Heat Pumps in Historic Buildings

The Viability of Ground Source Heat Pumps in Historic Buildings

Summary

This project was commissioned by Historic England and carried out by Max Fordham LLP. The research aligns directly with Historic England's climate change and sustainability objectives.

Electrifying heat is key to reducing reliance on fossil fuels across the heritage sector. No technology is better placed to electrify heat for space heating than heat pumps. The technology is mature, and if the whole heating system is well designed it will deliver comparable running costs to a natural gas system. Ground source heat pump (GSHP) technology can be deployed discretely without altering a site's appearance, and it delivers excellent efficiency. It is, therefore, a key technology in the decarbonisation of space heating in historic buildings.

The five case study visits took place between February and April 2023. Engineers from Max Fordham LLP carried out visual inspections of the GSHP installations and associated heating systems. They also interviewed building users to gauge their opinions on running costs, thermal comfort, noise and visual appearance. The engineers took as many quantitative measurements as possible, but time constraints and minimising the intrusiveness of site visits meant that most of the findings were qualitative. Assessing running costs was particularly difficult. Where data were available, they came in the form of energy bills. This made it challenging to make quantitative comparisons before and after installing the GSHPs. The users' perceptions of running costs are reported, but the information is highly subjective according to each individual's expectations.

The key findings were:

- Closed-loop GSHPs are a viable option for decarbonising heating systems in historic buildings.
- GSHPs are being deployed to decarbonise heating without major work to the existing heating system, particularly where conservation heating is the heating strategy. Further works can follow to help improve the effectiveness and/or efficiency of the heating system.
- Installing a ground collector is disruptive. After the ground is restored, the ground collector is barely noticeable, with only a small number of manhole covers visible.

- Issues with a heating system's performance are often due to its configuration, not the GSHP itself.
- GSHPs have similar noise levels to other heating system components, such as large circulation pumps. GSHPs are installed inside a in a plant room, and noise reduction measures are, therefore, more readily available than they are for outdoor air source heat pumps (ASHPs). Acoustics should be considered but may not require any more attention than those of a fossil fuel system.
- Building users need to have a good understanding of how to use system controls to maximise the efficacy of the system.
- The availability of skilled maintenance contractors was an issue at a number of sites.

This document has been prepared by Max Fordham LLP and Dan McNaughton, Senior Building Services Engineer at Historic England. This edition was published by Historic England September 2025. All images © Historic England unless otherwise stated. Please refer to this document as:

Historic England, 2025, Heat Pumps in Historic Buildings: The Viability of Ground Source Heat Pumps in Historic Buildings, Swindon. Historic England.

HEAG327

HistoricEngland.org.uk/installingheatpumps

Front cover: Ground Source Heat Pumps in a basement plant room. © Historic England

This page is left intentionally blank

Contents

This page is left intentionally blank

1. Introduction

This report aims to identify examples of best practice that have enabled good system performance, and also common mistakes that have led to poor system performance. These findings can be used to inform future work and strategy when installing and operating GSHPs in historic buildings.

Data were gathered from five GSHP installations across the UK, as shown in Figure 1:

- Site 1, Manchester
- Site 2, Cambridgeshire
- Site 3, Warwickshire
- Site 4, Scottish Borders
- Site 5, Kent

The first half of this report summarises the key findings from all five sites and discusses key lessons to be learnt. The second half presents the detailed findings of each individual case study.

The aim of the report is not to evaluate the sites against one another, but rather to consider the specifics of each site.

Figure 1: Locations of the case study sites.

Case studies evaluation parameters

The GSHPs at each site were evaluated to assess their efficacy. The building service engineers considered:

- Visual appearance
- Noise impact
- Electrical design
- Generic information about the GSHP
- Hydraulic design, including heat emitters
- Maintenance
- Controls
- Performance issues
- Thermal improvements to the building fabric
- Refrigerant used

For each case study, the building services engineers did a non-intrusive site survey. A staff member, typically the facilities manager, gave a tour of the site, and the system was then inspected.

This included:

- Taking photographs of the installation
- Measuring the free area around the GSHP
- Measuring the distance from the GSHP to the closest noise-sensitive location
- Taking thermal images of the GSHP
- Checking for the presence and quality of key installation components, such as anti-vibration mounts and pipework insulation
- Measuring radiator and pipe sizes
- Understanding the location and approximate extent of the ground collector

Relevant staff, tenants and owners were asked a prepared set of questions about their experience living with the GSHP heating system, including:

- Have you found the building comfortable since the GSHP was installed?
- How have you found the noise levels coming from the GSHP?
- How have the running costs changed, if at all?
- Do you know how to use the controller for the heating system?
- Do you understand the maintenance requirements of the GSHP?

The information from all five sites was analysed to assess the efficacy of each heating system and to determine best practice regarding the successful implementation of GSHPs in historic buildings.

Limitations

The available data for running costs were in the form of energy bills. Some of these were based on estimates or did not cover the appropriate time periods. It was often not possible to separate heating and hot water use from other household electrical consumption, such as cooking, lighting and domestic appliances. This made it difficult to make quantitative comparisons before and after the GSHP was installed.

The users' perceptions of running costs have been reported where available, but they are highly subjective according to each individual's expectations.

The case study findings are from a single visit to each site and are dependent on the weather that day.

Although each case study survey was thorough, it was not possible to inspect those parts of the property that were covered or inaccessible at the time of the visit.

2. Key Observations and Findings

2.1 Conservation heating

The fabric and contents of a historic building are vulnerable to decay and damage from the environmental conditions it is subject to, particularly humidity. The amount of water that can be held in the air depends on the air temperature. Warm air can hold more water than cold air. Relative humidity is a measure of how much water is in the air as a percentage of the maximum amount of water that the air can hold at its current temperature.

High relative humidity encourages mould growth, which may damage the building fabric and pose a risk to occupants' health. One way of combating this is to raise the air temperature. This will increase the maximum amount of water that can be held in the air and, in turn, reduce the relative humidity. To ensure proper control, every area must have a means of measuring temperature and relative humidity, such as individual or combined sensors. A humidistat sensor working in conjunction with a temperature sensor calls for heat whenever the relative humidity exceeds a target level, typically around 58 per cent. Heat is delivered until the relative humidity is appropriately reduced.

This method is the operating principle of conservation heating. It means that the heating system is not usually driven by the need for thermal comfort. In summer, the heating may be active to reduce the relative humidity, making the space uncomfortably hot. In winter, the relative humidity may be quite low, meaning that the heating does not come on and the space is uncomfortably cold. Some systems balance the needs of conservation and comfort to ensure that the internal spaces are still within reasonable comfort temperatures, by setting lower and upper bounds on the indoor temperatures. Figure 2 shows an example of the control strategy that a conservation heating system may use. The set points are indicative, and they are usually changed over the year. In summer, the relative humidity will naturally be higher than in winter, so a higher set point is used to reduce the amount of heating required. The key objective is to prevent sharp swings in relative humidity as this is what leads to damage of fabric and contents.

At each site that used conservation heating, the existing heat emitters from the previous fossil fuel system were reused. A GSHP typically operates at a much lower flow temperature than an oil or gas boiler (around 45°C instead of 82°C), so the heat output of these radiators will be reduced compared to their original design output. However, the required heat output will also be lower because the building is being heated for conservation and not comfort.

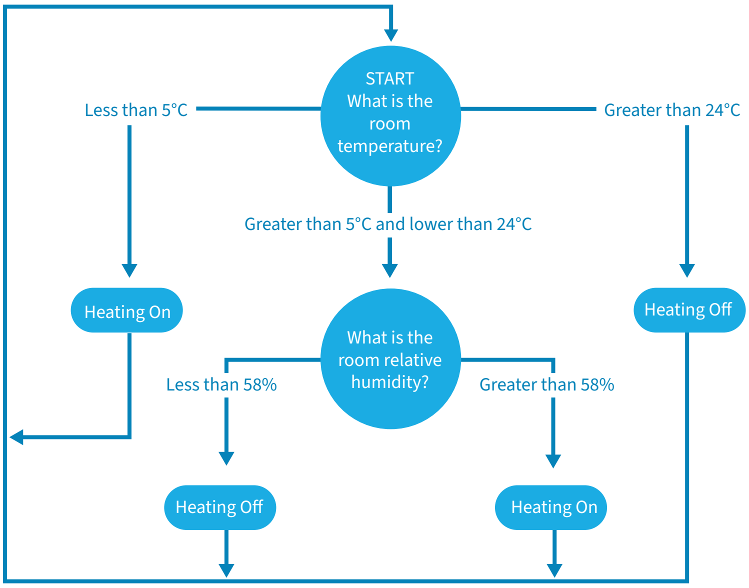


Figure 2: An example control strategy for a conservation heating system.

Assuming the original heating system was designed to maintain a comfortable indoor temperature of 20°C when it is -3°C outside, it is likely that the radiators were sized to meet this heat demand with a mean temperature of 76.5°C (flow at 82°C and return at 71°C). Often, radiators are sized to meet the static heat loss at worst-case conditions. The amount of heat loss is primarily determined by the temperature difference between the outside and inside, which is 23°C. In this example, we will ignore any additional radiator capacity that would be allowed due to the warm-up factor (additional heat emitter capacity that reduces the time taken for a room to reach the desired air temperature).

In a conservation heating scenario, the internal room temperature can drop to 5°C for frost protection or around 12°C if the relative humidity is high when it is -3°C outside. In the case of heating the space to 12°C, the difference in temperature between the outside and inside is 15°C, whereas heating the space for frost protection can reduce this temperature difference to only 8°C.

Table 1 summarises the effect that different design room temperatures have on the typical design heating system flow and return temperatures for an existing radiator. It can be seen that the heat loss for conservation heating and frost protection can be 65 and 35 per cent respectively of the heat required for heating for comfort. In this example, the existing radiator can operate with a mean temperature of 30.5°C (flow at 33°C and return at 28°C) to meet the heat loss for frost protection.

The calculated typical heat flow temperature for conservation heating of 55°C is a bit higher than the typical GSHP flow temperature of 45°C, however this will still be suitable for the majority of the year.

Table 1: Typical heating system temperatures

Design room temperature (°C)	Purpose of heating	% of comfort heating output	Typical heating flow temperature (°C)	Typical heating return temperature (°C)
20 *	comfort	100	82	71
12 **	conservation heating	65	55	50 ***
5	frost protection	35	33	28 ***

* varies depending on the type of room

** varies depending on the internal environment

*** calculated for heat pump systems

Existing radiators would likely be designed for a flow at 82°C and return at 71°C, which is referred to as 11°C ΔT. Most heat pump systems, excluding CO_2 heat pumps, operate at 5°C ΔT. To provide the same amount of heat, the heat pump system would need to run 2.2 times more water through the pipes. A lack of capacity to accommodate this increased flow is often why pipework has to be replaced when a heat pump system is installed. However, the reduction in heat demand more than compensates for the increased flow rate when changing from an 11°C ΔT to a 5°C ΔT heating system. This means pipework does not need to be replaced based on capacity.

To conclude, the existing radiators are suitably sized for providing conservation heating at typical GSHP flow temperatures. The low flow temperatures of the GSHP are also helpful for ensuring slower changes in the internal conditions. Rapid swings of internal temperature and relative humidity can increase the stress on historic building fabric and contents, leading to damage. Many historic buildings will likely have existing radiators that can be used as part of a GSHP conservation heating system. This should be verified by a suitably qualified building services engineer.

Heating for conservation and comfort

A heating system designed for thermal comfort may require different flow temperatures and/or larger heat emitters, and may operate at different times than a system intended for conservation heating.

Thermal comfort heating requires a high heat output during the winter, but no heat production during the summer. Conservation heating requires heat throughout the year, to keep relative humidity at an appropriate level until the internal temperature exceeds the set limit. If a single GSHP is used for both conservation and comfort heating, such as at Site 2, it may be oversized for conservation heating during the summer. This may lead to cycling and reduced efficiency. Cycling is when the heat pump switches on and off for short periods to avoid overheating the building (such as in spring and autumn, when the minimum output of a GSHP may exceed the heating demand). This increases the wear on the compressor which will reduce the expected life of the GSHP. It also means the GSHP operates longer in its inefficient start-up phase than in its optimum steady-state phase. Using separate GSHPs for thermal comfort and conservation heating allows each one to be sized according to its purpose, albeit at an additional capital cost. This approach enables each GSHP to operate at the lowest possible temperature, thus maximising its efficiency.

Alternatively, the areas heated for conservation and thermal comfort could be connected to the same GSHP, with a separate branch for each heating system. This is the approach taken at many of the other sites. One advantage is the lower capital cost of the initial plant installation. However, energy costs may be higher because the GSHP will always be required to produce water at the temperature of the most demanding circuit, even if that circuit is only a small part of the load. The cost implications of all options should be carefully considered.

A conservation heating system can be installed with a 'boost' function. This increases the heat output to achieve a comfortable air temperature for a set duration, after which the control resets to conservation mode. This is useful for buildings that periodically host events where higher levels of comfort are required. The temporary increase in heat output has been shown to not substantially increase the risk of damage to sensitive fabric and collections in a historic building.[1]

2.2 Heat collectors

Across the five sites, there were three different methods for extracting heat from the ground:

- vertical borehole
- horizontal ground loop
- radial drilled boreholes

Vertical borehole

Boreholes are often used when there is limited space. They require specialised drilling equipment, which increases project costs.

A vertical borehole is drilled down into the ground. A pipe loop is laid inside and fixed in place using a high thermal conductivity grout. Thermal transfer fluid, commonly called brine, is circulated through the pipe loop from the GSHP. The GSHP extracts heat from the thermal transfer fluid and returns it to the ground at about -3°C, usually about 13°C cooler than the ground temperature. The thermal transfer fluid then collects heat from the ground and is warmed to around 0°C when it returns to the GSHP. These temperatures are considered the worst-case limits for a borehole after 20 years of heating only (boreholes can also be used to provide cooling in some applications).

The depth of the borehole will impact the amount of heat that can be extracted. Depths range between 50 and 200m, depending on ground conditions, location and required heat demand. Multiple boreholes can be used in a borehole array. A connected array can serve one or more GSHPs.

When multiple boreholes are used, a manifold housed within a dedicated chamber can monitor and isolate the pipe loops within the separate boreholes. The manifold should be easy and safe to access for maintenance, monitoring and isolation. The manifold chamber should have sufficient space available for safe access and adequate drainage for groundwater and condensation, which will build up from the collector loop. It should also have sufficient lighting to allow for work to be carried out. Site 2, for example, has a borehole array of 30 vertical boreholes and makes use of three manifolds located externally.

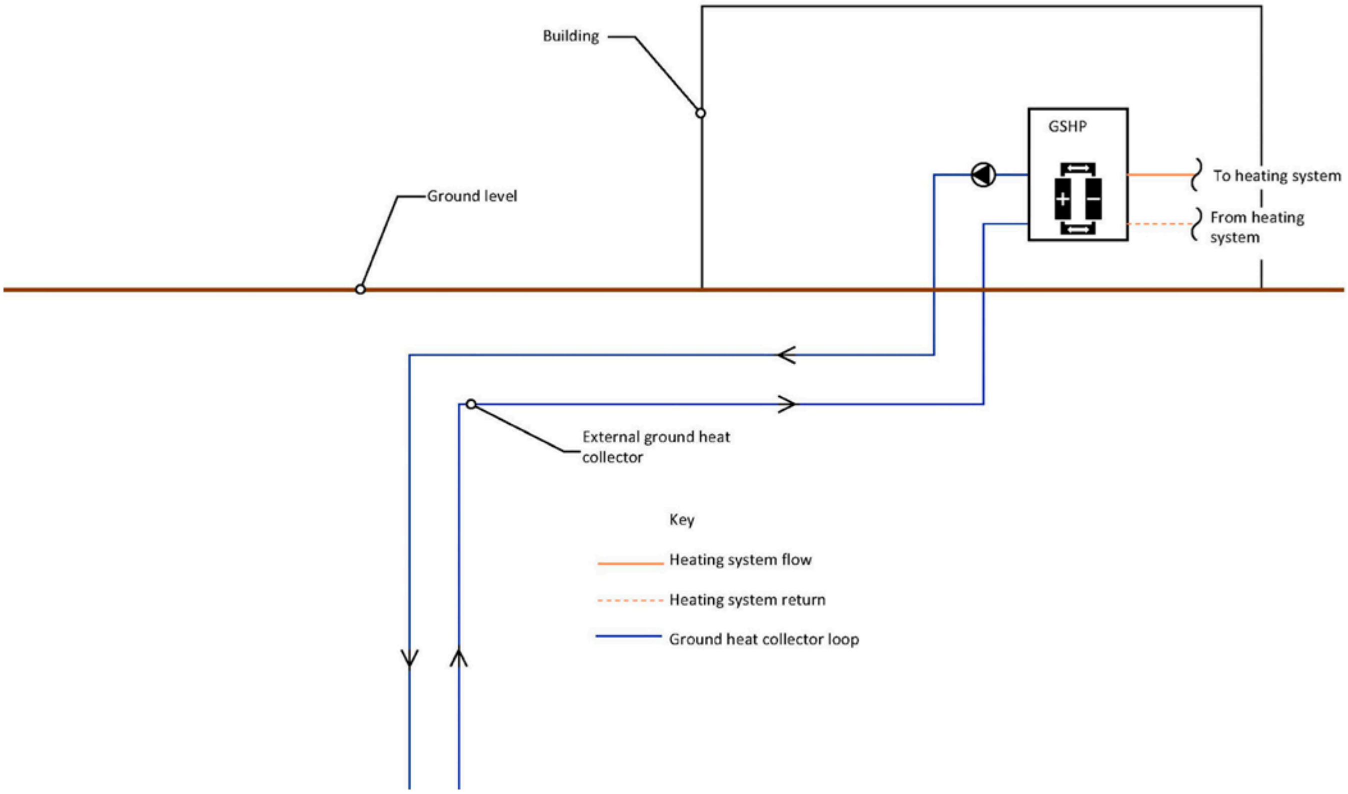


Figure 3: A simple diagram for a single vertical borehole heat collector.

Horizontal ground loop

Horizontal ground loop heat collectors consist of pipe loops placed within a trench dug into the ground, typically 1.2 to 2m deep. The pipe containing the thermal transfer fluid is laid in a linear configuration or in a coil (often called a slinky), covering a large land area. The required area and pipe length will depend on the heat output and the ground conditions. At Site 4, the ground loop is 24km long, and the ground loop at Site 3 occupies a total area of 3,000m^2. Ground loops can usually be installed without specialist equipment, often using an excavator. However, they require more space, and potentially time, to install than vertical boreholes. As the horizontal ground loop is relatively close to the surface, it may not return as high a thermal transfer fluid temperature as a vertical borehole configuration.

As with boreholes, multiple ground loops can be used for larger installations, with manifolds located in dedicated chambers used to connect and control the loops. At Site 4, there are 10 separate loops, connected to a manifold chamber. They are designed so they can be subdivided further if necessary.

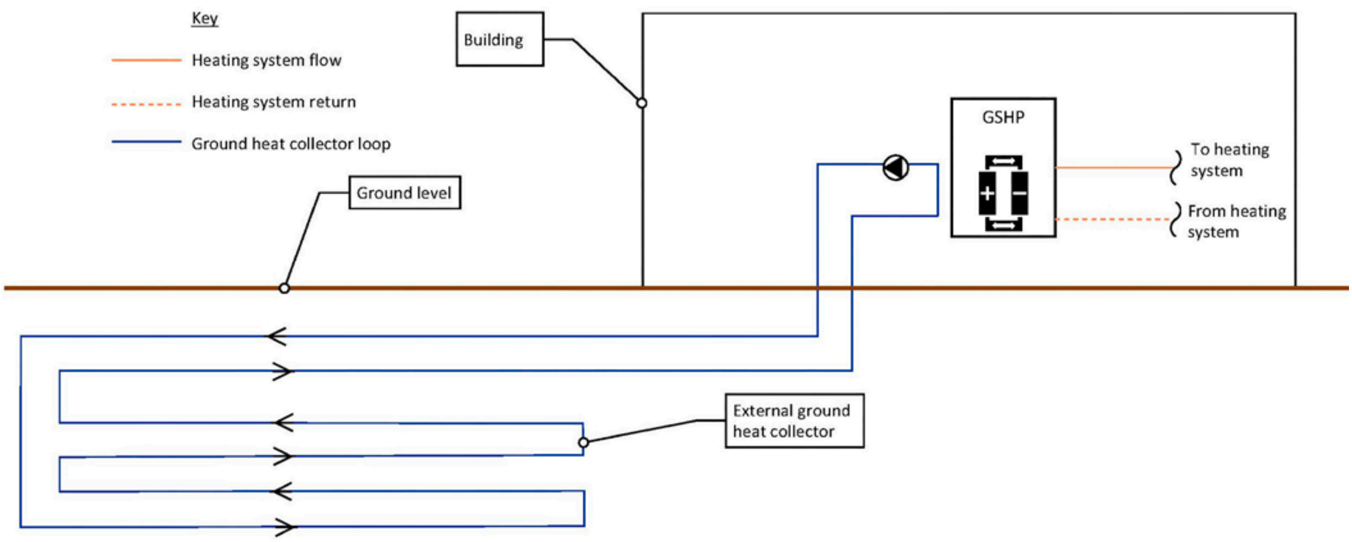


Figure 4: A simple diagram for a horizontal ground loop heat collector.

