well.

Having identified a lack of GSHP experience within the design team, Edge Hill University engaged the supplier of the system specifically to add expertise, ensuring the success of the project.

Collaboration
The way contracts are managed can make a difference.

Citu shared the feasibility ‘cost risk’ among the team, resulting in a successful project.

Early involvement
Engaging contractors early allows them to inform the design.

At Edge Hill University, early engagement meant the M&E designer and the GSHP sub-contractor finalised the system design together:

- opportunities to optimise and extend the system were identified
- the architect had time to make changes to the plant room
- costs were better controlled.

A large number of parties can be involved in the design of ground source systems, which can lead to gaps in construction packages and confusion over overall responsibility when things go wrong. It therefore pays to ensure responsibilities are clearly defined.

“During testing they discovered one of the boreholes was blocked. All the equipment had to be brought back and another borehole drilled. But because it was in the external works, it didn’t delay overall completion”

Howard Hammond, Project Manager, City of Stoke-on-Trent

Maintenance and monitoring
Contractors can offer valuable advice about running and maintenance from the earliest stages – ensuring that you end up with a simple, well-monitored and efficient system.
**Figure 3 Breakdown of costs – St Edmundsbury Borough Council**

### Cost control

**Early planning always pays**
Projects in which the design was completed before construction began received more accurate quotes from contractors and were generally more in control of final costs.

**Early design = early quotations = better cost control**

**Consider the cost of ancillary items**
Disparity between tender costs and final costs is often down to overlooked ancillary items. *Figure 3* shows a cost breakdown where ancillary items make up more than 25% of the total budget.

Edge Hill asked for quotations on an ‘open book’ basis, making it possible to compare estimates and spot whether any ancillary items had been overlooked in budgeting.

### Managing complexity

The integration of GSHPs with heating and cooling systems that also include gas boilers or chillers was a common issue in many projects. We found that it can be difficult to control and prioritise different heating or cooling sources; each working at different temperatures.

Poor control can reduce the efficiency of heat pumps and increase the running cost of the overall system. A simple system design is preferable and the designer needs to provide a clear description of how the heat pump interacts with the controls for the whole heating system. This is even more important where the system provides both heating and hot water.
Managing construction

Managing the quality of construction is key to success. Some recurring themes came up:

- locating boreholes away from other site activities helps avoid programme disruption
- 'clean' drilling methods can cut clean-up and soil removal costs
- marking boreholes prevents damage from other site activities
- without good quality lining to the correct depth, boreholes can collapse
- ensure safety equipment is installed and fully commissioned before testing the system. On one project, expensive parts were damaged by unauthorised testing by inexperienced contractors.

Contractual responsibilities and interfaces need careful consideration to ensure the success of systems

Lessons learned

- Team experience matters and outside expertise can be used to bridge knowledge gaps.
- Engaging contractors early enhances design outcomes and controls cost.
- System design should be simple with controls carefully integrated.
- Ensure costing includes all ancillary items.
- Careful consideration of borehole construction and quality control is vital for success.
- Contractual responsibilities need careful consideration.
Ensuring best performance

Commissioning, monitoring and engaging the facilities management team are often overlooked – but are vital to ensuring the heat pumps work as intended.

**Metering**

The projects demonstrate that the backbone to successful commissioning, monitoring and efficient running of a GSHP system is a good metering strategy incorporating submetering – that is, an electricity meter and a heat meter on every pump.

Stoke Local Service Centre quickly reaped the reward of installing submeters. When the heating was under-performing, the submeters identified the two faulty heat pumps responsible and the problem was easily fixed. In contrast, another project without submeters faced a protracted and expensive process to pinpoint the source of the problems.

**The right level of metering**

- makes problems easier to identify
- allows fine-tuning to achieve optimum performance
- maintains efficient energy use as a priority
- minimises running costs
- allows you to claim RHI.

**Commissioning**

There are four things to commission – the bore holes, the heat pumps and pipework, the overall system controls and the metering. These are commonly done by separate people, but somebody needs to be responsible for the overall commissioning.

**Specialist involvement** – Having invested so much so far, projects found it was worthwhile to keep specialists involved through the commissioning stage too.

At Edge Hill University, extra budget was allowed for specialist commissioning. This additional input at such a critical stage made commissioning smoother, and the GSHP system has functioned well from the outset.

Conversely, one project found the main mechanical contractor was unfamiliar with the appropriate tests required to commission boreholes, resulting in expensive delays on handover.
**Handover and fine-tuning**

**Specialist training** – The handover process is key, as the appointed facilities management team need to be able to monitor, fine-tune and maintain the system on a day-to-day basis. Several projects used dedicated training days and building user guides to facilitate this. Others used the BSRIA Soft Landings framework.

We monitored heating energy use and compared this to benchmarks on all projects. Using this technique, we identified high energy use on some projects that could be reduced by adjusting controls.

**Seasonal commissioning** – Monitoring and managing performance across seasons paid dividends in user comfort, convenience and running costs.

