Heat Pumps in Historic Buildings

The Viability of Water 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. Water source heat pump (WSHP) technology can be deployed discreetly without altering a site's appearance, and it delivers excellent efficiency. It is, therefore, a key technology in the decarbonisation of 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 WSHP 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 WSHPs. The users' perceptions of running costs are reported, but the information is highly subjective according to each individual's expectations.

The authors would like to thank the site organisations 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.

Front cover: The location of one of the case studies investigated.

The key findings were:

- Closed-loop WSHPs are a viable and readily available option for discreetly decarbonising heating systems in historic buildings.
- When used for conservation heating, WSHPs can operate efficiently with existing radiators and pipework.
- Many historic stately homes are located close to a body of water, because this would have been a priority when they were built. WSHPs are, therefore, particularly suited to these buildings. When a body of water is available nearby, a WSHP system can be a more discreet solution than an air source heat pump (ASHP) system and a more straightforward installation than a ground source heat pump (GSHP) system.
- Issues with a heating system's performance are often due to its configuration, not the WSHP itself. The open-loop system at Site 2 was the only one that experienced significant difficulties extracting heat from the source.
- Closed-loop WSHPs have similar noise levels to other heating system components, such as large circulation pumps. They are installed inside a housing in a plant room, and noise reduction measures are, therefore, more readily available than they are for outdoor 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 WSHP system.
- The availability of skilled maintenance and installation contractors was an issue at a number of the sites.
- Safe and effective maintenance options and a good understanding of the water source are essential when designing an open-loop WSHP system.

This document has been prepared by Max Fordham LLP and Dan McNaughton, Senior Building Services Engineer at Historic England.

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1. Introduction

This report aims to identify examples of best practices 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 WSHPs in historic buildings.

Data were gathered from five WSHP installations across the UK:

- Site 1, Somerset
- Site 2, Cambridgeshire
- Site 3, Warwickshire
- Site 4, North Yorkshire
- Site 5, Norfolk

The first half of this report summarises the key findings across 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 this 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 WSHPs were evaluated at each site to assess their efficacy. The building services engineers considered:

- visual appearance
- noise impact
- electrical design
- generic information about the WSHPs
- 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 WSHP
- measuring the distance from the WSHP to the closest noise-sensitive location
- taking thermal images of the WSHP
- checking for the presence and quality of key installation components, such as anti-vibration mounts and pipework insulation
- measuring radiator and pipe sizes
- determining the location of the water collector and manifold chambers and understanding the installation process.

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

- Have you found the building comfortable since the WSHP was installed?
- How have you found the noise levels coming from the WSHP?
- 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 WSHP?

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 WSHPs 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 WSHP 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 quantity of heating required. The key objective is to prevent sharp swings in RH as this is what leads to damage of fabric and contents.

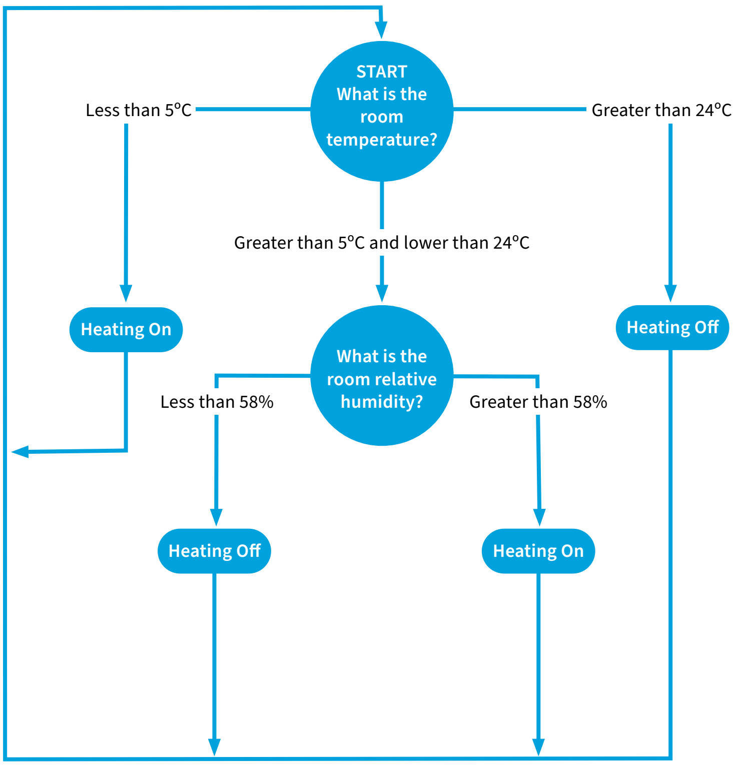


Figure 2: An example control strategy for a conservation heating system.