Radial drilled boreholes

Radial drilled boreholes start with a single central borehole drilled down to a suitable depth. Separate holes are then drilled, branching off from the main access chamber. This could be an access point that will house the manifold at the surface or it could be a borehole with a surface access point. The holes are often drilled at varying angles and depths around the circumference of the main hole, and they are used for separate thermal transfer fluid pipe loops. This means that one central borehole can be used, rather than multiple vertical ones. Radial boreholes require more specialised equipment than vertical boreholes, and so there are increased installation costs.

At Site 5, there is limited space available for either a horizontal ground loop or multiple vertical boreholes. Radial drilled boreholes were, therefore, used to install collector loops underneath an archaeological layer and to avoid any graves. Site 1 also uses radial boreholes to ensure that adequately sized heat collectors can fit on a site with very limited surface area. Both these sites are in urban areas, which can restrict the available area for horizontal ground loops or a vertical borehole array.

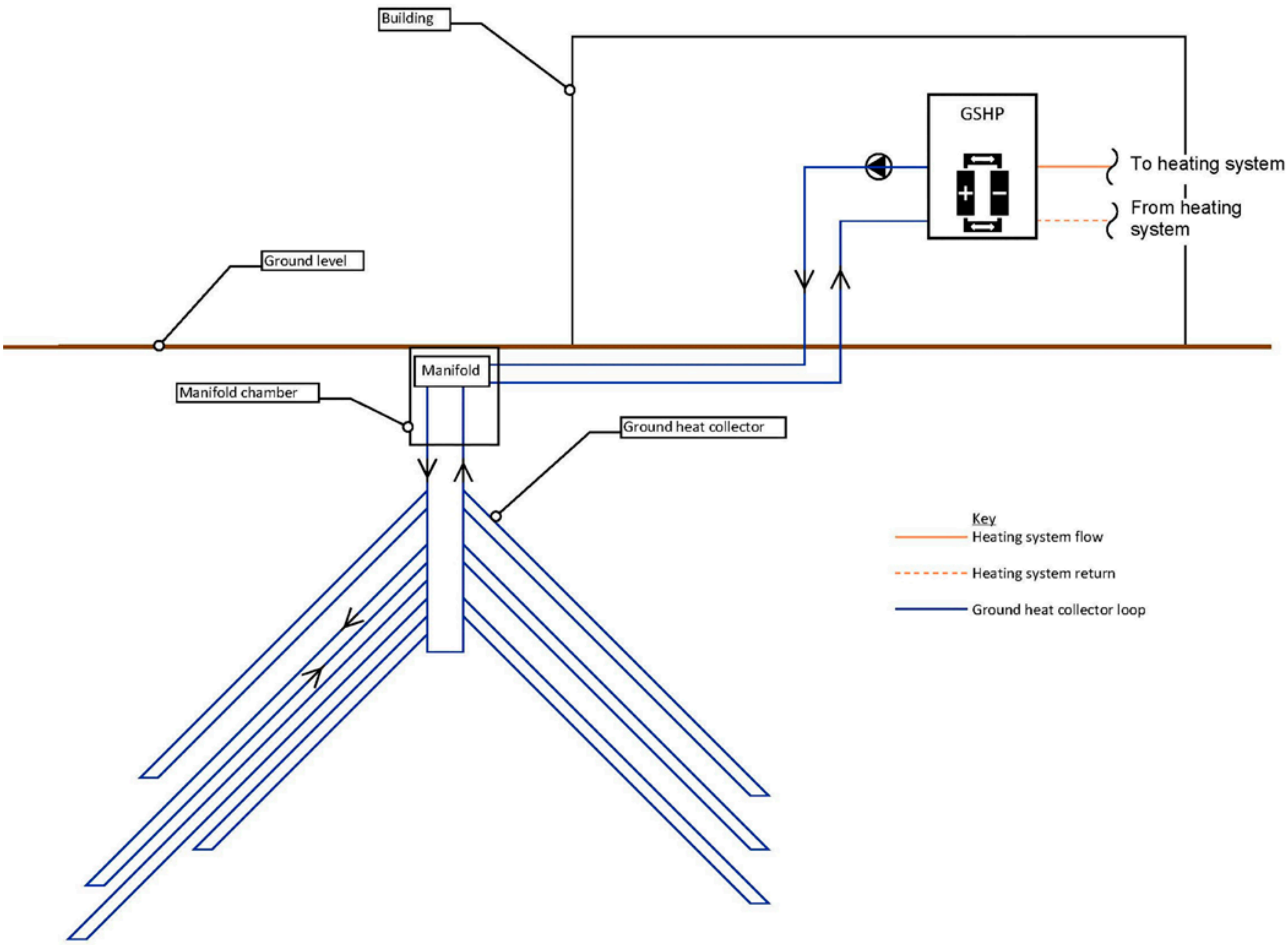


Figure 5: A simple diagram for a radial borehole heat collector.

Collector leaks

The pipes used for the heat collectors at the five case study sites have an expected lifespan of 50 to 70 years. Only Site 4 reported a leak in the collector loop. This was likely caused either by farm machinery being used in the field above or by faulty installation. The site has a ground loop system with multiple valves installed. The damaged/faulty collector loop could, therefore, be identified and isolated, which minimised the impact of the leak.

The most common symptom of a leak is loss of pressure in the collector loop. The best way to identify its location in a ground loop system is to inject environmentally safe dye into the loop and then wait until it makes its way through to the topsoil. This eliminates the need to dig up the entire ground loop. A sealant can then be added to the loop, which will seal the leak without requiring extensive groundwork. However, this could reduce efficiency if it restricts the flow within the loop. If the collector loop has a manifold, this can be used to identify and isolate the leak until it can be fixed.

To reduce the environmental impact of a leak, a collector loop can use non-toxic glycol as antifreeze. Several types of vegetable-based glycols, which are biodegradable, are also available, and these further reduce the environmental impact.

2.3 Domestic hot water systems

There are several methods to transfer heat from a GSHP to the water in a hot water storage cylinder. Two common types, coil and plate heat exchanger (PHX), are shown in Figure 6. When deciding on the best option, it is important to consider the specific characteristics of the GSHP, the required recovery time and storage utilisation (the amount of hot water storage that a particular building requires).

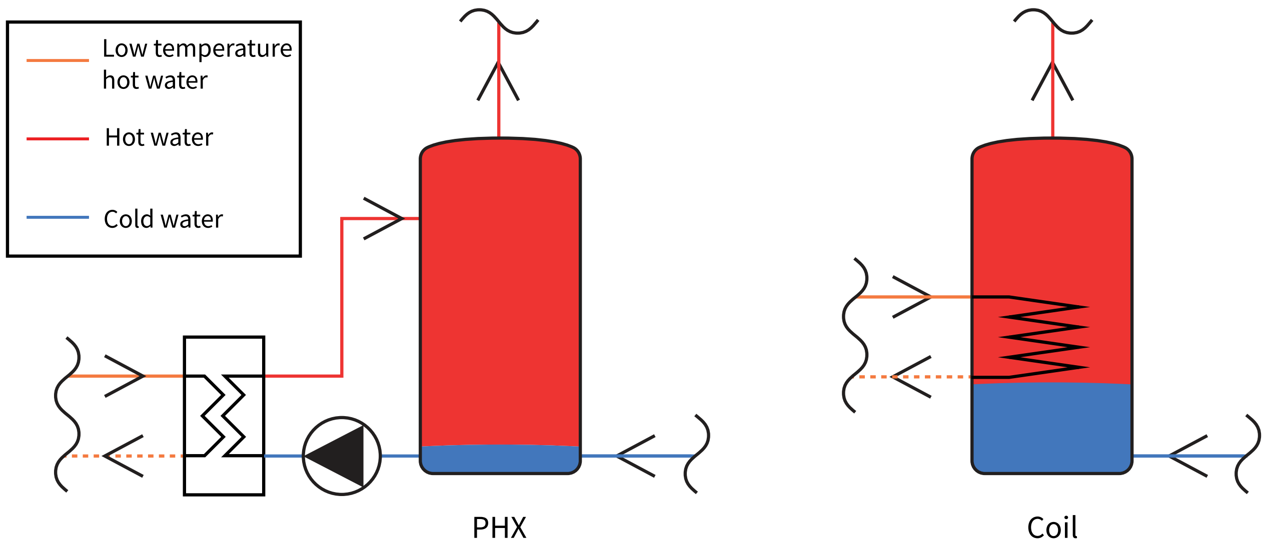


Figure 6: Domestic hot water cylinder configurations.

A coil-fed storage cylinder is often used because it is cheaper and more compact than having a separate heat exchanger within the plant room. However, it is important to note that the former typically has a lower heat output. This can lead to longer hot water reheat (recovery) times. A properly sized plate heat exchanger can use the full heat output of the GSHP, enabling a faster reheat time for the water.

The storage volume in a coil cylinder may be smaller due to the coil not covering the entire height of the cylinder. This can mean that the water at the bottom of the cylinder remains unheated, thus reducing the overall storage capacity.

Using a plate heat exchanger will allow for more even distribution of heat in the cylinder. Cold water can be drawn from the base of the cylinder and then passed through the plate heat exchanger to reach the desired water temperature. This effectively increases the storage volume, and so a smaller cylinder with a plate heat exchanger can achieve the same storage as a larger coil cylinder. However, a plate heat exchanger uses more energy in operation, because an additional charge pump is required to circulate the stored hot water through the heat exchanger.

2.4 Visual impact

A valid concern regarding GSHPs is how the heat collectors may affect the landscape. This is particularly relevant if the landscape is historically significant, such as a historic garden or a tree-lined approach. At all five case study sites, external groundwork was required. Pipes were run between the plant room and the heat collector, and either trench ground loops or boreholes were installed. During the site visits, it was difficult to spot where the groundwork had taken place. Often, the only visible signs were the covers for the access hatches to the boreholes or manifolds. These covers would probably go unnoticed by the public, but the engineers were actively seeking signs of groundwork and often knew where to look.

Multiple sites reported a significant impact on the surrounding landscape during and immediately after the heat collectors were installed. This led to some negative perceptions and complaints from members of staff, visitors and site owners. However, once the greenery had had time to regrow, these complaints stopped.

After the ground loop installation at Site 3, it was reported that the grass became 'reedier' in the field where the heat collector is located. Comparing photographs taken during the site visit with historic photographs of the field shows a difference in the type of grass. However, many other factors could have played a part in this change.

At all sites, the GSHPs were installed within a plant room away from public areas. This meant that the GSHPs themselves had no visual impact internally on the buildings they served. At some sites, pipework could be seen externally leaving the plant room before it went underground to the heat collector. This visible pipe run was always short and had a minimal visual impact on the building. Disruption was minimised at some sites by installing the GSHP as part of a larger renovation project.

2.5 Availability of experienced contractors

All sites had managed to secure a contract for an annual maintenance check-up, but some reported issues finding a maintenance contract to respond to callouts and optimise the system. This often led to extended periods when the GSHPs were not operational or were running at lower than expected efficiencies, with the building owners unaware this was happening.

At some sites, the contractor installing or maintaining the GSHP lacked experience and training in heat pumps or working on heritage buildings. It appears that some of the issues described in the case studies could be attributed to the fact that the contractor had inadequate experience and training in installing, optimising and maintaining GSHPs. These include refrigerant leaking from the GSHP, issues with achieving the desired efficiency or coefficient of performance (COP) and difficulty setting up optimal system controls.

Projects in historic buildings present distinctive challenges that are not typically encountered in modern constructions. Inexperienced contractors may struggle to meet clients' expectations within the designated time and budget. These challenges include**:**

- working on listed buildings with restrictions on fabric improvements
- managing the installation of building services and associated work while protecting the historic building fabric
- designing heating systems for conservation heating
- setting up conservation heating controls while optimising GSHP efficiency

2.6 Buffer vessels

Buffer vessels are an important part of a GSHP heating system. They provide additional volume and the capacity to store heat. The additional volume is useful to prevent cycling of the heat pump.

As the cycle duration becomes shorter, the GSHP becomes less efficient. This leads to increased wear on the compressor. Research on the impact of cycling on heat pump performance indicates that if the cycle lasts for at least 10 to 15 minutes, it will not affect the heat pump's overall efficiency. If the cycle durations are shorter than this, the overall efficiency will decrease.[2]

Depending on the required heat load and available heat stored, buffer vessels can allow for the system to respond to heat demands more rapidly or without switching on the GSHP at all. They can also be useful for storing energy to be used for instant domestic hot water. Unlike ASHPs, GSHPs do not require a defrost cycle, meaning the buffer vessel will not be required to add additional volume to allow the heat pump to defrost.

All the sites visited made use of buffer vessels. Those with separate systems or larger GSHP capacities often had multiple buffer vessels. Four of the systems used 500l buffer vessels, despite having widely ranging capacities. This indicates that buffer vessel sizing was more driven by standard sizes than precise calculations.

Table 2: A list of sites with the installed GSHP capacity and buffer vessel volume.

Site	Installed GSHP capacity (kW)	Buffer vessel size (l)	Buffer volume per kW of GSHP capacity (l/kW)
Site 1 - west plant room	45.8	500	10.9
Site 1 - east plant room	45.8	500	10.9
Site 2	140	500	3.6
Site 3	80	500	6.3
Site 4	537	4000	7.4
Site 5	24	200	8.3

Buffer vessel arrangement

Many different buffer vessel arrangements were seen across the five sites. The buffer vessels were either two or four pipe.

A four-pipe buffer vessel has two pairs of inlet and outlet connections. The primary pair completes the hydraulic circuit connecting the GSHP to the buffer vessel. The secondary pair connects the general heating circuits to the buffer vessel. A four-pipe buffer vessel provides hydraulic separation between the GSHP and the general heating circuits. The main advantage of this is that the water flow rate through the GSHP is separate from the flow through the general heating circuits, ensuring the minimum flow through the GSHP is maintained at all times. The disadvantage is that it is common for unintended mixing to occur in the buffer, resulting in cooler water being delivered to the general heating circuits than is generated at the GSHP.

A two-pipe buffer vessel has a single set of inlet and outlet connections. These connections are either installed in series with the flow or return leg of the heating system, or in parallel across the flow and return. The difference in flow rate between the GSHP circuit and the heating circuits will flow through the buffer. The advantage of this arrangement is that the likelihood of unintended mixing in the vessel is reduced.

If a two-pipe buffer vessel arrangement is connected in series to the flow and return leg of the heating system, it can provide additional thermal capacity to the system. However, it cannot guarantee the minimum required flow rate to the GSHP. This is discussed further in the section for Site 3.

2.7 Heat pump capacity

The size of the GSHP varied from site to site, depending on the area to be heated, the level of thermal insulation and whether the GSHP was intended for conservation heating, thermal comfort, domestic hot water or a combination of all three. Table 3 shows the sizes of the GSHPs at each site.

Table 3: Installed GSHP capacity and the capacity per unit area.

Site	Heating type	Installed GSHP capacity (kW)	Capacity per unit area (W/m²)
Site 1– west plant room	Comfort	45.8	83.5
Site 1 – east plant room	Comfort	45.8	83.5
Site 2	Conservation and small amount of comfort	140	40
Site 3	Conservation and small amount of comfort to offices	80	55
Site 4	Comfort	537	88
Site 5	Comfort	24	24*

* Site 5 is supplemented by a gas boiler.

Sites 2 and 3 are both primarily heated for conservation, which is reflected in the lower capacity per unit area (40–55W/m^2). The other sites are heated for comfort and have correspondingly higher capacities. Correct sizing of a GSHP is critical for the success of the heating system. If the GSHP is too large, this will lead to cycling, which will increase wear on the GSHP compressor and require more maintenance. System efficiency will also be reduced, and running costs increased. If the GSHP is too small, it will not be able to meet the heat load or will have to produce a higher flow temperature The latter would reduce its efficiency.

2.8 Refrigerants

The type of refrigerant that a GSHP uses can greatly affect the emissions it produces over its lifetime. There are several different types on the market today.

Refrigerants can cause atmospheric ozone depletion, measured in ozone depletion potential. European GSHP manufacturers now only use refrigerants with an ozone depletion potential of 0, meaning they cause no harm to the ozone layer. If a refrigerant were released into the atmosphere, its global warming potential (GWP) allows you to calculate the equivalent effect on global warming compared to CO_2. For example, R-410a is a commonly used refrigerant with a GWP of 2088. If 1kg of R-410a were released into the atmosphere, it would be the equivalent of releasing 2,088kg of CO_2. Table 4 sets out the GWP of some common refrigerants.

Table 4: Comment refrigerant properties

Refrigerant	R-410A	R-32	R-290 (Propane)	R-744 (CO_2)	R-717 (Ammonia)
Global warming potential	2088	675	3	1	0
Ozone depletion potential	0	0	0	0	0
Fluorinated gas regulations	Phasing out in small systems from 2025	Phasing down planned, timeline tbc	n/a	n/a	n/a
Safety classification to ISO 817	A1 (Non-flammable, lower toxicity)	A2L (Lower flammability, lower toxicity)	A3 (Higher flammability, lower toxicity)	A1 (Non-flammable, lower toxicity)	B2L (lower flammability, higher toxicity)

The BEIS report ‘Energy Follow Up Survey: Household Energy Consumption and Affordability’ (2021) gives a median annual gas consumption for a UK home of 12,400kWh. The Government Standard Assessment Procedure for energy performance certificates gives carbon intensity factors for gas and electricity of 0.21 and 0.136 $kgCO_2e/kWh$, respectively. (CO_2e means ‘carbon dioxide equivalent’ and allows for the environmental effects of various greenhouse gases emitted by a process to be represented by a single value). Using these figures, the potential carbon savings associated with replacing a natural gas boiler with a GSHP with a COP of 3 can be estimated: it would reduce the CO_2 emissions associated with the heating system for a median UK home by around 2,000kg per year. However, if there were to be a total refrigerant leak from a typical domestic GSHP that uses R-410A, that would be equivalent to releasing 3,300kg of CO_2 into the atmosphere. This would cancel out 1.6 years of the carbon savings associated with the running of that heat pump system.

Although GSHP systems have measures to prevent refrigerant leaks, the risk can never be eliminated. Where a blend of refrigerants is used, even a small leak can necessitate a full system recharge. This is because it is difficult to determine the remaining quantities of each refrigerant in the mix.

Selecting a GSHP with a low GWP refrigerant is essential for minimising the system's emissions. Figure 7 shows the full leakage emissions and system output for each of the GSHPs in this study, based on the GWP of the system refrigerant. It does not account for the embodied carbon that is emitted during the manufacturing of the refrigerant.