At Stoke Local Service Centre, the contractor’s defects and liabilities period was extended to cover a full heating season. This meant that any complications caused by extra demands on the heating or cooling could easily be rectified.

**Maintenance**

Part of the appeal of a GSHP is that it has few maintenance requirements. However, that does not mean that a system can be left to its own devices. Throughout a building’s life the GSHP system will need to be maintained. The facilities management team has a key role to play in optimising performance.

Edge Hill University alleviated this potential issue by setting up a remote diagnostics contract with the GSHP supplier. This meant the specialists could spot potential problems early from a distance, and guide the facilities management team to resolve problems which could be easily fixed.

**Lessons learned**

- Adequate metering, designed in from the outset, will aid performance tuning and fault finding.
- Keep specialists involved throughout commissioning.
- View commissioning as a long-term process that allows for seasonal change.
- Make sure the facilities management team is aware of the design intent.
- Use heating energy benchmarks to check overall system performance.

One project team recommended keeping GSHP systems as simple as possible. Evidence suggests the projects with a greater number of commissioning problems have been those with more complicated designs.
# Project summaries

<table>
<thead>
<tr>
<th>Description of project</th>
<th>The City Academy, Hackney, London</th>
<th>St Edmundsbury Borough Council, Suffolk</th>
<th>Royal Horticultural Society, North Yorkshire</th>
<th>Citu, Greenhouse, West Yorkshire</th>
<th>London School of Hygiene &amp; Tropical Medicine</th>
<th>Stoke Local Service Centre, Staffordshire</th>
<th>Edge Hill University, Lancashire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor area</td>
<td>11,217m²</td>
<td>6,430m²</td>
<td>703m²</td>
<td>11,500m²</td>
<td>2,105m²</td>
<td>1,314m²</td>
<td>7,069m² + 2,065m²</td>
</tr>
<tr>
<td>Heating capacity</td>
<td>200kW</td>
<td>463kW</td>
<td>22kW</td>
<td>645kW heating</td>
<td>586kW hot water</td>
<td>Cooling only</td>
<td>90kW</td>
</tr>
<tr>
<td>% Annual heating &amp; hot water</td>
<td>53% heating</td>
<td>100% heating</td>
<td>90% heating</td>
<td>100% heating</td>
<td>100% heating</td>
<td>100% heating</td>
<td>30% heating</td>
</tr>
<tr>
<td>Cooling capacity</td>
<td>57kW</td>
<td>430kW</td>
<td>Free cooling</td>
<td>570kW</td>
<td>200kW</td>
<td>None</td>
<td>525kW</td>
</tr>
<tr>
<td>% Annual cooling</td>
<td>89.5% cooling</td>
<td>100% cooling</td>
<td>53% cooling</td>
<td>100% cooling</td>
<td>53% cooling</td>
<td>100% cooling</td>
<td></td>
</tr>
<tr>
<td>Total cost</td>
<td>£465,000</td>
<td>£435,000</td>
<td>£71,000</td>
<td>£1.3m</td>
<td>£650,000</td>
<td>£149,000</td>
<td>£575,000</td>
</tr>
<tr>
<td>No. of boreholes</td>
<td>51</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>Open/closed loop</td>
<td>Closed</td>
<td>Open</td>
<td>Closed</td>
<td>Open</td>
<td>Open direct cooling</td>
<td>Closed</td>
<td>Open</td>
</tr>
<tr>
<td>Distance between boreholes</td>
<td>8m</td>
<td>~ 70m</td>
<td>10m</td>
<td>~ 80m</td>
<td>~ 10m</td>
<td>7m</td>
<td>180m</td>
</tr>
</tbody>
</table>
Further information

- **Energy Savings Trust**

- **BRE**

- **NHBC Foundation**

- **The Environment Agency**

- **BSRIA**
  Soft Landings framework
  [www.bsria.co.uk/services/design/soft-landings](http://www.bsria.co.uk/services/design/soft-landings)

- **CIBSE**
  TM 45: Ground water cooling systems

- **The Ground Source Heat Pump Association**
  www.gshp.org.uk
  Closed Loop Vertical Borehole Design, Installation and Materials Standards.
The Carbon Trust is a not-for-profit company with the mission to accelerate the move to a low carbon economy. We provide specialist support to business and the public sector to help cut carbon emissions, save energy and commercialise low carbon technologies. By stimulating low carbon action we contribute to key UK goals of lower carbon emissions, the development of low carbon businesses, increased energy security and associated jobs.

**We help to cut carbon emissions now by:**
- providing specialist advice and finance to help organisations cut carbon
- setting standards for carbon reduction.

**We reduce potential future carbon emissions by:**
- opening markets for low carbon technologies
- leading industry collaborations to commercialise technologies
- investing in early-stage low carbon companies.

[www.carbontrust.co.uk](http://www.carbontrust.co.uk)
0800 085 2005