At each site that used conservation heating, the existing heat emitters from the previous fossil fuel system were reused. A WSHP typically operates at a much lower flow temperature than an oil or gas boiler (~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.

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 WSHP 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, a heat pump system would need to run 2.2 times more water through the pipes. This 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 to a 5°C 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 WSHP flow temperatures. The low flow temperatures of a WSHP are also helpful for ensuring slower changes in the internal conditions. Rapid swings of internal temperature and relative humidity can increase the stress on the historic fabric and contents of a building, leading to damage. Many historic buildings will likely have existing radiators that can be used as part of a WSHP conservation heating system. This should be verified by a suitably qualified building services engineer.

Heading for conservation and comfort

A heating system designed for thermal comfort may require different flow temperatures and/or larger 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, until the internal temperature exceeds the set limit. If a single WSHP is used for both conservation and comfort heating, 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 WSHP may exceed the heating demand). This increases the wear on the compressor which will reduce the expected life of the WSHP. It also means the WSHP operates longer in its inefficient start-up phase than in its optimum steady-state phase. Using separate WSHPs 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 WSHP 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 WSHP, with a separate branch for each heating system. One advantage is the lower capital cost of the initial plant installation. However, energy costs may be higher because a WSHP 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 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.

Open loop vs closed loop

A WSHP extracts heat from a body of water, such as a river, lake, sea or canal. The system can be configured as open loop or closed loop, as shown in Figure 3. In an open-loop system, water is extracted from a source, passed through a heat exchanger and returned to the source. In a closed-loop system, the heat exchanger is submerged in the water source, usually as a thermal transfer fluid pipe or ‘brine’ loop. No water from the source enters the system.

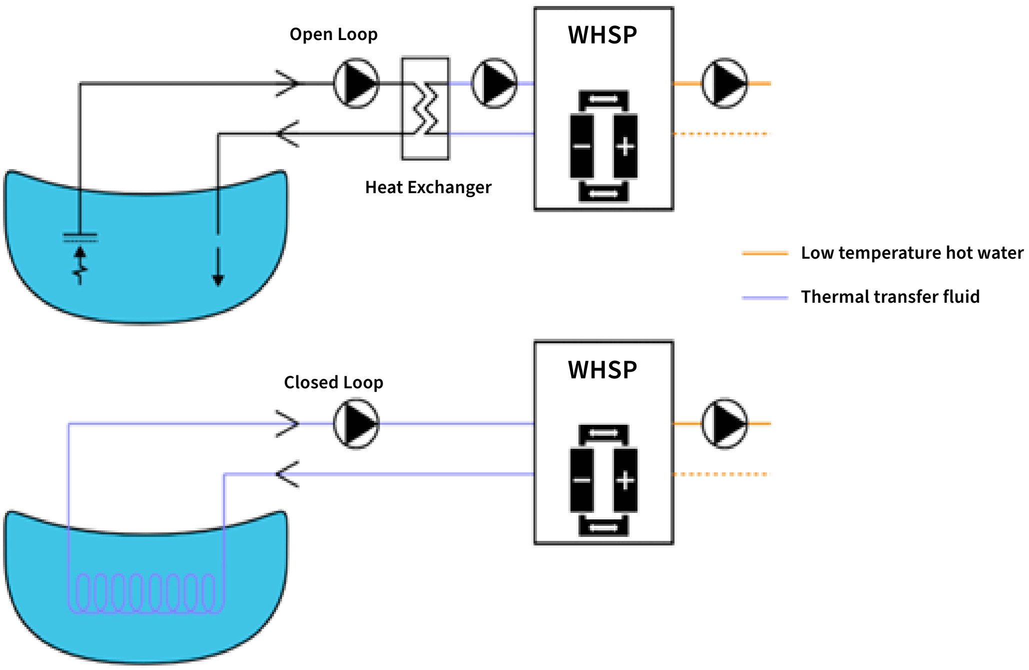


Figure 3: Open loop and closed loop systems.