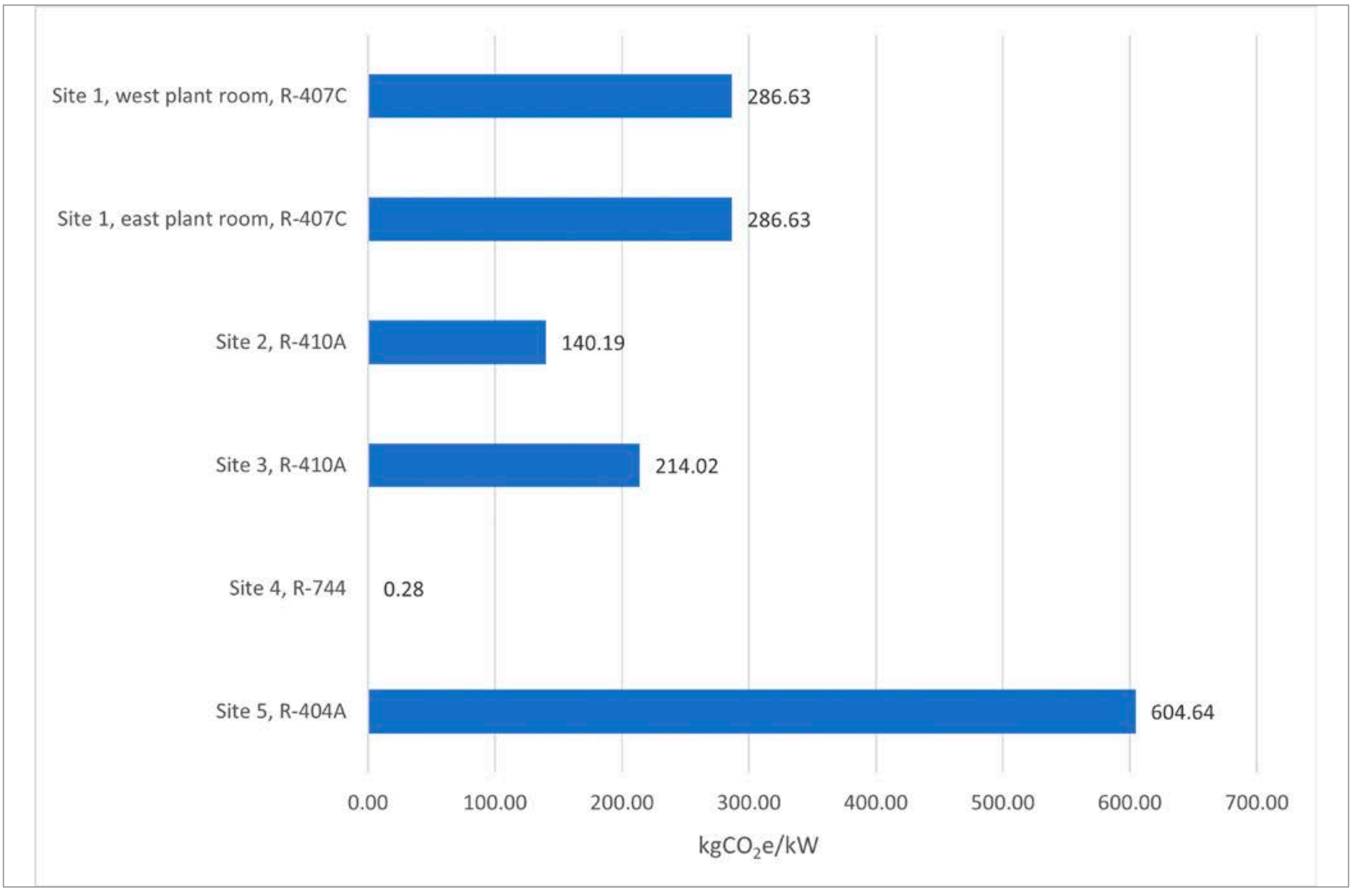


Figure 7: Total refrigerant leakage emissions per kW of installed system output.

Site 4 stands out because the full leakage emissions are extremely low. This is because the GSHP uses R-744, which is a CO_2 refrigerant with a low GWP of 1. This is a significant choice given the large scale of the heating system.

System designers should select a low GWP refrigerant GSHP to minimise the equivalent emissions in the event of a leak. Furthermore, a key goal of Fluorinated gas (F-gas) regulations is to phase down using refrigerants that have significant GWP when released into the atmosphere, such as R-410A. These high GWP refrigerants will, therefore, have a more constrained supply, meaning the price is likely to rise significantly. This is important because it means that the costs of repairing R-410A GSHPs will probably increase. R-32 has a much lower GWP than R-410A, and so is less likely to be limited in the short term. However, R-32 will probably be a target of future F-gas phasedowns. Selecting a low GWP refrigerant will help reduce the maintenance cost of the heating system by avoiding F-gas driven refrigerant price increases. Further information on F-gas regulations can be found at www.gov.uk/guidance/fluorinated-gases-f-gases.

Natural refrigerants such as R-744 and R-290 can achieve a much lower GWP and are now becoming commonly available. They are also outside the scope of F-gas regulations. However, their use introduces other design challenges and requires additional safety measures. R-290 has higher flammability, and R-744 requires high operating pressures. Currently, R-290 is being used in ASHPs and is beginning to appear in GSHPs.

The choice of refrigerant has a significant effect on the temperatures at which the GSHP can efficiently operate. CO_2 GSHPs can produce high temperature water (~70°C) far more efficiently than conventional GSHPs. Additionally, they require a low return temperature (~30°C) for efficient operation, meaning a greater temperature difference (~40°C) and low flow rate across the system. This is particularly advantageous in a building that already has a wet heating system designed for a gas or oil boiler, because the existing pipework will probably have been sized for a temperature difference of 11°C. Since a CO_2 GSHP operates with a temperature difference of 40°C, the required flow rate is lower, meaning the existing pipes are oversized and the required pumping energy is reduced. It may be possible to use existing pipework with a CO_2 GSHP, but this may not be the case for other low temperature GSHPs. Using existing pipework can deliver significant cost savings, but CO_2 GSHP systems are typically bespoke, so capital costs will be higher. And the low return temperatures that CO_2 GSHPs require are not straightforward to achieve. For more information, see Site 4.

A monobloc GSHP typically uses less refrigerant than a direct expansion (air to air) system. The design of a monobloc GSHP means the refrigerant is contained in the heat pump, whereas a direct expansion system requires refrigerant to be piped to multiple indoor units. Overall, the amount of refrigerant used in either system will depend on the specific size and capacity of the GSHP being used.

2.9 Building fabric improvements

There is a common perception that GSHPs are only viable in new buildings because they do not produce enough heat for older buildings. The sites visited for this report prove this is not the case. GSHPs were found to be successfully providing heating for thermal comfort to a medieval church, and conservation heating and thermal comfort to a medieval hall and a Georgian manor, all with limited fabric improvements. However, as with every type of heating system, the energy needed to heat a building will reduce if the building's thermal insulation and infiltration losses are addressed.

The amount of fabric improvements that can be made to a historic building may be limited by listed building consent, and also by the need to avoid adverse implications to the way the building manages moisture. However, various improvements can be made, as seen across the sites. These include draught lobbies, secondary glazing and additional insulation installed in keeping with historic methods. At some sites, these improvements were not part of the GSHP installation, nor were they carried out to improve the energy efficiency of the building. However, they would still benefit the heating system and energy consumption at the site.

Improving the building fabric will reduce the amount of heat lost from a building. If less heat is lost, less energy is needed to keep the building at a constant temperature or to increase the internal temperature. The overall energy consumption of a building will reduce no matter what heating system is used.

Improving the building fabric can also improve the efficiency of the GSHP, depending on the heating system. Most GSHPs are more efficient when producing lower flow temperatures, with less difference in temperature between the flow and return. If the heat emitters are undersized for low flow temperatures and temperature differences, then the heat output of the GSHP may increase to compensate. This will reduce the heat pump's efficiency: a 2.5 per cent decrease in efficiency is seen for every 1°C rise in the flow temperature.

2.10 Controls

The heating system controls vary across the five sites. In all cases, changes could be made to improve the controls and optimise system performance.

GSHPs installed for conservation heating were used in at least one area at four of the sites. Conservation heating targets relative humidity rather than desired temperature to prevent historic fabric and artefacts from damage. This means that the heating should be controlled by humidity sensors in conjunction with temperature sensors.

It is common for historic buildings to be fitted with a system that monitors humidity and temperature. Wireless sensors are positioned throughout the building, and a central base station records data from them. The base station then interfaces with the heating system, providing a 'heating on/off' signal as appropriate. It can either be a proprietary standalone system or integrated into the Building Management System where available.

Many properties contained multiple environmental monitoring sensors, typically one per room. Across the sites, it was often unclear how these sensors' data were being processed. Some building owners thought the heating used average data from all the sensors, while others reported that one sensor in the most sensitive location (in terms of protecting historic fabric and artefacts) was used as a control point.

When an environmental monitoring system sends a 'heating on' signal, the onboard GSHP controller uses a weather compensation curve to regulate the temperature of the water produced by the heat pump system. It increases the temperature of the water provided as it gets colder outside.

This set-up has advantages over older systems without weather-compensated control. Without weather compensation, whenever the environmental monitoring system calls for heat, the boiler supplies circa 80°C water to the heating system regardless of the external temperature. Often, this results in a rapid temperature increase, which is both uncomfortable and risky because it drives a rapid change in relative humidity. A weather-compensated GSHP will provide water at the lowest possible temperature to meet the heat demand. It results in a gradual internal temperature increase and, therefore, less fluctuation in relative humidity.

Heating system controls could be improved by integrating the environmental monitoring system and the GSHP controller. With only a 'heating on/off' signal from the environmental control system, the GSHP controller is unaware of how close or far away it is from the required setpoint. If the GSHP controller had the capability and it knew the room temperature and humidity, it could use that information to optimise the flow temperatures to reduce cycling and improve efficiency and control.

Locally, the output of radiators was generally controlled by thermostatic or manual radiator valves. The age of some of the reused valves brought their effectiveness into question. If a radiator valve is defective, the radiator will probably produce maximum heat output regardless of the room temperature. This increases energy consumption and the internal temperature.

It was observed that multiple sites would benefit from improved zone control. However, zoning can be difficult when the layout of existing pipes is unknown. Areas with distinct load characteristics – for example, those heated for thermal comfort as opposed to conservation control – would benefit from zoning, to allow for the optimisation of flow temperatures to the different areas.

The type of control needed will vary depending on the system's complexity. Sites with multiple GSHPs and heating zones will require more complex controls than those with one GSHP and a single branch.

Several sites made use of humidity sensors to control the conservation heating within the building. At one site, a sensor placed in the room with the most sensitive artefacts controls the whole heating system. Additional standalone sensors are located throughout the building, but these do not feed into a central system. Instead, they are read by staff members who manually adjust radiators to raise or lower the relative humidity as required.

Another site had humidity sensors installed throughout the building. The intention was that all the sensors would feed back into the central system and dictate the heat output. Initially, the staff on site thought that the GSHPs were not working, when the issue was, in fact, with the controls. The heating system was being controlled by one sensor, rather than feedback from all the sensors. This was unintentional, and it was unclear if anyone knew which sensor controlled the system.

Controlling multiple heat pumps

Lead heat pump rotation

When using multiple GSHPs, it is important to share the load equally between them to prevent premature failure caused by overusing any specific one. This is done with sequencing. When demand arises, the lead GSHP will be the first to be activated. After a set period of time or run hours, another GSHP takes on the lead role. This helps to ensure that all GSHPs have similar run times.

System optimisation

When deciding on the best approach to sharing the heat demand between GSHPs, it is crucial to consider whether the GSHP is fixed-speed or inverter driven.

A fixed-speed GSHP operates at maximum output regardless of the heat demand. To prevent cycling, a buffer vessel should be used to provide enough water capacity to allow the GSHP to operate for long periods in its optimal steady-state phase. To provide the right amount of heating, the GSHP starts and stops as needed to keep the buffer vessel within the correct temperature boundaries. The flow rate from the buffer vessel can be adjusted to meet the specific heating demands of the building.

An inverter-driven GSHP is more expensive due to its additional internal components and controls. An inverter allows the electrical signal to the GSHP compressor to be adjusted, and so operate at lower speeds. The GSHP can then modulate its output to match the heat demand, typically down to 30 per cent of its stated maximum.

Data from a GSHP manufacturer shows that you can expect a 0.4 per cent improvement in efficiency for every 1 per cent a GSHP is operated below its maximum output. The heat exchangers effectively become generously sized at reduced outputs, leading to improvements in GSHP efficiency. If the heat demand was 50 per cent of a GSHP maximum, you could expect around a 20 per cent increase in efficiency.

Running multiple GSHPs at reduced outputs is often more efficient than running a single unit close to 100 per cent in an inverter-driven multi-heat pump system.

2.11 System design

Two different approaches can be used when GSHPs are required to provide both conservation heating and comfort heating.

The first has separate GSHPs and heating systems for the conservation heating and comfort heating areas. The systems share a collector loop. This approach has the advantage of optimising the GSHP for each application, but heat cannot be shared or act as a back-up to different zones. This system is used at Site 2, where separate GSHPs serve the main house and refectory but share one ground loop.

The second option is to use one or more GSHPs to heat the conservation heating and comfort heating areas through separate heating system branches. Careful consideration should be given to sizing the GSHPs for two different heat profiles. If the GSHPs are undersized or oversized, it can lead to cycling, reduced efficiency or inability to meet demand. However, installing multiple GSHPs in this configuration increases redundancy in the design (a level of resilience in the event of one GSHP not working), as seen at Site 3.

The chosen approach should consider the trade-off between capital and running costs.

3. Case Studies

The following section discusses each site in detail. The GSHP installations were graded for technology choice, thermal comfort and system design/installation quality.

System details key

Technology choice

☆☆	Poor	An alternative technology would offer significant or multiple advantages to the installed system.
★☆	Good	The installed system is not detrimental to energy use/running cost, but an alternative technology may offer other advantages.
★★	Excellent	Optimal technology match for the type of building and its use.

Thermal comfort

☆☆	Poor	Users expressed dissatisfaction with their thermal comfort.
★☆	Good	Users reported satisfaction with their thermal comfort most of the time.
★★	Excellent	Users reported satisfaction with their thermal comfort at all times.

System design/installation quality

☆☆	Poor	Specific design choices or poor quality installation could be contributing to suboptimal efficiency.
★☆	Good	Aspects of system design or install quality could be improved but are unlikely to impact system efficiency.
★★	Excellent	Optimally designed and installed system.

3.1 Site 1

Building history and overview

A church was first recorded on the current site of this cathedral in AD923. Since that time, the church has been expanded and rebuilt many times. The most recent major renovation works took place after the cathedral was damaged during an air raid in 1940, and in 1996 when the cathedral was again damaged by a bomb. The cathedral is used for multiple services daily and it hosts additional concerts and events. Outside of services, the cathedral is also open daily to members of the public.

Figure 8: Site 1.

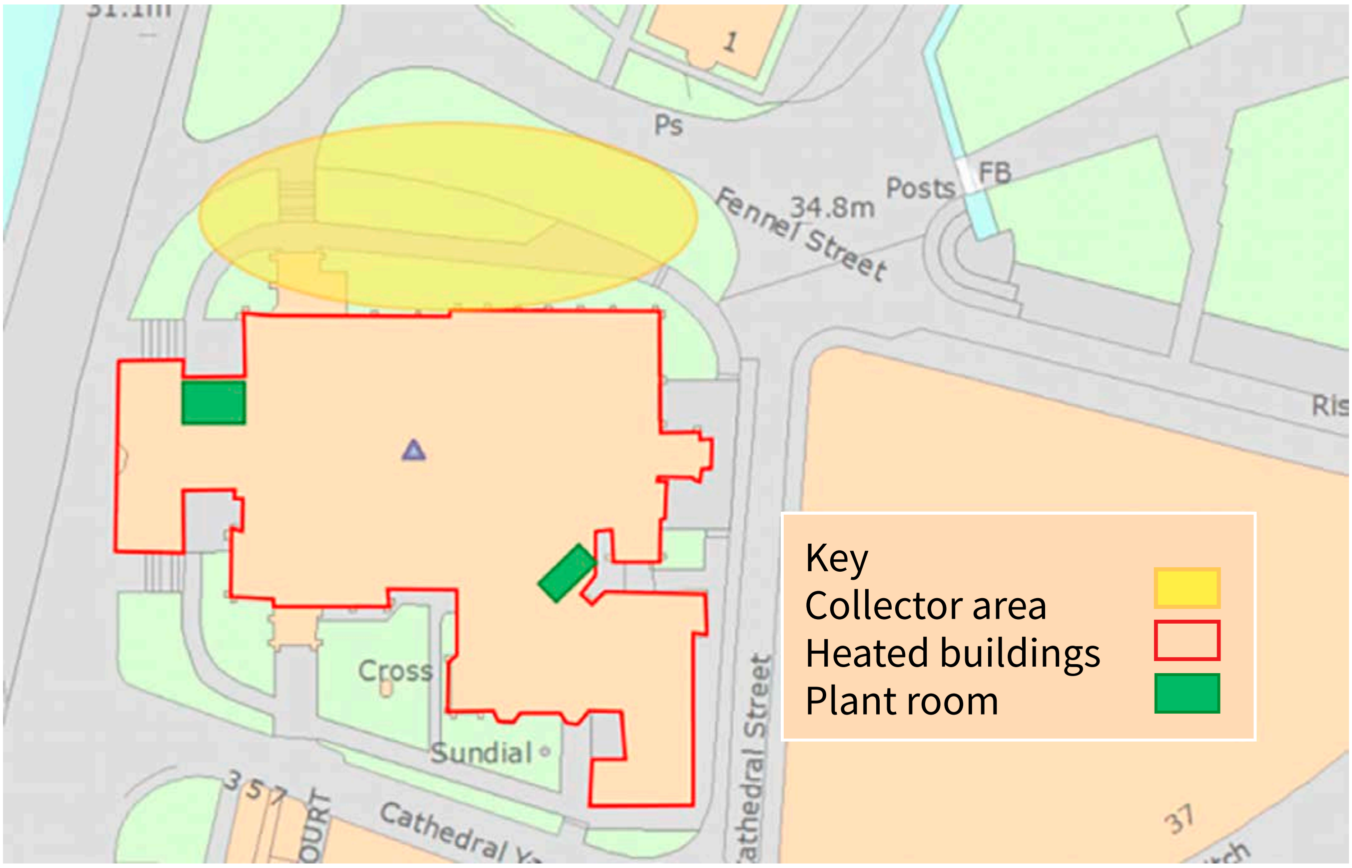


Figure 9: A map of the Cathedral site, showing the location of the buildings heated by the GSHPs, the plant rooms where the GSHPs are located and the approximate location of the heat collectors.

Heating system

The main sanctuary and chapels are heated by underfloor heating, with additional wet radiators on the walls. The offices within the cathedral are heated by wet radiators.

The underfloor heating system was installed in 2016/17 to replace the previous underfloor heating, which was leaking and no longer producing the design heat output. Alongside the project to renew the underfloor heating, four Dimplex GSHPs, each with an output of 22.9kW, were installed. The GSHPs supply heat to the underfloor heating only. Four gas boilers supply heat to the wet radiators and also serve as a back-up for the underfloor heating system if the GSHPs fail to generate the required heat.

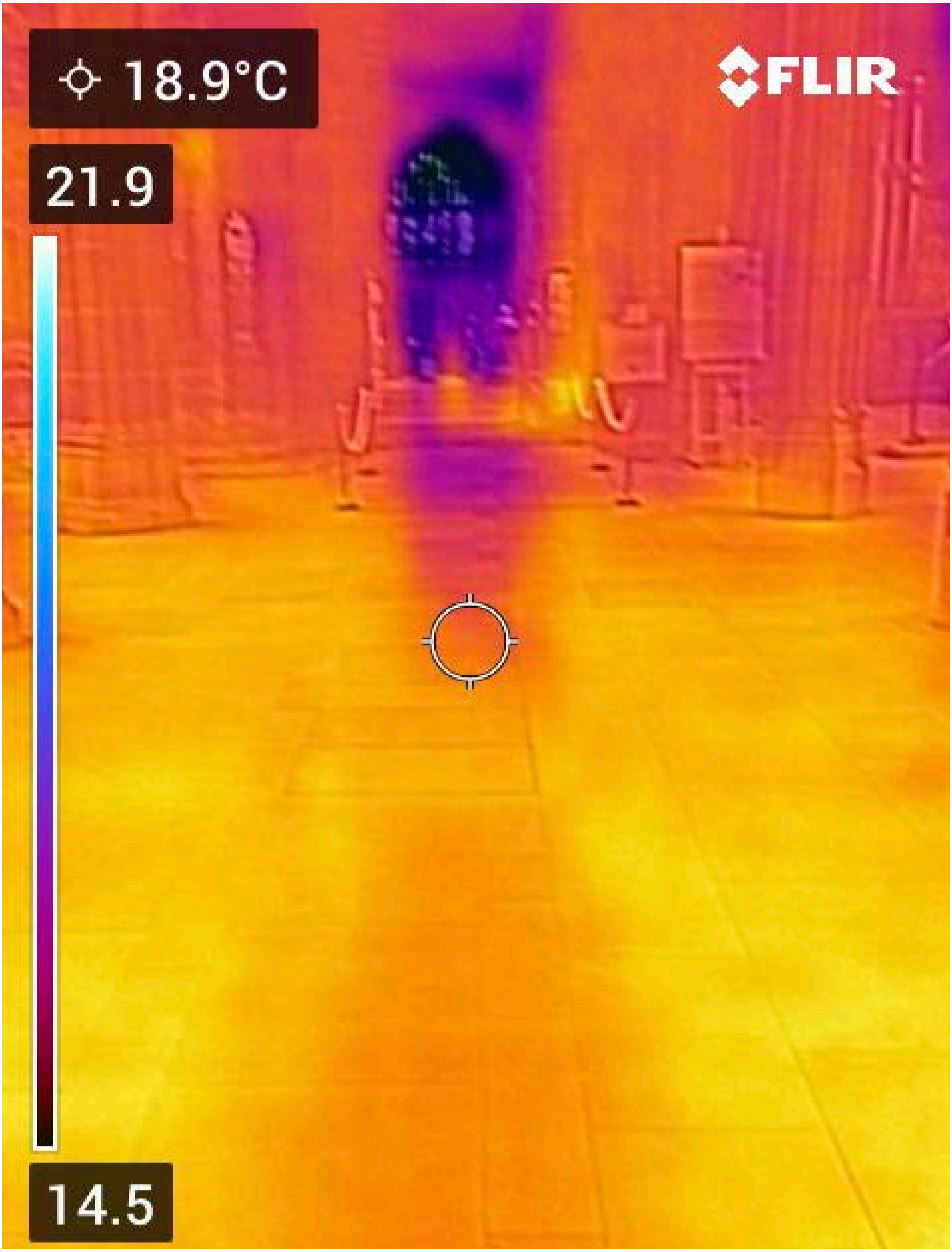


Figure 10: A thermal camera image of the nave at the cathedral, heated by underfloor heating.

Summary

Property type		Cathedral
Heat pump technology		Closed-loop radial boreholes
Installed heat pump capacity		45.8kW (2 x 22.9kW units) for each plant room (east and west), 91.6kW total
Heat pump capacity/m^2		83.5W/m^2
Heating system		Wet underfloor heating and radiators
Hot water system		Point of use direct electric water heaters
Use pattern		Open daily from 9am. Sometimes open late for concerts and services.
Technology choice	★★	During the initial design stages, a water source heat pump was considered because there is a river nearby. However, this option was ruled out because of the permissions required for putting loops in the river. With limited space available at the site due to graves and its urban location, boreholes were deemed the best choice for the heat collector. Radial boreholes were selected, to create the largest available collector size while avoiding areas of archaeological importance.
Thermal comfort	★★	Users reported higher levels of thermal comfort compared to the previous heating system, with minimal changes in running costs. However, there were some complaints when the heating system’s run time was reduced to cut costs. Insufficient heat-up time prevented the building from reaching a comfortable temperature. This was attributed to the longer response time of underfloor heating, rather than a specific problem with the GSHPs.
System design/ installation quality	★★	A bivalent heating system has improved the heating systems on both the east and west sides. However, there is a danger that the gas boilers that are meant to serve as back-up or top-up for the GSHPs may assume most of the heating duties.

Initial GSHP observations

- There are four GSHPs, each with a capacity of 22.9kW, providing a total GSHP capacity of 91.6kW.
- The total ground loop collector length is 1,600m.
- The GSHPs use R-407C as a refrigerant. Each GSHP has a refrigerant charge of 3.7kg, making a total of 14.8kg.
- The GSHPs in the east plant room were in good working order during the visit. The GSHPs in the west plant room displayed an error message and had shut down.
- GSHPs and heat collectors are not visible from areas accessible by the public. The GSHPs are located in two basement plant rooms used by the previous system. The underfloor heating system helps to conserve historic building materials and artefacts while having no visual impact on the building.
- The GSHPs are mounted on anti-vibration mounts.
- The GSHPs are located in separate isolated plant rooms away from occupied building areas.
- No specific sound barriers have been installed. The walls of the plant rooms are constructed from brick and stone.
- The site's electrical capacity remains unchanged and is insufficient to meet peak demand. As a result, during periods of very high demand, the GSHPs are automatically turned off to redirect power to other areas of the site.

External GSHP observations

- The GSHPs use approximately 30 radial closed-loop boreholes as a collector system.
- There are two collector loops, one for each heating system.
- A radial system was chosen because it provides the largest available collector size without impacting archaeological features.
- The borehole installation was part of a larger project that disrupted the whole site. In this context, the borehole groundwork did not cause any significant disruption.
- The boreholes and the heat collectors themselves are not visible.

Heating system observations

- The church is heated using both underfloor heating and wet radiators. The exact output of the underfloor heating in the main sanctuary is currently unknown.
- Radiators have been installed on specific walls in the main sanctuary as well as in the offices.
- The heating systems on both the east and west sides each use 500l buffer vessels.

Environmental permits and surveys

- Since the collectors are closed loop, no environmental permits were needed.
- There have been no reported leaks from the ground loop.

User interview

- The client expressed satisfaction with the initial design, deeming it to be thoroughly planned.
- The designer continues to work with the cathedral to resolve ongoing issues with increased gas usage and to optimise the performance of the GSHPs.
- The GSHPs were installed when the cathedral was closed for more than a year. However, replacing the underfloor heating caused archaeological issues that led to delays.
- According to reports, there was no significant change in running costs when transitioning from the old gas boiler to the bivalent GSHPs and boiler system. However, there was a notable improvement in thermal comfort.
- The site receives regular renewable heat incentive (RHI) payments, which add an additional income stream. Receiving payments from the RHI scheme was a big incentive for choosing to install the GSHPs.
- There have been no reports of noise issues.
- The individuals in charge of the heating system, specifically the vergers, are having difficulty understanding how to operate the controls. The client has contacted the GSHP manufacturer for assistance, but they still do not have enough knowledge to optimise the system.
- It appears that the building owners are not fully aware of the maintenance required for the heating system. The external company responsible for maintenance seems to prioritise fixing issues as they arise rather than optimising the system’s efficiency.

Discussion

Bivalent system

The heating system was designed so that the GSHPs fulfil 80 per cent of the heat load, while the remaining 20 per cent is met by gas boilers. This ensures that heat is available if one system is out of order. However, during the visit, it was observed that the gas boilers were providing the majority of the heat, and the GSHPs were operating only briefly. This highlights the importance of correctly designing the system and the controls for a bivalent heating system. Otherwise, the gas boilers may take over the heating duties, thus reducing the cost-saving and environmental benefits of the GSHPs.

There are several reasons for using a bivalent system, including running costs, environmental benefits and reducing capital expenditure for the GSHPs. A bivalent system was chosen at this site due to limited electrical infrastructure, with the existing connections unable to support a full GSHP option. It was designed to maximise the use of GSHPs and minimise the use of gas boilers, to reduce the CO_2 emissions associated with the heating system. However, the installed system can draw too much power from the grid during periods of high electrical demand on site. This results in the GSHPs being switched off to prioritise other electrical systems.

After analysing the gas and electricity expenses at the cathedral, it is clear that a significant portion is attributed to gas usage – specifically, between 50 and 65 per cent. This indicates that the gas boilers are being used for heating purposes beyond their intended 20 per cent.

RHI payments

Owners of buildings that use heat pumps can receive quarterly payments through the RHI scheme, based on the amount of heat generated by the pumps. The RHI scheme is now closed to new applicants.

At this site, compared to previous years, there was a reduction in the amount received through the RHI scheme. Part of the drop was likely caused by the COVID-19 restrictions, when the cathedral did not need to be heated as much. However, after restrictions were lifted, the amount received from the RHI scheme did not recover to its previous level, and there was a significant and continued drop in payments. It appears that the heat generated by the GSHPs has decreased over time, resulting in a rise in gas consumption. This could be due to a decrease in the efficiency of the GSHPs or a malfunction in the control systems that prioritises using the gas boilers over the GSHPs.

Plotting the metered output of the thermal production with the payments received through the RHI scheme shows that increased RHI payments coincide with increased production from the GSHPs (Figure 11). This increased output has not been seen on the same scale for the same periods in other years. It is unclear what caused this increase in output from the GSHPs, but it does explain the fluctuations in RHI payments.

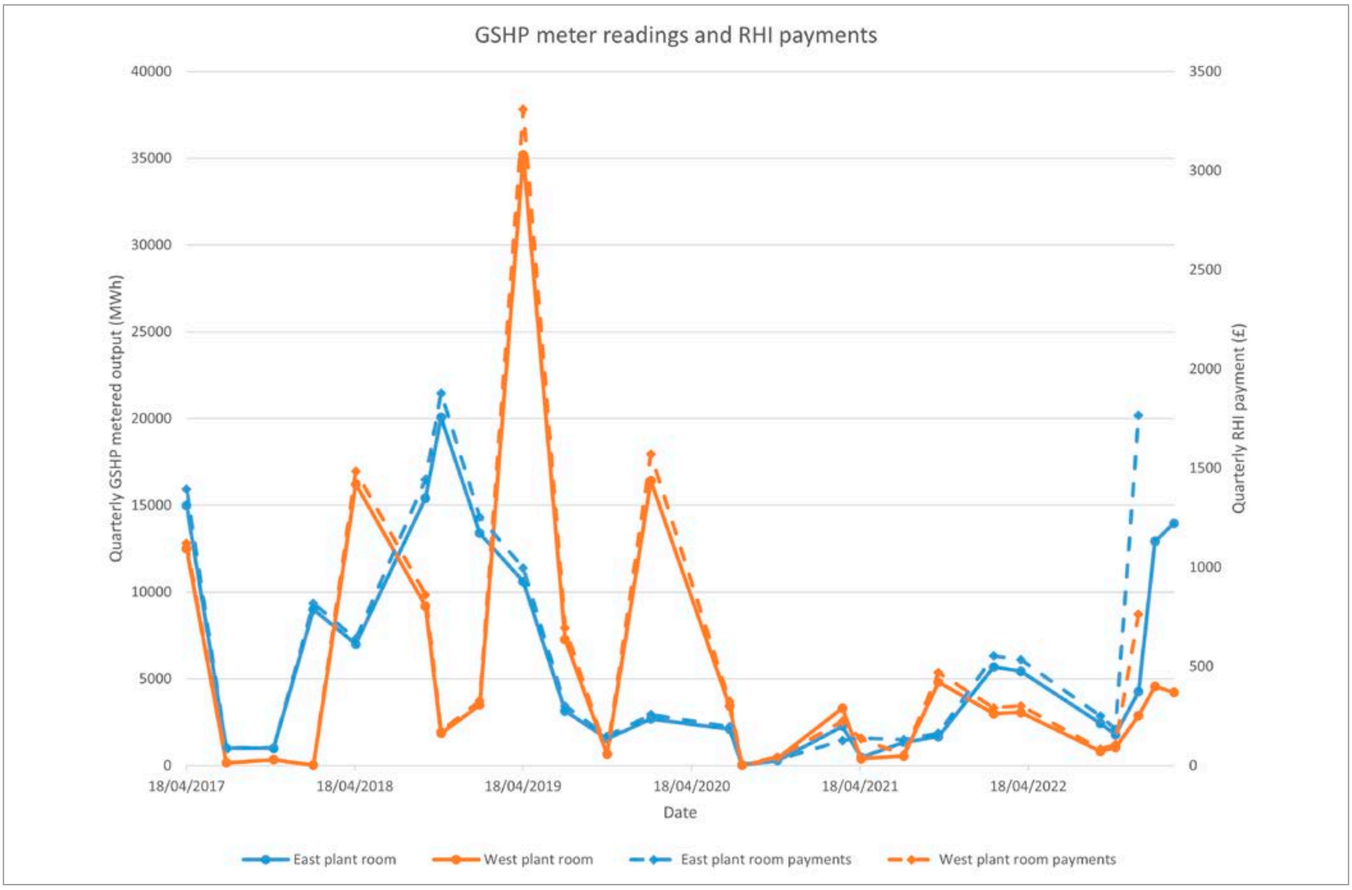


Figure 11: Metered output of the GSHPs and the RHI payments received.

Staff reported that it is not very easy to take meter readings due to the meters being located in separate plant rooms. To address this issue, an upgraded remote metering system, using app or website access to metering data, could be implemented. Such systems are readily available, and they enable better monitoring of energy usage. At this site, a remote metering system would also help to identify any system inefficiencies or overreliance on the gas boilers.

Heat pump flow temperatures

During the site visit, the flow and return temperatures of the GSHPs were recorded where possible. Unfortunately, the GSHPs in the west plant room were faulty, and readings could not be taken. However, the flow temperatures of the GSHPs in the east plant room were recorded at 56.0°C and 52.9°C, while the return temperatures were at 41.6°C and 38.3°C. The heat was targeting a set return temperature of 42°C.

Looking at the available design information and schematics, the system appears to be designed to be weather compensating, with external temperature sensors installed. During the site visit, the GSHP control panel reported that the external air temperature was 20.7°C. However, the external temperature recorded on the Building Management System control panel was 13°C, consistent with weather forecast data. Based on sample heating curves from the GSHP manufacturer, the recorded targeted flow temperatures are higher than would be expected for either of these temperature readings. The targeted and recorded flow and return temperatures are also higher than the design temperature of the system. The design flow and return temperatures for the GSHPs and underfloor heating are 45°C and 35°C, respectively. This indicates that the GSHPs are running hotter than they need to for the designed system, which will reduce their efficiency.

The system controller showed that the flow temperature of the underfloor heating was 40.1°C, lower than the return temperature recorded and targeted by the GSHPs. This indicates that mixing is occurring in the low loss header between the GSHPs and the underfloor heating. The difference in flow and return temperatures on either side of the header indicates that most of the flow from the GSHPs is mixing in the low loss header and returning to the GSHP. In contrast, only a small amount of the flow is seen by the underfloor heating.

The sensors to record the floor temperature for various underfloor heating zones all read a temperature of 0.2°C. This indicates a fault with the sensors.

Electrical connections

Most of the heat a GSHP provides is drawn from the ground collectors, but it still uses a significant amount of electricity. When switching from a gas boiler to a GSHP, the electricity usage will increase. The electrical connections between the building and the grid may, therefore, need to be upgraded.

When the GSHPs were installed at the cathedral, the electrical connections were not fully upgraded. The GSHPs are programmed to switch off during periods of high energy usage, known as load shedding. This can be an effective way to avoid the expense of upgrading the electrical system or to work around any imposed electrical capacity limitations.

It is anticipated that the gas boilers will be used to make up for any heat shortage resulting from the deactivation of the GSHPs. However, there are alternative solutions that do not rely on fossil fuels. For example, a thermal store could be incorporated into the heating system to provide heat when demand exceeds supply.

Another option is to use the thermal mass of the building. Thermal mass is the ability of a material to absorb, store and release heat. Stone, tiles and concrete have high thermal mass, whereas wood and textiles have low thermal mass. A building with high thermal mass takes longer to adjust to temperature changes. Therefore, heating needs to be turned on much earlier in a high thermal mass building than in a low thermal mass building to achieve the same internal temperature. However, short periods without heating can go unnoticed, especially at sites where the heating system operates for extended periods.

It is crucial to evaluate each project individually to determine the most appropriate design approach with regards to the electrical connection.

3.2 Site 2

Building history and overview

This estate has a Grade I listed hall in Cambridgeshire that dates back to the 1640s. The hall contains an extensive art collection and library. The estate is now open to the public seven days a week.

Heating system

The building's heating system was upgraded in 2018, with a 140kW Eco forest GSHP system replacing the previous oil-fired boilers. An array of 30 closed-loop vertical boreholes was drilled in a section of the former visitor car park, located roughly 280m from the plant room.

The main building is heated for conservation, and the staff flats are heated for comfort. Heat is delivered via the existing wet radiators and pipework. New radiators were installed in the staff flats to ensure comfortable temperatures at lower GSHP flow temperatures. There were no building fabric upgrades.

The boreholes also serve a 40kW GSHP in a neighbouring restaurant, but this installation falls outside the scope of this case study.

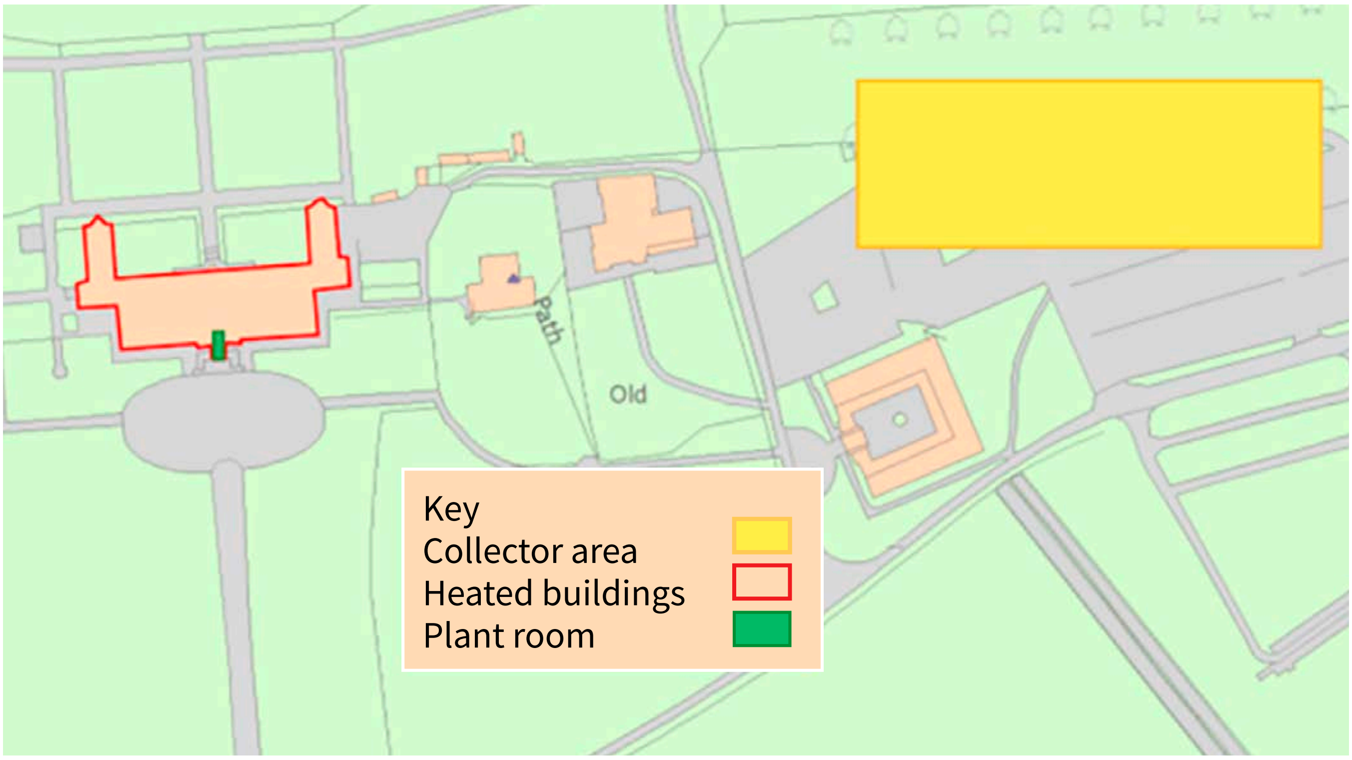


Figure 12: A map of Site 2, showing the location of the buildings heated by the GSHPs, the plant room where the GSHPs are located and the approximate location of the heat collectors. The location of the staff flats is not shown.

Figure 13: GSHPs in the basement plant room.

Summary

Property type	Historic stately home
Heat pump technology	Closed-loop vertical boreholes
Installed heat pump capacity	140kW (2 x 70kW units) (main building)
Heat pump capacity/m^2	40W/m^2
Heating system	Wet radiators
Hot water system	Point of use direct electric heaters
Use pattern	Open all year round to visitors.

Technology choice	★★	Considering the rural location of the site and the availability of nearby land, a GSHP is a suitable option for heating. The closest water source is 0.8km away. There are no apparent back-of-house areas that can conveniently accommodate an ASHP.
Thermal comfort	☆☆	The primary purpose of heating in the main hall is conservation, aimed at controlling humidity. Therefore, thermal comfort is not the main priority of the heating system. The staff flats are heated for thermal comfort, but the current system is often supplemented with electric heaters supplied by the tenants.
System design/ installation quality	★★	The installation quality is impressive, and the previous pipework and emitters have been used effectively.