Provided there is suitable volume and flow, a smaller body of water can be used for an open-loop system because it does not have to accommodate the large lengths of pipe coil used in a closed-loop system. The installation process is also simpler.

Open loop WSHPs achieve higher coefficients of performance (COPs) than closed loop WSHPs by directly passing source water through the heat exchanger. Closed loop systems collect the heat from the water source by submerging the heat exchanger in the body of water. COPs are a measure of the WSHP efficiency. However, with closed loop systems, the water source must stay above 3–4°C at all times. Otherwise, there is a risk of the water freezing and damaging the heat exchanger. If the surface water temperature drops below 5°C, which can happen during winter, an alternative heat source will be needed. However, this secondary source may not be as efficient and may compromise the benefits of an open loop system.

In a closed loop system, the heat exchanger normally contains a brine solution with an antifreeze agent. The WSHP can operate at a lower source temperature than in an open-loop system.

A further challenge with an open loop system is that filtering is required to protect the heat exchanger. All water sources contain suspended debris and fine particles, and these must be filtered so the heat exchanger does not become blocked. These filters need regular maintenance and will eventually stop the system from operating altogether if they are not properly cleaned. A closed loop system does not require a filter.

An open loop system will require an abstraction licence from the relevant body: in England, this is often the Environment Agency. This licence limits the quantity of water that can be abstracted and the permitted temperature change in the water (see Site 2). A typical abstraction license will last for twelve years and require metering of the abstracted water and annual reporting to the Environment Agency.

Across the five sites, four had a closed loop system, and one had an open loop system. The four closed loop sites reported that the collectors were virtually maintenance free. Site 2, experienced significant issues with the open loop collector: specifically, keeping the filters clean and unblocked. As a result, the owners considered converting to a closed loop system to reduce the ongoing maintenance burden. This wasn't possible and a revised filtration system is planned to be designed.

We cannot dismiss open loop systems based on only one example. However, the Site 2 case study highlights how system maintenance must be factored into the design to ensure trouble free operation.

For a very large output system, the size of the collector in a closed loop system would be prohibitive in terms of cost and the required area. An open-loop system may be more appropriate in this case.

WSHPs are generally more efficient than GSHPs and ASHPs because of better heat transfer in water. Additionally, water temperatures remain relatively stable throughout the year, averaging between 7 and 12°C. This temperature is higher than the average air and ground temperature during winter.

Collector leaks

The pipes used for the heat collectors at the five case study sites have an expected lifespan of 50 to 70 years. None of the sites reported any issues related to leaks from the collectors. There is minimal boat traffic and other potentially damaging activities across all sites, so the likelihood of future damage remains low.

To minimise the risk and impacts of leaks, the 'Surface water source heat pumps: Code of Practice for the UK', published by CIBSE in 2016, recommends certain measures:

- protecting the heat collector loops from physical damage
- regularly inspecting the collectors, with the inspection frequency tailored to the characteristics of the specific water source.

Furthermore, the design of the collector loop can be instrumental in mitigating the risk of leaks. One option is to incorporate constant pressure monitoring to promptly identify any signs of a leak. However, an automatic top-up system is not recommended for a closed-loop heat collector, because it may mask leaks and lead to significant damage to the environment or the heat pump system.

At sites with larger heat collectors, the use of manifolds will be beneficial. Manifolds enable multiple loops to be used for heat collection, and in the event of a leak, the affected loop can be isolated while the remaining ones continue to operate.

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.

2.2 Domestic hot water systems

There are several methods to transfer heat from a WSHP to the water in a hot water storage cylinder. Two common types, coil and plate heat exchanger (PHX) are shown in Figure 4. When deciding on the best option, it is important to consider the specific characteristics of the WSHP, the required recovery time and storage utilisation (the amount of hot water storage that a particular building requires).