Internal GSHP observations

- Two 70kW GSHPs serve the main building, totalling 140kW.
- The GSHPs use R-410A refrigerant. The system has a total refrigerant charge of 9.4kg (4.7kg per GSHP). A complete loss of refrigerant would be equivalent to releasing 19,627kg of CO_2 into the atmosphere.
- The GSHPs are installed in a roomy basement plant room beneath the primary entrance hall.
- The installation quality is high, and pipework is routed neatly.
- The ground loop pipework is well insulated with nitrile rubber. The closed-cell nature of this insulation prevents moisture in the air from coming into contact with the cold ground loop pipework and causing condensation. If allowed to occur, condensation can cause pipework to corrode.
- Unfortunately, some areas lack mechanical protection and insulation. Some insulation was damaged, and condensation was forming on the exposed surfaces of the pipework and valves.
- The GSHPs are operating with an average seasonal coefficient of performance (SCOP) of 4.3. SCOP is the measure of a heat pump's efficiency over a year. It is considered a more accurate measurement than COP because it is calculated over a longer period and is less affected by weather conditions.

External GSHP observations

- The GSHP uses 30 closed-loop vertical boreholes as a collector system.
- The boreholes were installed in what was previously the main visitor car park.
- Initially, the borehole installation was programmed to take place after a new car park was completed to the south of the site. Unfortunately, the new car park was not finished when the borehole work began. This meant that parking was severely reduced over a busy Easter period.
- The location where the boreholes were installed has been replanted. There are only three manhole covers (to access the manifolds) indicating the presence of the boreholes. The manifolds are seldom accessed.

Heating distribution system

- Heating is supplied via a wet radiator system, with most radiators being reused from the previous oil-fired set-up. Replacing them was a concern due to the possibility of leaks in the old pipework resulting from making new connections. Additionally, many existing radiators were installed in window bays and so could not be enlarged.
- New radiators were fitted in the residential flats to match the heat provided by the previous system, which was operating at a higher temperature.
- The heating system uses a 500l four-pipe buffer vessel.
- Domestic hot water is provided by local point of use heaters.

Environmental permits and surveys

- Since the collectors are closed loop, no environmental permits were needed.
- There have been no reported leaks from the ground loop.

User interview

- Although the main hall is heated for conservation purposes, visitors do not perceive it as cold.
- Volunteers are thermally comfortable despite remaining in one location for long periods.
- After being introduced to the benefits of preserving the hall, the house team showed great enthusiasm for the GSHP installation. The previous oil-fired system operated at a

high temperature in short bursts, which is not ideal for conservation. However, the new GSHP system operates at a lower temperature for extended periods, better controlling the building's temperature and humidity. This helps protect fragile materials.

- In general, there have been no issues with noise. On one occasion, the GSHPs directly under the entrance hall were audible because they had been poorly maintained. The noise was only observed by the volunteers in the entrance hall and went unnoticed by visitors passing through the area. The noise stopped after maintenance was carried out.

- The new radiators in the residential flats were sized to match the heat provided by the previous system, which was operating at a higher temperature. Based on user feedback, the previous system did not offer adequate thermal comfort, because the historic windows were draughty. Secondary glazing was considered but rejected on conservation grounds. More historically sensitive options are being researched to improve the windows' thermal performance and provide better living conditions in the flats. Plug-in direct electric heaters are currently being used to supplement the wet radiator system to help reach comfortable temperatures.

- The primary conservation heating system is controlled by a humidity sensor in the library, which houses the most sensitive artefacts. Staff manually read local humidity sensors in all the other rooms and adjust the thermostatic radiator valves accordingly.

- The existing electricity supply to Site 2 did not have sufficient capacity to supply the new GSHP installation. However, installing a new supply from the nearby cafe was possible because it was relatively new and had enough spare capacity for the GSHPs.

- By transitioning from an oil-based system to a GSHP system, the annual running costs have been reduced by roughly 41 per cent, saving £8,000 per year.

Discussion

The GSHP system is well designed and has led to large reductions in carbon emissions while improving the environmental conditions for preserving the historic building and its contents.

Technical installation

Before settling on a ground source system, a water source system was considered. There is a lake on the estate, but it is located more than 600m from the main house. Trenching the heat collectors to the lake was prohibitively expensive. An air source system was also considered. However, it was assumed that planning would not permit outdoor ASHP units because there was no clear back-of-house area to accommodate them. Instead, a ground source system was chosen, and there are now very few visible signs of the external installation.

A thermal response test found that the project required fewer boreholes than initially estimated. This reduced the installation costs and duration of the groundworks. A thermal response test involves measuring the rate of heat transferred from the ground to the borehole. It is conducted on a single borehole before drilling the final borehole array. The test results optimise the number of boreholes in the final array, ensuring it is as cost-effective as possible. Thermal response tests are typically only carried out on larger projects where the cost will likely be offset by optimising the final array design.

At Site 2, the boreholes are located away from the plant room, requiring a pipe run of 280m. The greater the distance between the GSHPs and the borehole array, the greater the required pumping energy and associated operational costs. There will also be an increase in the initial cost of pipe material and installation. These perceived disadvantages were balanced against the advantages of siting the boreholes away from historically or aesthetically senstive locations. For example, there are large lawn areas to the south of the main house that are about 200m closer to the plant room. Using this location would have meant reduced installation costs and reduced pumping energy requirements. However, the latter saving would be relatively small, estimated at around £400 per year at 30p/kWh. The ground loop pipes are sized for a low pressure drop, which reduces the required pumping energy. Using the old car park meant no risk to the land closest to the main building.

Figure 14: Borehole field.

Archaeologists were required to be present when the trenches were dug for the pipework connecting the plant rooms and the below-ground manifolds. There were no discoveries that disrupted the construction process. Initially, the trench scar was visible but it has now bedded in, and there is a renewed road surface and reseeded soft landscaping.

The physical size of the equipment posed a number of challenges. The outer casing of the GSHPs and the door frames needed to be removed to get the heat pumps into the plant room. Fire doors were removed and reinstalled the same day to ensure safety was not compromised overnight. This required a high level of coordination between several trades.

It is essential to consider the potential impact of new services on existing ones. The external pipework route cuts perpendicularly across some old land drains, assumed to have been used to drain the old kitchens and supply the water features. It was deemed low risk to allow the pipework to be installed across these drains without maintaining their functionality. Since the external pipework was installed, water seems to seep through the flagstones in the basment with increased frequency. Several gullies are also visible in the basement floor where water is sitting. These gullies were reported to be dry before the external works. The new pipework route may have altered the functioning of the old land drains, which may, in turn, be restricting the groundwater's ability to drain away into the landscape. Further investigations are required to verify if the drainage dynamics have been altered and are harming the building.

It is a good idea to engage a building services engineer to consider all aspects of a GSHP installation and how it will interact with other services and the building as a whole. They will also be able to advise on the appointment of specialists if particular expertise is required. At Site 2, a contractor specialising in heat pump installations was employed, but the project may have benefited from broader building services expertise.

Reusing radiators

Site 2 has had at least six types of radiators installed throughout its lifetime, some of which are shown in Figure 15. Most of these were connected to the previous oil-fired system and have been reused in the new GSHP system. The original radiators were sized to provide comfort heating at a high flow temperature (likely 82°C). Staff thought that the house would feel colder due to the lower flow temperature of the GSHP system. However, the heat is now more constant, and this gentle heat makes the building feel warmer, despite comfort not being the system's primary function.

The new GSHPs operate at a much lower flow temperature (45°C), reducing the radiators' heat output significantly. However, the required heat output is lower because the building is now heated for conservation and not comfort. Heat loss calculations show that the existing radiators are suitably sized for providing conservation heating at efficient GSHP flow temperatures.

Figure 15: Radiators at site 1

Reusing an existing heating distribution system can allow significant savings in cost, disruption and embodied carbon, but it does bring its own challenges. Undocumented additions and alterations to the system have likely occurred since it was initially installed, so the precise piping arrangement may be unknown. This can make it hard to design the system hydraulics and to appropriately size plant, such as GSHPs. At Site 2, thermal imaging surveys were undertaken to identify pipework routing and better understand the system.

Due to corrosion, old heating systems may contain debris in suspension, shed from the inside wall of the pipework and radiators. This poses a particular risk to the plate heat exchanger inside a GSHP, as the narrow waterways can become blocked by debris. The existing system at Site 2 was flushed to protect the new GSHPs, and a magnetic filter was installed to collect debris from the ageing pipework and radiators. The large buffer vessel that hydraulically separates the GSHPs from the radiators will allow some larger debris to fall out of suspension and settle at the bottom of the tank. There is also a small viewing window that allows the heating system water to be visually inspected for debris.

Conservation heating controls

The control system at Site 2 is relatively simple, with the GSHPs receiving an on/off signal from the conservation heating control panel, which measures humidity in the library as the single control point. The library was selected as the most sensitive location due to the many books that need protection. It is also located on the north side of the building, so it will naturally be colder due to reduced solar gains. A weather compensation algorithm was implemented. It aims to calculate the optimum GSHP flow temperature to regulate the humidity according to the weather conditions at that time.

Figure 16: Local humidity sensor.

There are humidity sensors in the rest of the building, one of which is shown in Figure 16. These do not report to the central control system. Instead, staff read them locally, and manually adjust the radiator outputs via thermostatic radiator valves to keep the relative humidity within a suitable range. This approach was also used with the previous oil-fired system, but staff now have to adjust the thermostatic radiator valves less frequently because the GSHPs are more consistent in operation.

The chapel within the hall has never been heated. At the time of the visit, the humidity in the chapel was 68 per cent, and mould blooms had appeared in the past year. While this cannot be attributed to any one cause, climate change impacts long-term weather trends, which could be tipping the balance. Staff are also concerned that any negative impact on the drainage system caused by the external works may be contributing to the poorer environmental conditions seen in the chapel. It may be that the conservation heating system should be extended to the chapel to protect the space.

The old oil boiler was large, designed to provide comfortable heating temperatures for the previous occupants. When used for conservation heating, the large boiler would overheat the system before entering its shutdown cycle. This resulted in large swings in the relative humidity, which is detrimental to the historic building fabric and contents. The relative humidity is now reported to be more stable with the lower flow temperatures provided by the GSHP system.

A zone control strategy based on humidity sensors and radiator valves that can be controlled automatically was initially proposed as part of the project but deemed too costly. However, it would likely improve environmental conditions throughout the building, minimise the amount of energy used and free up staff resources.

Despite not having the best level of control, the GSHP system is an improvement. It provides better humidity control, reduces running costs and decarbonises the estate. It is appropriate that the project focused on the urgent matter of removing the reliance on oil. Further improvements and optimisations can be made as funds become available.

Comfort heating in staff flats

The heating system provides comfort heating to two staff flats within the hall. The GSHP flow temperatures are optimised for the conservation of the hall, and there is a perception that this means the system fails to deliver comfortable conditions to the staff accommodation. It should be noted that the GSHP system was installed to provide a heat output equivalent to the previous oil system in the flats. It was reported that the previous oil system did not produce comfortable conditions in the flats either.

The flats have had few fabric upgrades, and tenants are exposed to draughts, particularly around the windows. Responding to this issue, the tenants regularly use plug-in electric heaters to achieve comfortable conditions. These heaters consume far more electricity than a GSHP to deliver the same amount of heat and so drive up running costs. There is no sub-metering of the flats, so it is not currently possible to compare the energy consumption of the flats with the rest of the hall.

It may be that a different method of control would deliver more comfortable heating conditions to the flats without the need to use direct electric heaters. One tenant reported that they turned the heating on for a short period in the morning and again in the evening. They never keep the heating on when they are not in the flat, partly because they are aware that large amounts of heat will be lost through the leaky windows. This method of control, sometimes called ‘pulse heating’, can be suitable with fossil fuel boilers and appropriately sized emitters, but it can be problematic when used with a GSHP. At Site 2, the low flow temperature of the GSHPs is optimised to maintain stable conditions in the main hall and provide more gentle changes in indoor temperatures. This means it is not good at providing the rapid change in room temperature that pulse heating requires. The GSHP needs more time to heat the staff flats to a comfortable temperature, so it is likely that using the GSHP to heat the flats for longer periods, or even 24/7, would provide more comfortable conditions. The GSHPs at Site 2 operate with a good SCOP of 4.3, so it is possible that running the system constantly would consume less energy than using inefficient direct electric heaters.

3.3 Site 3

Building history and overview

It is believed that the initial structures in the current grounds of Site 3 were built in the early 1300s. Subsequent enhancements and modifications were made to the property, including extensive renovations in the 1700s and significant restoration work from 1940 to 1970.

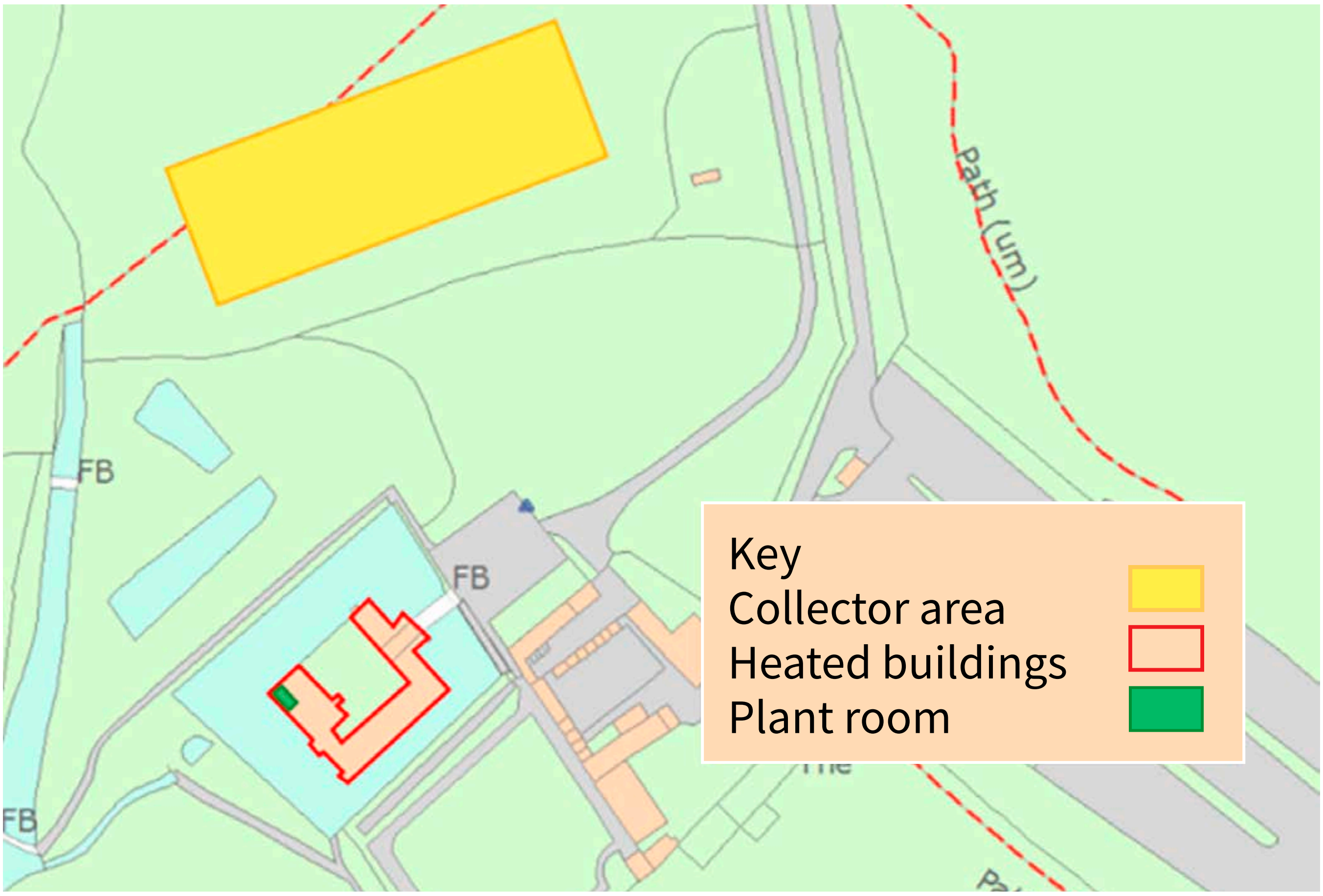


Figure 17: A map of Site 3, showing the location of the buildings heated by the GSHPs, the plant room where the GSHPs are located and the approximate location of the heat collectors.

Heating system

In 2017, two GSHPs were installed on the site and connected to the main house's existing heating system, which was installed in the 1930s.

The GSHPs supply heat to a buffer vessel, from which separate circuits are taken for the staff offices and main building area.

The offices are well equipped with modern wet radiators that ensure a comfortable temperature for the staff. The main heating system of the house uses historic radiators and is designed to maintain relative humidity for conservation purposes, rather than thermal comfort.

Summary

Property type		Historic stately home
Heat pump technology		Closed-loop horizontal ground collector
Installed heat pump capacity		80kW (2 x 40kW)
Heat pump capacity/m^2		55W/m^2
Heating system		Existing radiators installed in 1934
Hot water system		Point of use direct electric heaters
Use pattern		Open year round to visitors
Technology choice	★☆	Due to the rural location and ample land available, horizontal ground loops within trenches were deemed the best option rather than vertical or radial boreholes. The site has multiple water sources that could have been used as a heat source, such as the moat located near the plant room. It remains unclear why a GSHP was selected over a water source heat pump, which potentially could have resulted in lower capital costs.
Thermal comfort	★☆	The heating system is designed to provide conservation heating rather than thermal comfort throughout the historic house. To maintain the desired level of humidity control, plug-in electric heaters are currently in use. However, the GSHPs are designed to provide thermal comfort in the staff offices, and they have proven to be very effective.
System design/ installation quality	★☆	The GSHPs have been installed to a high standard. Only a small section of the ground loop pipework can be seen externally, where it passes from the plant room to the moat. Multiple sensors are placed throughout the property, but only one is driving the heating response.

Internal GSHP observations

- Two 12-40kW Ecoforest modulating GSHPs are installed, providing a total capacity of 24-80kW.
- The capacity of the ground collector is unknown.
- The GSHPs use R-410A. Each GSHP has a refrigerant charge of 4.1kg, giving a total system refrigerant charge of 8.2kg.
- The GSHPs appear to be well maintained, and they can be easily accessed for additional maintenance.
- The installation has made no significant impact on the historic site. Two pipes are visible leaving the building before they go underground or under the moat. One volunteer commented that the pipes are an eyesore, but they are likely to be mistaken for drains.
- The GSHPs are located in a plant room across a corridor from the visitors' area. The plant room has thick walls and a solid timber door without specific acoustic seals. Anti-vibration rubber mats are used as mounts for the GSHPs. No noise could be heard in the visitors' area when the GSHPs were running.
- During the site visit, there was no noticeable noise coming from the GSHPs or any of the pumps associated with them when outside the plant room. Inside the plant room, some noise was coming from the circulating pumps for the heating system. This was louder than that coming from the GSHPs.

External GSHP observations

- The GSHPs use a horizontal ground loop as a collector system. The collectors cover an area of 3,000m^2.
- The collectors and pipes are not visible, except for their entry and exit points into the building.
- The external pipework between the collector and the plant room is underground. The small section above ground appears to have mechanical protection and thermal insulation, but it is unclear what type or thickness of insulation has been used.

Heating distribution system

- Heating is provided via existing radiators installed in 1934. The radiators are still in use within the historic section of the building.

- Triple panel radiators in the office area are appropriate for lower flow temperatures.

- The heating system uses a 500l buffer vessel to supply heat to separate circuits for the staff offices and main building area.

Environmental permits and surveys

- Since the collectors are closed loop, no environmental permits were needed.

- There have been no reported leaks from the ground loop.

User interview

- The GSHPs were installed to reduce the amount spent on oil. User feedback suggests this has been achieved.

- The heating system in the historic house prioritises conservation heating over thermal comfort by regulating humidity levels.

- The offices have high levels of thermal comfort.

Discussion

Heat pump and system control

The heating system is intended to provide heating for conservation rather than thermal comfort. The main house's heating system is set up to be regulated by humidity sensors in rooms throughout the building. However, the heat output in each room is not controlled by individual sensors as would be ideal, or by data from all the sensors combined as was designed. Instead, one sensor oversees the entire house's heating. During the visit, the facilities manager mentioned that it was unclear which sensor was controlling the heating system, and this was impacting its efficacy.

The GSHPs are inverter driven. The compressor within the GSHP can vary the speed at which it runs, thus allowing the heat output to be modulated. This provides greater control and reduces the amount of electricity the heat pump uses. It also helps reduce cycling.

During the visit, it was observed that the GSHPs were adjusting their compressor speeds to match the load. One of the GSHPs turned on when the buffer vessel's temperature dropped below the minimum set temperature. As the GSHP operated, the buffer vessel increased in temperature. As the vessel approached the target temperature, the GSHP decreased its output to prevent overshooting the target. If a GSHP runs at maximum capacity until the moment the target temperature is reached, there will still be some heat in the system when it switches off, which will transfer to the buffer vessel. The buffer vessel will then overshoot the target temperature, and more energy will have been expended than was actually required. This can be prevented by reducing the GSHP output prior to reaching the target temperature and 'coasting' the rest of the way up to the target temperature.

At Site 3, it seemed likely that the GSHP would be able to avoid overshooting and match the building's load. However, when the target temperature was almost reached, the control system activated the second GSHP. It ran at maximum capacity for a short period before adjusting its compressor down to 20 per cent of its maximum. Unfortunately, the buffer vessel quickly surpassed the set point, causing both GSHPs to shut off.

To avoid frequent cycling of the compressor and enhance the efficiency of the GSHPs, adjustments can be made to the target set points or the internal settings to maximise the time that the GSHPs operate.

Recirculation and mixing within the buffer vessel

The heating system uses a 500l four-pipe buffer vessel to achieve hydraulic separation. This arrangement matches the example schematic from the GSHP manufacturer. Hydraulic separation ensures that the GSHPs can consistently maintain their minimum flow rates, regardless of the conditions in the upstream heating system. For this reason, manufacturers often recommend some form of hydraulic separation as it guarantees a minimum flow rate through their heat pumps without relying on the heating system's design, which they cannot control.

System designers use hydraulic separation to balance the flow rates in a heating system. They achieve this by allowing the flow difference between the primary side (GSHP side) and the secondary side (heating circuits that supply the building) to flow through the buffer vessel. In this way, the system's GSHPs and heating circuits function separately.

If the heat required by a building is greater than the capacity of the GSHPs, the heating circuits can extract stored heat from the buffer vessel. During periods of low heat demand, the GSHPs can continue to operate until the buffer vessel reaches its target temperature. This feature can increase the GSHP's run time and minimise the risk of it frequently cycling on and off.

The downside, illustrated in Figure 18, is that the flow from the GSHPs mixes a little with the water in the buffer vessel before being directed to the heating system. This was observed at Site 3. Temperature sensors showed that the GSHPs were producing 45°C water and delivering this to the top of the buffer vessel. The heating circuits received a flow temperature of 40°C. This mixing means the GSHP is producing water 5°C hotter than it otherwise needs to satisfy the building, which reduces heat pump efficiency by about 12.5 per cent.

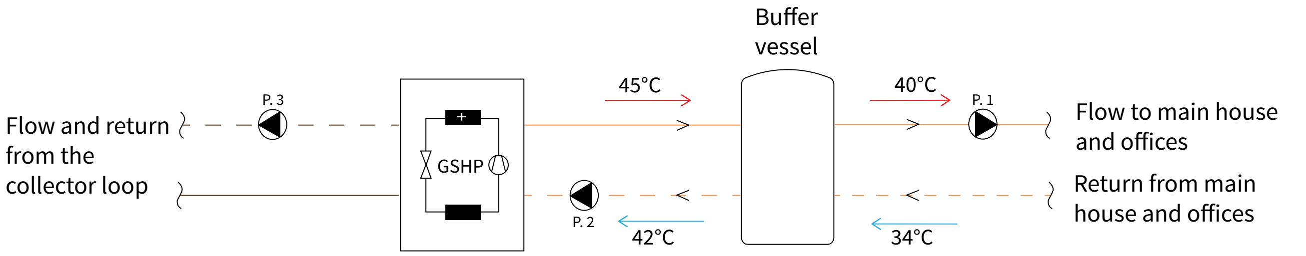


Figure 18: A four-pipe buffer vessel arrangement, with the readings from temperature gauges taken during the site visit.

An alternative arrangement would be to install a two-pipe buffer vessel. A two-pipe buffer vessel would ensure minimum GSHP flow rates, and a difference in primary and secondary flow rates could be accommodated while avoiding mixing the heat pump flow. A two-pipe buffer vessel could be installed on a common pipe that branches between the flow and return pipework, as shown in Figure 19.

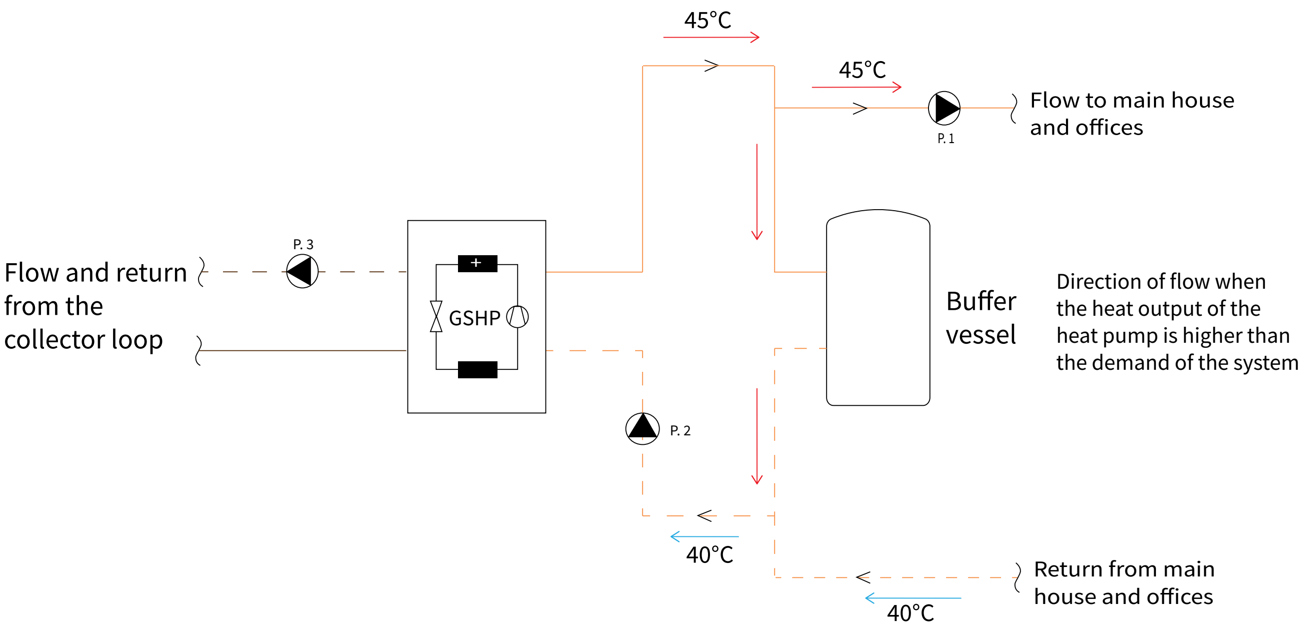


Figure 19: An alternative two-pipe buffer vessel arrangement.

When the GSHP output is higher than the demand, excess hot water flows through the buffer vessel, heating it, before joining the return from the heat emitters, back to the GSHP. This allows the GSHP to run for longer periods when the heat demand is low and reduces the risk of cycling. It also allows the buffer vessel to act as a thermal store.

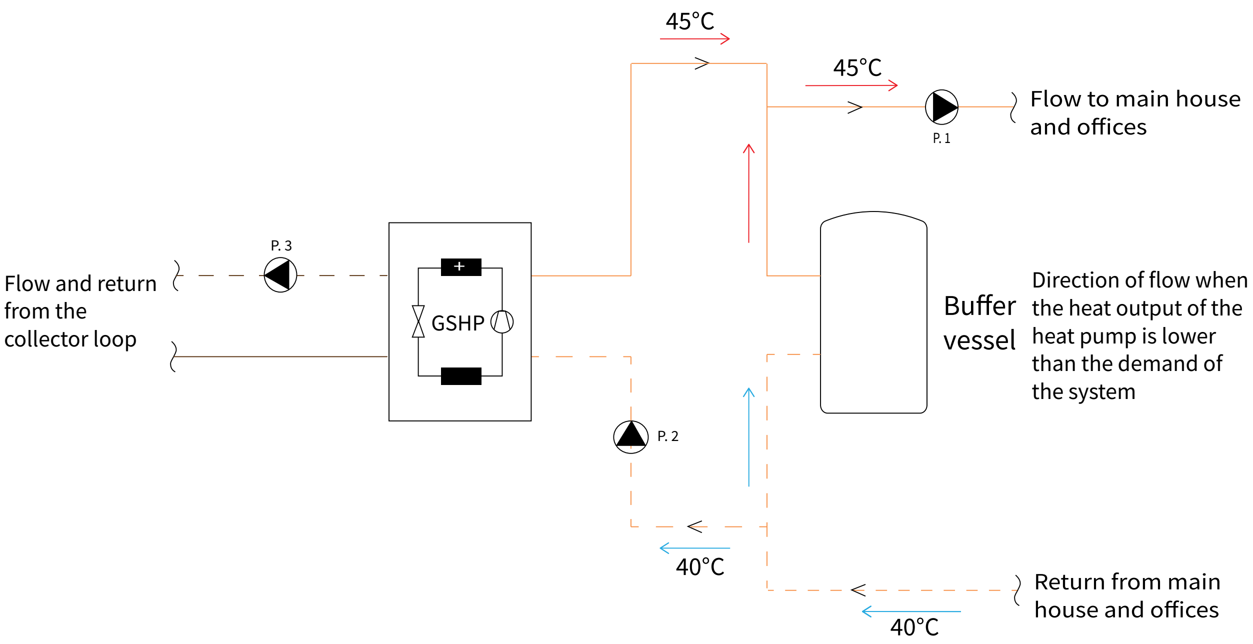


Figure 20: An alternative two-pipe buffer vessel arrangement, with the direction of flow shown when the output of the GSHP is lower than the demand.

When the heat demand is higher than the output of the GSHP, the pump (P.1) on the flow leg will draw water from the buffer vessel to account for the deficit, using any heat stored in the buffer vessel. This means that water will be drawn from the return leg and passed through the buffer vessel to balance the flow, as shown in Figure 20.

Using existing heat emitters

The GSHPs at Site 3 were connected to the existing heating system within the historic section of the house, with more modern radiators used in the staff areas and flats. The heat emitters in the staff areas and flats provided high thermal comfort levels for the occupants.

Electric oil-filled radiators, controlled by humidity sensors, were added to complement the heat emitters in the main house. These are often used in buildings that have conservation heating, because they are easy to set up. However, using both direct electric radiators and a wet system could be causing a control conflict, if the electric radiators are responding quicker than the wet ones. This could mean that the electric radiators are doing the majority of the heating, which would lead to increased running costs and increased carbon emissions.

The existing heating system was not part of the original building and was reportedly installed in the 1930s as part of renovation works. Often, radiators were hidden in recesses and alcoves, as shown in Figure 21. This reduces their obtrusiveness, but also reduces their heat output, meaning that the output is wholly convective (heats the air without any radiant heat output).

Figure 21: An electric oil radiator in front of a historic radiator hidden behind wooden panels.

It is generally considered more acceptable for older radiators to be visible, compared to newer radiators. Many older radiators, and pipes between radiators, were visible throughout Site 3. These were seen as part of the house and seemed less intrusive than modern radiators.

The historic radiators were originally designed for thermal comfort, so they should be able to meet the heat output requirements for conservation, at the lower temperatures generated by GSHPs, without any fabric improvements being made to the building. This has multiple benefits, such as avoiding the embodied carbon associated with installing new heat emitters and additional insulation. If existing heat emitters are used, the building work required when installing a GSHP in a conservation heating system is significantly reduced, as is the associated cost.

Heat source

Site 3 has multiple water features on site that could potentially have been used as a source for a heat pump. Water source heat pumps are a popular choice when water features are available, because ground loops sunk into water features tend to have a lower installation cost than digging trenches or drilling boreholes. However, the collector loops installed in water sources can reduce the surrounding water temperature. If the water feature is too small or if too much heat is extracted, the overall temperature of the water can be affected.

This can harm local wildlife or lead to poor heat pump efficiency if water is not able to flow freely around the collectors.

GSHPs using a horizontal ground trench were chosen at Site 3. The pipes connecting the GSHPs to the ground collector run through a water feature, specifically the moat surrounding the main house. Why ground loop collectors were chosen instead of water loop collectors for this site is currently unknown. However, the absence of visible water flow in the moat and the year-round use of the heating system for conservation heating imply that the decision may have been influenced by the desire not to lower the temperature of the water source.

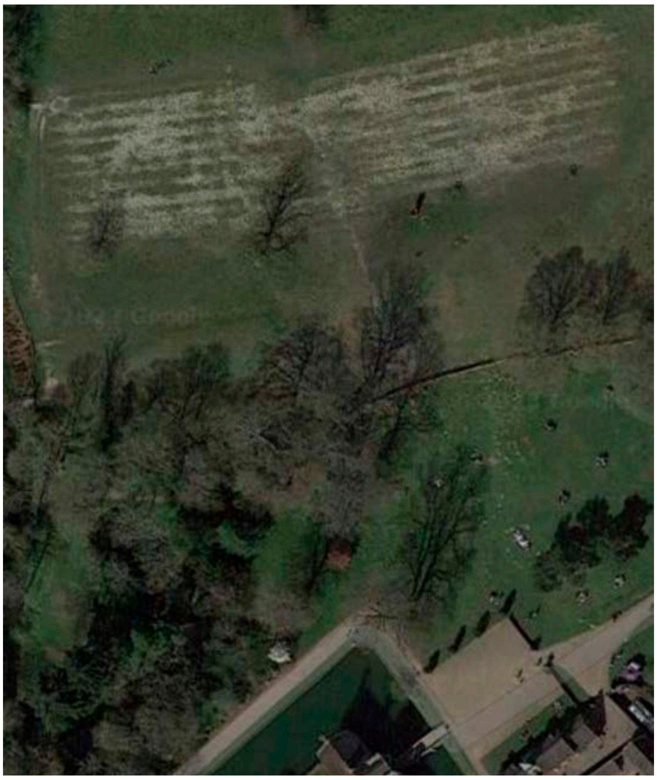


Figure 22: A satellite image of the location of the collectors (top), with the house visible at the bottom (right)
Google maps: Imagery © 2025 Maxar Technologies, Map data 2025.

The ground loop collectors are situated in a field approximately 125m from the plant room. These collectors occupy an area of 3,000m^2 and are not easily visible, except for two pipes leaving the plant room. During the installation, the trenching for the collectors caused significant local disruption and a visible scar, as shown in Figure 22. During the site visit, the collectors were no longer obvious.

Conservation and thermal comfort

The GSHPs provide conservation heating in the areas of the house open as a dressed monument, and they also provide thermal comfort to staff offices in the main house. Staff and volunteers thought that the heating provided to the dressed monument was minimal during the winter. However, to control humidity in summer, the heating runs for extended periods.

The moat around the building often causes high humidity levels inside, as the water evaporates. This leads to a curious situation, where heat is required in the summer to lower the internal humidity to protect the building and its contents. This can make the building uncomfortably hot. An upper temperature limit can be set on a conservation heating system to avoid this. Based on feedback from building users, this was not in operation at Site 3.

In winter, it is typical for buildings in which the heating system is controlled by relative humidity levels to feel cold. When cold external air that contains little moisture enters a building and is warmed, even slightly, the relative humidity in the building drops. Typically, only a small amount of heat is required on even the coldest days to nudge the relative humidity in the building to an acceptable level. Being surrounded by a moat, the external air is often more humid than usual. This leads to even less heat being required, and the building can become quite cold for its users. This can be mitigated by a 'boost' control function, which raises the heat output for a set duration to allow the space to reach comfort conditions when required.

Interrogating the GSHPs showed that they recorded data on the heat output, energy input and COP for a year. Comparing this data shows the heat output from the GSHPs was higher during the winter than the summer, despite being perceived as cold during the winter. The system design meant that both GSHPs were used for conservation heating and thermal comfort simultaneously. A graph of the heat output is shown in Figure 23.

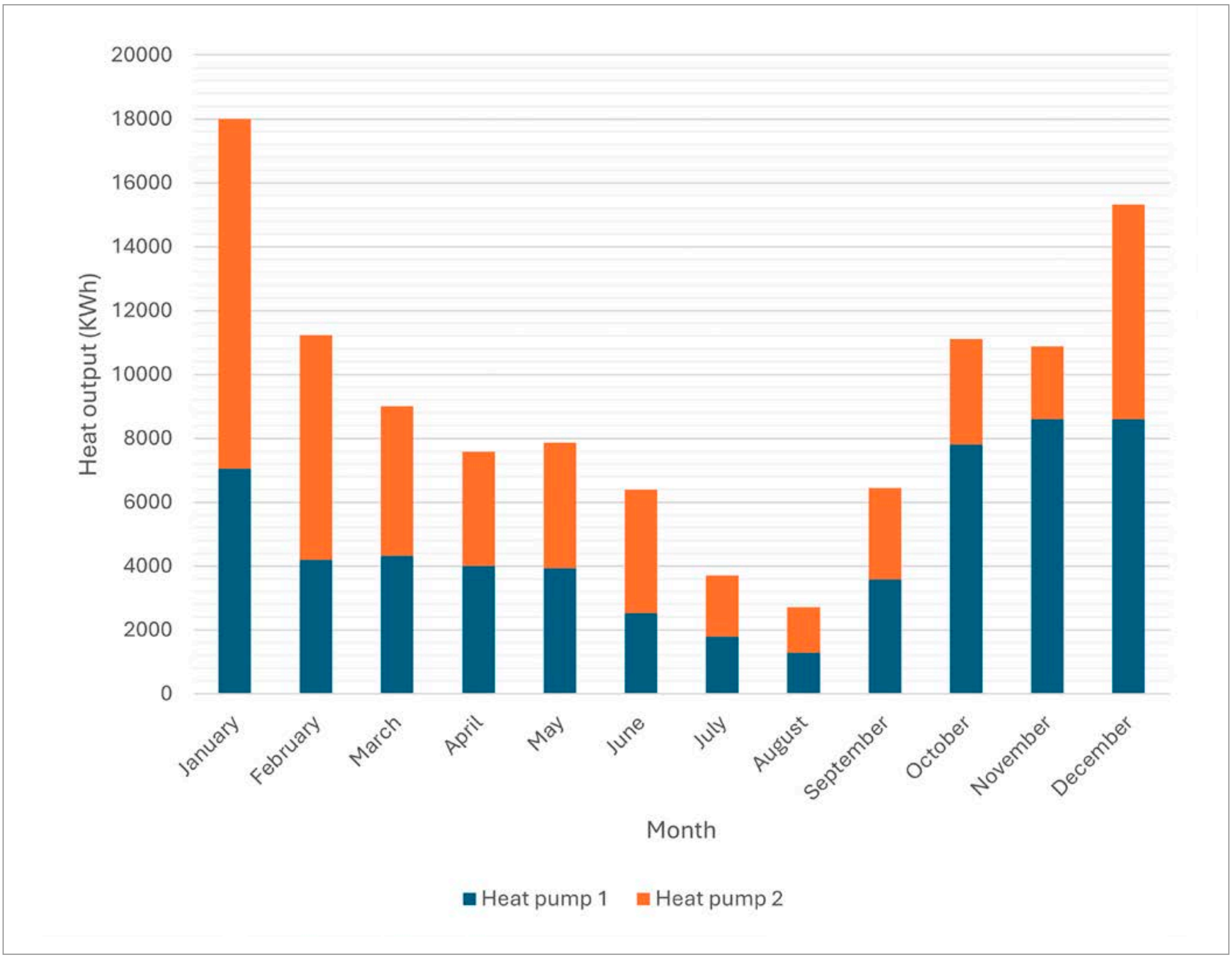


Figure 23: Monthly recorded heat output from the GSHPs at Site 3.

The high winter heat load could indicate that the primary heat load is determined by heating the significantly smaller office area for thermal comfort rather than the larger main area for conservation heating. However, this cannot be confirmed due to a lack of accessible metering on the various branches of the heating system.

3.4 Site 4

Building history and overview

Most of the existing house dates back to 1812, with extensions added throughout the 19th century. After being used by the military during World Wars I and II, the building was extensively renovated to reduce the damage caused by dry rot and general wear and tear. The house is currently still owned, managed and used as a residence by the Buccleuch family.

Above: Figure 24: Site 4.

Right: Figure 25: A map of Site 4, showing the location of the buildings heated by the GSHP, the plant room where the GSHP is located and the approximate location of the heat collectors.

Heating system

The GSHP was installed in 2021 and was connected to the existing heating system, which uses wet radiators. The GSHP replaced three custom-built direct electric hot water generators for low temperature hot water (LTHW), each consisting of 70 3kW immersion heaters. There are plans to expand the heating system to currently unheated areas and to connect the GSHP to provide domestic hot water for the entire house.

Figure 26: CO_2 GSHP at Site 4.

Summary

Property type	Historic stately home
Heat pump technology	Closed-loop horizontal ground collectors
Installed heat pump capacity	537kW
Heat pump capacity/m^2	88W/m^2
Heating system	Wet radiators
Hot water system	The GSHP provides domestic hot water for two flats within the house. There are plans to extend this to the entire house.
Use pattern	The house and flats are occupied year-round.

Technology choice	★★	The use of CO_2 refrigerant allows for existing emitters to be reused. Ground source is a sensible choice due to the large amount of land available for collectors. The GSHP is connected to an anaerobic digester so all the electricity used by the GSHP is generated by a renewable energy source on site, making the installation self-sufficient.
Thermal comfort	★★	There have been no problems with thermal comfort.
System design/ installation quality	★☆	Existing pipework and radiators have been reused to deliver good levels of comfort. However, the heating system is currently unable to deliver the low return temperatures required by the GSHP to operate efficiently, significantly reducing COP.

Internal GSHP observations

- A 450kW GSHP with a total collector length of 24km has been installed.
- The GSHP uses CO_2 refrigerant (R-744). The system has a refrigerant charge of 150kg.
- The GSHP was installed less than two years ago. The plant room is well maintained, tidy and clean.
- The main historic building remains visually unaffected. The GSHP is situated in a repurposed outbuilding. The buffer vessels and system pumps are located in a plant room in the main house.
- The outbuilding that houses the GSHP is more than 600m from the main house and 400m from the nearest occupied building.
- The outbuilding is adjacent to a car park often used by anglers. There are plans to improve the sound insulation of the outbuilding. However, the GSHP was running during the visit, and the noise observed from the car park was minimal.
- The dedicated frame on which the GSHP is mounted sits on anti-vibration feet, effectively reducing the vibrations.
- The GSHP is entirely powered by electricity produced by an onsite anaerobic digester, fed from agricultural waste.

- The anaerobic digester is located more than 1km from the main house, so supplying electricity from the digester to the main house would require step-down and step-up transformers. The decision was made to locate the GSHP between the house and the digester because it was a more cost-effective installation. The length of the heating pipework from the GSHP to the house was greater, but there was no need for transformers.

External GSHP observations

- The GSHP heat collector consists of 24km of horizontal pipework buried 1.2m deep at 1m centres (distance between the centreline of the pipes) in a field adjacent to the GSHP. The collector consists of 60 loops, each 400m in length.

- The individual loops are collected in manifolds in the field. Some manhole covers are visible at the edge of the field, but otherwise the ground collector is not visible.

- The groundworks took approximately one year to complete.

- Exterior pipes appear well insulated and run underground for 663m to the house. The exact heat loss was impossible to calculate due to inconsistent readings from temperature gauges and the inability to ascertain the flow rate at the time. However, the manufacturer's data for a ø90mm buried insulated pipe at 60°C gives a heat loss of 9.5W/m. Accounting for the flow and return would yield about 12.6kW of heat lost into the ground. To provide hot water to the house, the GSHP would have to operate 24 hours a day, 365 days a year, with an annual heat loss to the ground of 110,350kWh per year. This should be viewed in context: the GSHP was located here so it could use electricity generated by the onsite aerobic digestor.

Heating distribution system

- Heating is provided by a combination of existing historic radiators and more modern radiators.

- Work is about to start to add more radiators to the system, to provide heating to currently unheated areas.

- The heating system uses two 2,000l buffer vessels, totalling 4,000l, on the heat pump side of the heat exchanger, and five 718l buffer vessels, totalling 3,590l, on the house side.

Environmental permits and surveys

- No environmental permits were needed because it is a closed-loop system.

- One ground loop leaked in the past. It is not clear what caused the leak. Farm machinery may have been used too deeply or the installation of the ground loops may be faulty.

User interview

- The contractor that installed the GSHP was unfamiliar with systems of this size. A heat exchanger was installed to hydraulically separate the mechanical installation, to provide a contractual boundary and to separate the installation works between the GSHP installer and the contractor for the house heating system.

- There have been no issues with thermal comfort when the GSHP is running. Sometimes, the hot water in the flats is not hot enough.

- Over the winter, there was a period when the GSHP stopped operating and the house had no heating. This was because the return temperature to the heat pump was too high, causing it to lock out.

- There have been no issues with noise, although there are plans to improve sound insulation to the GSHP housing.

- Running costs are less than they were with the old direct electric system. This is due to the greater efficiency of the GSHP and the fact that it can connect to the anaerobic digester and use the electricity generated on site. The previous direct electric system used energy bought from the grid.

- The system runs on a timer with no internal temperature feedback. There are plans to install a better control system for the different zones of the house.

- A maintenance contract has been secured with the installers. The system is still being refined to get a better COP, primarily by lowering the return temperatures. Two different contractors installed the GSHP and house heat distribution, so it is unclear who is contractually responsible for carrying out the work.

Discussion

Refrigerant choice

Site 4 was one of the first buildings in the UK to be heated by a CO_2 refrigerant GSHP. The refrigerant choice is a key factor in the environmental impact of a heat pump system, managing concerns of high GWP, toxicity and flammability.

The market supply of high GWP refrigerants such as R-410a is being phased out by F-gas regulations, meaning systems using these refrigerants will become increasingly expensive. CO_2 is a natural refrigerant with a GWP of 1, low toxicity and low flammability, making it an attractive solution. However, the nature of the CO_2 refrigeration cycle means that some of the rules of conventional hydrofluorocarbon heat pump efficiency (low flow temperatures, low ΔT) do not apply, so the heating system must be designed accordingly.

While hydrofluorocarbon refrigerant GSHPs suffer a significant drop in COP at high flow temperatures (>60°C), CO_2 GSHPs can efficiently produce high flow temperatures above 70°C. The nature of the transcritical CO_2 refrigeration cycle means the COP is optimised when the return temperature is kept very low, and the efficiency drops off as the return temperature of the system increases, as shown in Figure 27. Above a certain return temperature, a CO_2 GSHP will be unable to operate and will switch off. This means a CO_2 heating system must operate with a high temperature difference and a low flow rate compared to a hydrofluorocarbon GSHP system. This is advantageous when replacing an existing gas or oil-fired heating system, as the pipework will have been sized for smaller temperature differences and high flow rates. As a result, the existing pipework can sometimes be reused instead of upsized, as may be required when changing to a low temperature difference, high flow rate hydrofluorocarbon GSHP system.

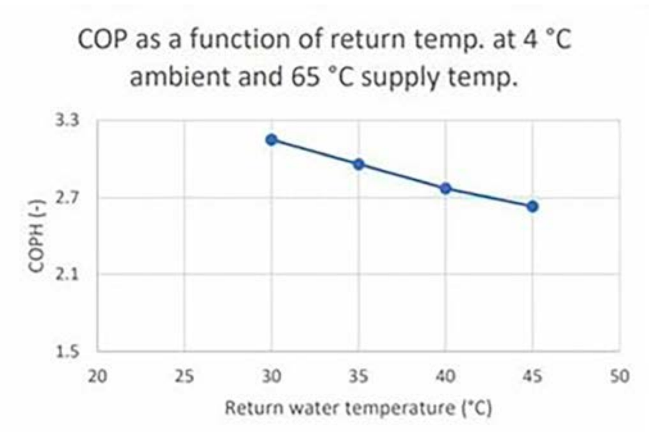


Figure 27: CO_2 efficiency at varying system return temperatures (COPH is the heating COP) © Clade Engineering: [clade-es.com/how-to-use-co2-for-heating-and-hot-water/.](clade-es.com/how-to-use-co2-for-heating-and-hot-water/)

Managing return temperatures

The challenge of achieving low return temperatures highlights that using a CO_2 GSHP is not straightforward. The high flow temperatures that can be delivered are attractive to historic buildings with existing heat emitters, but careful design and installation are required to obtain low return temperatures and good COPs.

At Site 4, achieving low return temperatures to the GSHP has been challenging. At the time of the visit, the return temperature was measured as 52.8°C, much higher than the design temperature of 35°C. As a result, the system has been operating with a COP of about 1.7.

This has been a particular problem with regard to the RHI payments, which require a minimum COP of 2.9. The RHI scheme is now closed to new applicants.

During the winter of 2022–23, the system shut down entirely because the return temperature was too high for the refrigeration cycle to operate correctly. This led to a complete loss of heating for several days while waiting for a manual reset. The users knew that high return temperatures led to increased running costs, but they were surprised when the GSHP shut down as a result. They wish they had been informed of this possibility before installing the GSHP.

To efficiently operate a CO_2 GSHP, achieving low return temperatures from the heating system may require a combination of solutions. Some of these are considered below.

Insulation

Removing insulation from sections of the indoor pipework is also being considered. Typically, heating pipework will be insulated when it passes through unheated areas, such as basements, to conserve energy. However, in the case of CO_2 GSHPs, losing some heat in these areas can sometimes be beneficial. While not typically occupied, these areas are still within the building envelope, so the heat emitted is helpful in reducing the heat loss from neighbouring occupied rooms. It will also help drive down the return temperature to the GSHP. Such an approach must consider the total energy consumption of the GSHP rather than just the COP.

Limiting return temperatures

Installing return temperature limiting (RTL) valves on the system radiators may be a solution. These valves are fitted to the return connection of the heat emitters (predominantly radiators) and only allow water to enter the return when the water temperature is at or below the value set on the valve. However, there will be significant additional capital costs if RTL valves are fitted to every heat emitter. Occupants may confuse RTL valves with more common thermostatic radiator valves, so the RTL valve must be tamper-proof to prevent the system return temperatures being altered inadvertently. There are also aesthetic considerations. Various traditional style thermostatic radiator valves are available for use with older radiators, but this is not the case for RTL valves.

Contractual responsibility

At Site 4, the installation was split between two contractors: one for the GSHP and one for the building side plant room. More clarity is needed to determine who is responsible for improving the GSHP's efficiency, because it is directly related to the return temperature that the building side delivers.

Buffer vessels

The buffer vessel configuration can affect the return temperature to the GSHP. At Site 4, the buffer vessels installed are shorter than originally designed. This means there will be less heat stratification and more heat transfer between the flow and return, raising the return temperature.

Location

The GSHP is located in a separate outhouse that was previously used to store fishing equipment. It is connected to the main house by a 663m-long below-ground heating pipe.

It is unusual for a GSHP to be located so far from the space it is heating, because minimising the distance between the two reduces heat loss and the pumping energy required. The location was selected so the GSHP could be close enough to the onsite anaerobic digester to be served by a low-voltage connection. Locating the GSHP next to the house would have required a high-voltage connection to the digester, which would have been more expensive. The GSHP runs entirely from electricity generated by the digester, which is fuelled by agricultural waste.

After careful consideration, it was determined that the continuous heat loss from the pipe linking the GSHP to the primary residence could be balanced out by the probable expense of fitting a high-voltage connection and the accompanying transformers.

The outhouse is next to a fishing pond, but the water is not used as a heat source. When a suitable body of water is available, installing a water source system instead of a ground source one reduces the amount of groundwork required. It is a quicker and cheaper installation process, and the system is easier to alter in the future. At Site 4, it is likely that the fishing pond was not thought to be large enough to supply energy to the whole house.

Left: Figure 28: GSHP outhouse.
Right: Figure 29: Ground collector field.

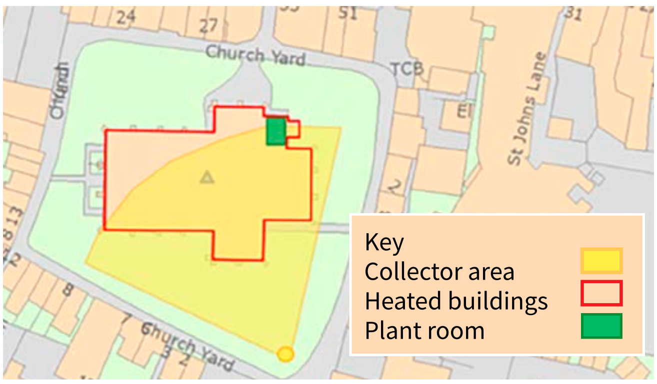
3.5 Site 5

Building history and overview

Site 5 is a Grade I listed church, located in Kent. The first record of a church on the site dates to 1086, and the oldest part of the current building is believed to date back to the 13th or 14th century. Over time, the church has been renovated and expanded on several occasions, including a significant extension in the 19th century. More recently, in 2010–11, the church underwent a thorough renovation, which included installing underfloor heating and a GSHP to increase the building's versatility for a broader range of activities.

Above: Figure 30: Site 5.

Right: Figure 31: A map of the church site, showing the location of the buildings heated by the GSHP, the plant room where the GSHP is located and the approximate location of the heat collectors.



Heating system

The church has installed a Dimplex GSHP that is connected to wet radiators in the side rooms, chancel, galleries and vestry. Additionally, underfloor heating is used in the main sanctuary, entrance hall and ground-floor toilets. To ensure uninterrupted heating, a back-up gas boiler is also connected to the system.

Right: Figure 32: The Dimplex GSHP in the basement plant room at Site 5.

Summary

Property type	Church
Heat pump technology	Central borehole with angled radial closed loops
Installed heat pump capacity	24kW
Heat pump capacity/m^2	24W/m^2
Heating system	Underfloor heating and radiators
Hot water system	Direct electric calorifier
Use pattern	The church offers Sunday services and annually holds approximately 60 concerts and art exhibitions. Additionally, local schools use the space for various events, and other organisations use the front meeting room and kitchen for weekly meetings.

Technology choice	★★	Given the limited space and urban location of this site, borehole collectors are a good solution. By using radial boreholes, archaeological sites and graves are avoided while still providing sufficient collector capacity. A water source heat pump would not be viable at this site because the nearest water feature is approximately 400m away, and the church does not have ownership of the intervening land. ASHPs would have been a viable but more visible alternative. Two domestic 12kW ASHPs would be able to deliver the same heat output as the GSHP and would be small and quiet enough, given the size of the churchyard and the background noise of the urban location.
Thermal comfort	★☆	During the visit, the GSHP was not functioning. However, when it was working in the past, it provided a high level of thermal comfort. The heating was operated for extended periods to optimise the GSHP's efficiency and prevent any warm-up time issues with the underfloor heating. The gas boiler is currently being used instead of the GSHP, and it is turned on an hour before an event. This results in lower thermal comfort levels due to the slow response time of the underfloor heating.
System design/ installation quality	★☆	The GSHP heating system was designed well, with the gas boiler intended for back-up use only. Due to the location and dimensions of the plant room, the GSHP had to be disassembled when it was installed, which voided its warranty. This is believed to be the root cause of the problems the church is experiencing.

Internal GSHP observations

- A 24kW Dimplex SI 24TE GSHP has been installed.
- The GSHP uses R-404A refrigerant. The system has a refrigerant charge of 3.7kg.
- The GSHP is located under the vestry/green room in a basement plant room, away from public areas.
- The GSHP and heating system are not visible from any areas accessible to the public. However, hatches for the underfloor heating manifold can be seen on a raised dais used as an altar and stage.

- The basement plant room houses the GSHP, back-up gas boiler and an organ blower. The organ blower has to be disabled whenever anyone goes into the plant room (due to the noise levels), so accessing the heating system can be challenging. Despite this, the GSHP has undergone necessary maintenance.

- The GSHP is mounted on anti-vibration mats.

- The basement plant room has solid stone walls and ceiling, which effectively minimises sound transmission.

- As part of a larger upgrade to the church, a new electrical system was installed at the same time as the GSHP.

- All electrical cables have been routed tidily and appropriately.

External GSHP observations

- The GSHP uses a closed-loop borehole with radial loops as a collector system. The radial collector arms are spaced at angles between 2 to 20° away from each other and cover a minimal area on the surface.

- A central borehole was used to avoid disturbing archaeological layers and graves. Radial collector arms extend away from the borehole once it is deep enough to avoid any disruption.

- Only the borehole covers are visible. They do not stand out from the area around them, so there is very limited visual impact.

- Pipework appears to be well insulated. However, the plate heat exchanger in the plant room is not insulated, which will lead to significant heat loss.

Heating distribution system

- The church uses underfloor heating and radiators. The underfloor heating is designed to be heated by the GSHP, while the radiators are heated by the gas boiler. The boiler has more recently been connected to the underfloor heating system to allow all of the heating to be provided by gas, should the GSHP fail.

- While the output of the installed system is unknown, underfloor heating is used for the larger areas of the church and the downstairs entrance, toilet and meeting room. Meanwhile, the side rooms and raised galleries are fitted with large radiators.

- The heating system uses a 200l buffer vessel.

Environmental permits and surveys

- Since the collectors are closed loop, no environmental permits are needed.
- There have been no reported leaks from the ground loop.

User interview

- The GSHP installation was part of a larger renovation, which included installing an underfloor heating system, so significant disruption was already occurring.
- The GSHP had to be disassembled to fit into the plant room, which voided the manufacturer’s warranty. The client did not know that the warranty was void until they contacted the manufacturer about a fault. They regret that the installers did not inform them of this at the time.
- After the installation, there were high thermal comfort levels, and the running costs were considered reasonable. When the GSHP began to leak refrigerant and was not operational, the gas boiler was used more. To mitigate the increased running costs of the gas boiler, the heating is switched on for less time before an event, thus reducing overall thermal comfort.
- The building managers and users reported no issues with noise.
- There were no issues with the running costs of the GSHP. However, there are ongoing concerns with the cost of running the back-up boiler as the primary heating plant, maintenance and replacing the refrigerant.
- The building managers have a basic understanding of the heating system controls, which is enough to achieve what is required. Thermostats are only used to set an upper limit for the room temperature, and they are not regularly changed. The ‘party’ mode on the GSHP allows the room temperature to be raised for a fixed length of time and it has been used effectively for events.
- There have been issues with maintenance and dealing with leaking refrigerant. The contractor said they repaired the leak when they added more refrigerant, but the leak continued and more refrigerant was needed a couple of months later.

Discussion

Plant room access

The GSHP is installed in a basement plant room below the vestry. Although the room has enough space for the heat pump and all the necessary piping and heating system accessories, the access stairway is very narrow. The installer disassembled the GSHP on site and then reassembled the unit inside the plant room to make it fit. Unfortunately, this voided the manufacturer's warranty. The building owners were not informed of this beforehand.

When monobloc heat pumps are manufactured, they are assembled and tested as hermetically sealed units to prevent any refrigerant leaks. This is crucial for two reasons: to ensure the heat pump's optimal performance and reliability, and to prevent any harmful effects from refrigerant leaks. At Site 5, some refrigerant has leaked from the GSHP, so it now does not work correctly. While it is not certain that disassembling the GSHP caused this issue, it is likely to be a contributing factor. Refrigerant leaks will be covered in more detail in the next section.

To prevent a similar problem at Site 5 in the future, the plant room could be relocated to an additional extension or back room. Alternatively, the access route could be widened, or an alternative entry to the basement could be made available through a shaft or similar means.

Listed building consent was granted for an extension to an existing lean-to during the same project. In hindsight, an additional extension to the building may have been a more suitable location for the plant room, rather than the basement.

An alternative approach to the plant room access issue would be to look for multiple smaller GSHPs to meet the required output. Several smaller ASHPs may have been a viable alternative option given the urban location of the site and the size of the churchyard, especially if an acoustic enclosure were used.

Refrigerant leaks

There are two reasons why losing refrigerants from a GSHP is detrimental:

1. Heat pumps operate by utilising a refrigeration cycle. GSHPs extract ambient heat from the ground to the collector, which heats the refrigerant. This heat is subsequently transferred to the heating system. However, if there is low refrigeration pressure, often caused by insufficient refrigerant, the GSHP will function inefficiently or cease to work altogether.

2. Most refrigerants, especially older ones, have a high GWP. This means they will greatly impact global warming when released into the atmosphere. The GSHP at Site 5 uses R-404A, which has a GWP of 3922. This means the recorded 0.8kg of refrigerant leaked during one maintenance visit will be the equivalent of 3,138kg of CO_2 released into the atmosphere. This could negate any operational CO_2 reductions the building has achieved from switching from a gas boiler to a GSHP.

During the site visit, no leak detection devices were noticed (but the door to the plant room did have mesh openings to allow for additional ventilation). The F-gas regulations do not require automatic leak detection for an R-404A system of this size, but yearly leak tests are required. The GSHP has been out of operation due to leaks that multiple contractors have been unable to fix. This has led to increased expenses for replacing the lost refrigerant. As the refrigerant in question approaches its phased-out date, prices are likely to increase even more.

Newer GSHPs have refrigerants with lower GWPs. Some can operate on natural refrigerants, such as R-290 and R-744, which both have a low GWP. R-744 has a GWP of 1. Although these natural refrigerants are now widely used with ASHPs, they are yet to be introduced into the mainstream GSHP market. Natural refrigerants also have additional technical challenges. R-290 (propane) is highly flammable, and R-744 (CO_2) has unique properties that make it challenging to install into an existing heating system. R-744 heat pumps are generally more expensive per kW compared to other refrigerants.

The current expected lifetime for a GSHP unit is around 20 to 25 years. As the GSHP at Site 5 was commissioned in 2010, it could be approaching the end of its expected life, even without the leaks.

Thermal comfort and run time

When the GSHP was installed, the heating system was programmed to run for extended periods, using setback temperatures (a lower internal set point temperature) rather than switching the system on and off. This benefited the lower temperature output of the GSHP and the longer response time of the underfloor heating. During this time, high levels of thermal comfort were reported from those attending church services and other events. The GSHP's efficiency allowed the church to maintain a comfortable temperature while keeping running costs reasonable.

When the GSHP was not working after a refrigerant leak and the back-up gas boiler was being used, thermal comfort was reported to be lower. This was partly due to the heating being on for less time to reduce running costs. However, the concerns about running costs may be unfounded due to the price difference between gas and electricity. Turning the heating on an hour before an event does not provide enough time for the underfloor heating system to warm up sufficiently to provide adequate thermal comfort.

Heat collector

The collection area at the church was limited by its location in the middle of town and the presence of a graveyard and significant archaeological artefacts within the church grounds. To overcome this, radial boreholes were used. Instead of drilling multiple vertical boreholes for each loop of collectors, a single borehole was drilled with smaller radial boreholes branching out once it had passed below any graves or significant layers, as shown in Figure 33 and 34.

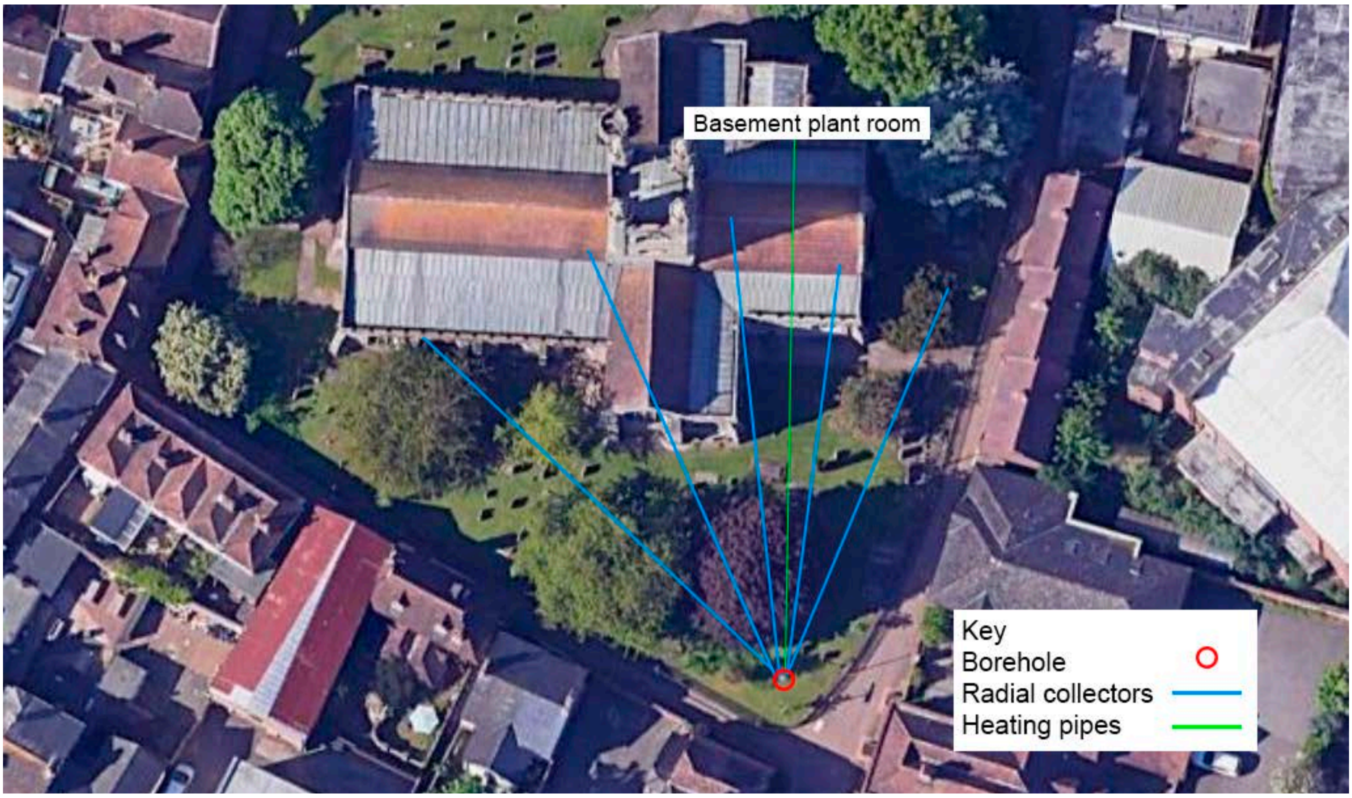


Figure 33: A satellite view of Site 5, showing the location of the vertical borehole and example locations of the collector loops. Google maps: Imagery © Maxar Technologies, Map data © 2025. Annotations added by Historic England.

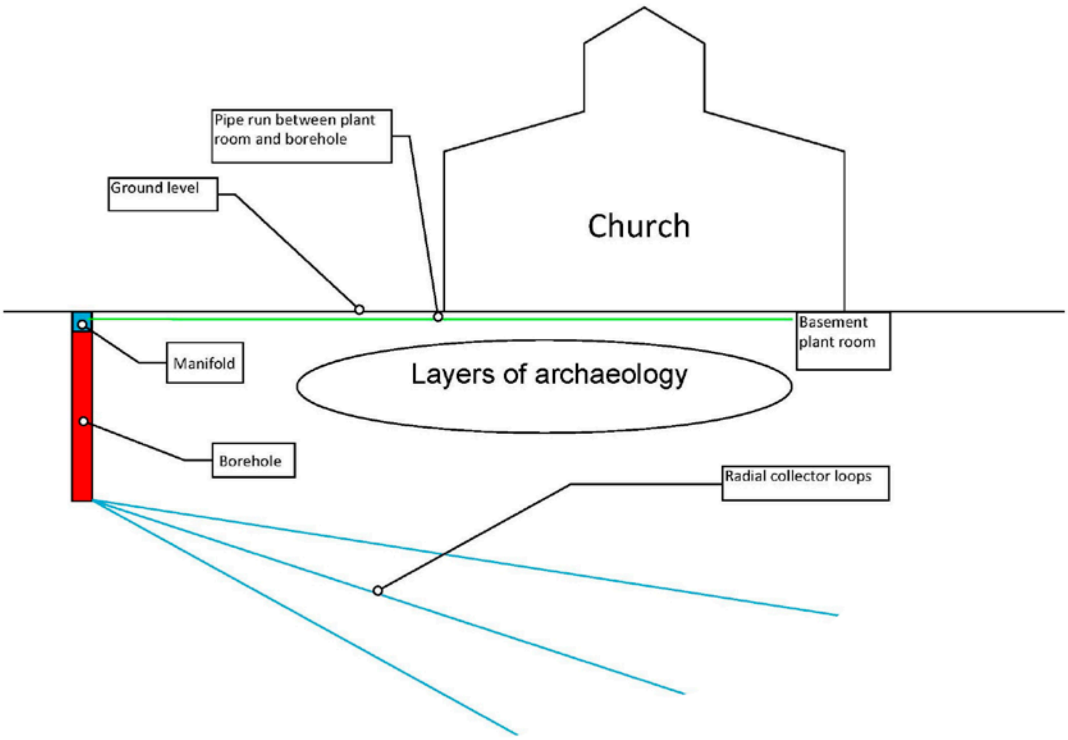


Figure 34: A section view of the church, showing the vertical borehole and the radial collectors avoiding archaeological layers.

This eliminated the need for deeper boreholes, and the maximum depth drilled on site was 50m. A manifold was installed at the top of the borehole, allowing for control and isolation of the loops when necessary. Placing the collector loops at various angles around a 360° arc, and at various angles of elevation, allowed for greater space between the loops. This reduces the risk of the collectors cooling each other and, therefore, reducing the efficiency of the collector circuit.

The system at Site 5 is an efficient and effective solution for collecting heat in a limited space. However, it requires more specialised equipment (a remotely operated boring rig) than a horizontal trench collector (installed with an excavator) or conventional vertical borehole collector. The costs are likely to be higher, and there may be fewer contractors available to do the groundwork, compared to alternative collector types.

Underfloor heating

Installing the GSHP at this site was part of a larger church project that involved installing underfloor heating and replacing the pews with flexible seating. The aim was for the church to be used for a wider variety of roles, including as a performance space and gallery. Underfloor heating was chosen partly to help maintain the efficiency of the GSHP, and partly to allow for flexible use of floor space.

The project was subject to an archaeological investigation, as part of the below-ground works at a historic site. Care was also taken while designing and installing the underfloor heating system to avoid damaging anything of archaeological significance.

Underfloor heating commonly operates at a lower temperature than radiators, with the maximum temperature allowed often determined by the required floor surface temperature. This is affected by the type of floor above the system or the room that is being heated. The BSRIA BG 4/2011 underfloor heating and cooling guide provides some recommended maximum floor temperatures, to minimise the risk of damage. For wooden floors, the recommended floor temperature is 27°C. For stone or tile floors in general areas, the recommended floor temperature is 29°C. The floor temperature will be affected by the spacing between pipes in the underfloor heating system and the flow temperature through them.

The GSHP at Site 5 is connected to the underfloor heating system, with a gas boiler able to connect to the system as a back-up. The underfloor heating system was designed to use the lower flow temperatures of the GSHP. To ensure the maximum temperature for the underfloor heating system is not exceeded, the flow temperature needs to be reduced. As the boiler is still required to supply the radiators on site, the flow temperature from the boiler cannot be reduced. Mixing manifolds have been used to reduce the hotter flow temperature of the boiler to one that can be used in the underfloor heating – by mixing the flow with the return. This has allowed the boiler to be successfully used as a back-up to the GSHP without compromising the designed efficiency of the system or risking damage to the floor.

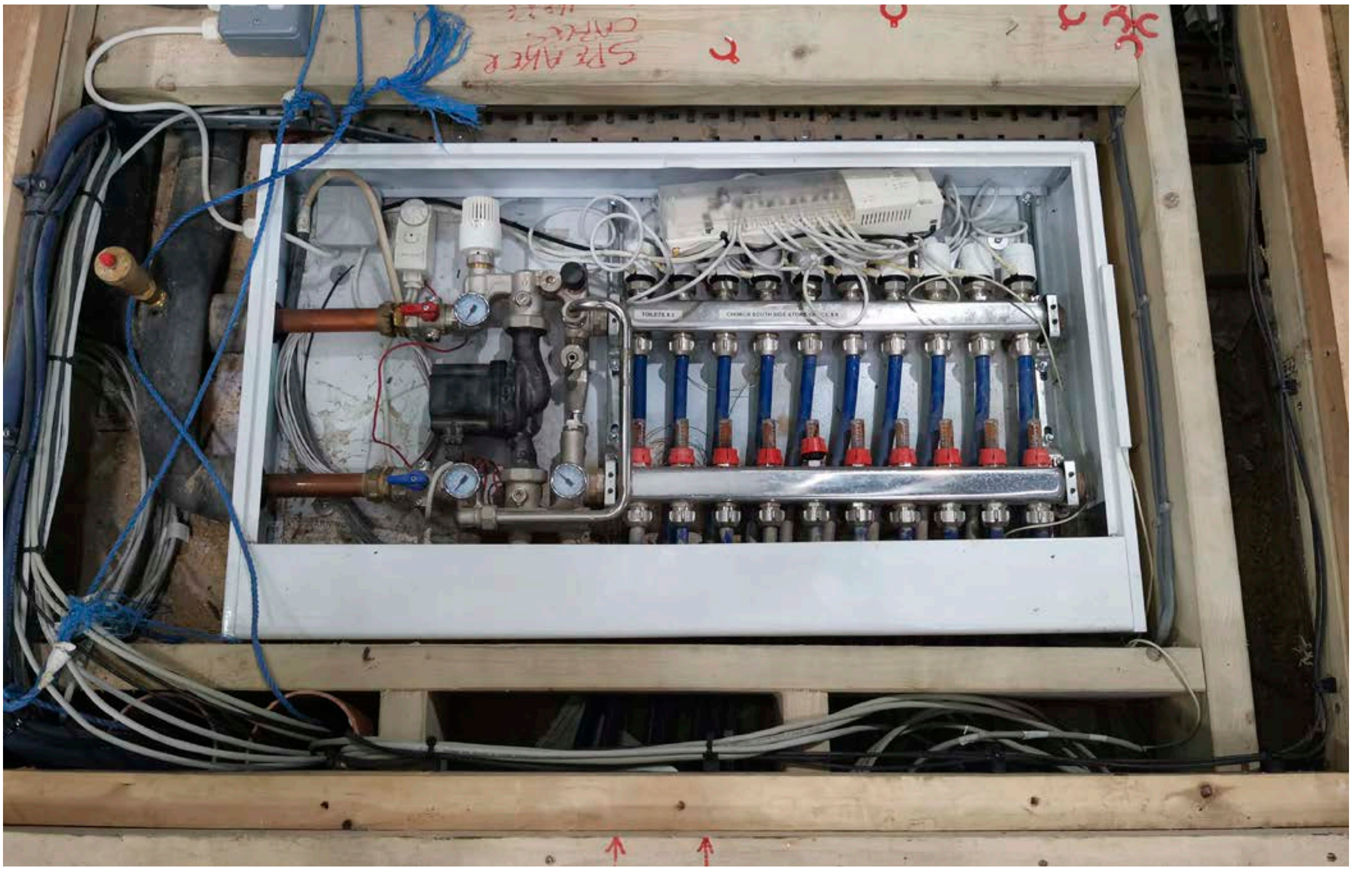


Figure 35: One of the underfloor heating manifolds at Site 5.

4. Conclusion

The five case studies show that closed-loop GSHPs are, in fact, viable and necessary in historic buildings. They are providing a path to decarbonisation that is available right now. The various sites have been able to successfully use GSHPs for conservation heating, comfort heating, domestic hot water or a combination of all three. Existing radiators have also been successfully reused within heating systems using GSHPs for conservation heating.

The initial groundwork needed to install the ground collectors for the GSHPs can be disruptive and have a significant visual impact on the surrounding area. After the ground has been allowed to settle, the visual impact from the external work is not noticeable. There are only manhole covers for boreholes and manifold chambers visible, and these generally go unnoticed by staff and visitors.

Manifold chambers appeared to be well sized for access and maintenance, with adequate light and drainage. Two sites used trenched heat collectors, while the remainder used boreholes. In some cases, the heat collector was located further away from the GSHPs to avoid disturbing areas of historic or visual significance. Some of the sites were in urban locations with limited available land. In these cases, radial boreholes were used, allowing for a larger collector while minimising archaeological disruption.

The components of a GSHP that create noise are the pumps and compressors, located within the heat pump housing. GSHPs are generally installed in a plant room, and noise reduction measures are, therefore, more readily available than they are for ASHPs, which are located outside. GSHPs have similar noise levels to other heating system components, such as large circulation pumps. Acoustics should be considered, but may not require any more attention than those of a fossil fuel system.

Issues reported were often not a direct impact of the GSHPs themselves, but were usually caused by the design of the heating system or by the limitations imposed by control systems. Each site made use of buffer vessels, and in some cases the buffer vessel arrangement may have been limiting system performance. Buffer vessels must be designed carefully to keep return temperatures to the GSHP at a minimum.

Every site reported finding it difficult to find qualified and competent contractors to perform maintenance and optimisation on GSHP systems. This often led to suboptimal heating system performance and low efficiencies – and, in one case, premature equipment failure. Employing contractors with knowledge of working in heritage buildings and with conservation heating systems is advised for historic buildings.

Alternative refrigerants such as CO_2 are becoming more common. They can be of particular use when heating historic buildings for thermal comfort due to the higher flow temperatures available. However, CO_2 GSHPs require a different system design for good efficiency and operation, and this will need careful consideration.

5. Endnotes

[1] Blades, N, Lithgow, K, Staniforth, S and Hayes, B 2018 ‘Conservation heating 24 years on’. Studies in Conservation, 63 (1), 15–21

[2] Green, R 2012 The Effects of Cycling on Heat Pump Performance. EA Technology for the Department of Energy and Climate Change (DECC), Project No: 46640

6. Acknowledgements

Contributors

The authors would like to thank the landlords and tenants for allowing the heating systems in their buildings to be appraised publicly, and for contributing their valuable time. Their willingness to participate is testimony to their determination to drive forward the process of decarbonising heat in the UK's building stock.

Images

Max Fordham LLP for Historic England

Google Maps

Clade Engineering

7. Where to get advice

Contact Historic England

East of England
Brooklands
24 Brooklands Avenue
Cambridge CB2 8BU
Tel: 01223 582749
Email: eastofengland@HistoricEngland.org.uk

Fort Cumberland
Fort Cumberland Road
Eastney
Portsmouth PO4 9LD
Tel: 023 9285 6704
Email: fort.cumberland@HistoricEngland.org.uk

London and South East
4th Floor, Cannon Bridge House
25 Dowgate Hill
London EC4R 2YA
Tel: 0207 973 3700
Email: londonseast@HistoricEngland.org.uk

Midlands
The Foundry
82 Granville Street
Birmingham B1 2LH
Tel: 0121 625 6888
Email:
midlands@HistoricEngland.org.uk

North East and Yorkshire
Bessie Surtees House
41-44 Sandhill
Newcastle Upon Tyne NE1 3JF
Tel: 0191 269 1255
Email: northeast@HistoricEngland.org.uk

37 Tanner Row
York YO1 6WP
Tel: 01904 601948
Email: yorkshire@HistoricEngland.org.uk

North West
3rd Floor, Canada House
3 Chepstow Street
Manchester M1 5FW
Tel: 0161 242 1416
Email: northwest@HistoricEngland.org.uk

South West
Fermentation North (1st Floor)
Finzels Reach, Hawkins Lane
Bristol BS1 6JQ
Tel: 0117 975 1308
Email: southwest@HistoricEngland.org.uk

Swindon
The Engine House
Fire Fly Avenue
Swindon SN2 2EH
Tel: 01793 445050
Email: swindon@HistoricEngland.org.uk

We are the public body that helps people care for, enjoy and celebrate England's spectacular historic environment.

Please contact guidance@HistoricEngland.org.uk with any questions about this document.

HistoricEngland.org.uk

If you would like this document in a different format, please contact our customer services department on:

Tel: 0370 333 0607
Email: customers@HistoricEngland.org.uk

All information and weblinks accurate at the time of publication.

Please consider the environment before printing this document

HEAG327
Publication date: v1.0
September 2025
Design: Historic England