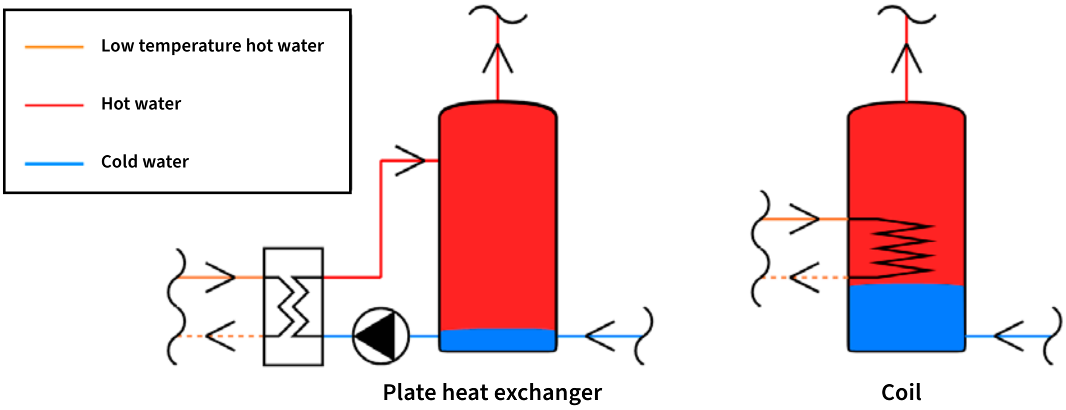


Figure 4: Domestic hot water cylinder configurations .

A coil-fed storage cylinder is often used because it is cheaper and more compact than having a separate plate 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 times. A properly sized plate heat exchanger can use the full heat output of a WSHP, 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 may 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.

2.3 Visual impact

For a historic building or landscape, the visual impact of any works will be of particular concern. At all five case study sites, some form of external groundwork was required. Pipes were run between the plant room and the heat collector, often via a manifold chamber located close to the water source. However, during the site visits, it was difficult to spot where the groundwork had taken place, and closed loop heat collectors were only visible upon close inspection at the water's edge, as shown in Figure 5.

Figure 5: The closed loop collector.

Often, the only visible signs were the covers for the access hatches to the manifolds. These covers would probably go unnoticed by the public, but the visiting engineers were actively seeking signs of groundwork and often knew where to look. The site with an open loop system had a pump submerged in the water source, which could be seen and heard. However, the visual impact had been somewhat mitigated by locating the assembly underneath a bridge.

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.

Disruption was minimised at some sites by installing the WSHP as part of a larger renovation project.

At some sites, pipework had to be run underneath historic walls, which required listed building consent.

2.4 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 WSHPs 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 WSHP lacked experience and training in heat pumps or working on heritage buildings. It appears that some of the issues encountered could be attributed to the fact that the contractor had inadequate experience and training in installing, optimising and maintaining WSHPs. These include refrigerant leaking from the WSHP, issues with achieving the desired efficiency or 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 that have 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 WSHP efficiency.

2.5 Buffer vessels

Buffer vessels are an important part of a WSHP 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 WSHP 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.

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 WSHP at all. They can also be useful for storing energy to be used for instant domestic hot water. Unlike ASHPs, WSHPs 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 WSHP capacities often had multiple buffer vessels

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

Site	Installed WSHP capacity (kW)	Buffer vessel size (l)	Buffer volume per kW of WSHP capacity (l/kW)
Site 1: Bishop's Palace	20	200	10.0
Site 2: historic house	170	600	3.5
Site 2: cottage	34	300	8.8
Site 3: historic house	75	10 00	13.3
Site 3: offices and flats	60	500	8.3
Site 4: historic house	288	1000	3.5
Site 5: historic house	205	1000	4.9

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 WSHP 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 WSHP and the general heating circuits. The main advantage of this is that the water flow rate through the WSHP is separate from the flow through the general heating distribution circuits, ensuring the minimum flow through the WSHP 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 heating circuits than that generated at the WSHP.

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 WSHP 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 WSHP.

This is discussed further in Site 3.

2.6 Heat pump capacity

The size of the WSHP varied from site to site, depending on the area to be heated, the level of thermal insulation and whether the WSHP was used for conservation heating, thermal comfort, domestic hot water or a combination of all three.

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

Site	Heating type	Installed WSHP capacity (kW)	Capacity per unit area (W/m^2)
Site 1: Bishop’s Palace	Comfort	20	46
Site 2: cottage	Comfort	34	114
Site 2: historic house	Conservation	170	72
Site 3: offices and flats	Comfort	60	85
Site 3: historic house	Conservation	75	65
Site 4: historic house	Comfort	288	97
Site 5: historic house	Conservation and comfort	205	50

The case study buildings range from a medieval hall to a modern visitor's cafe, and the WSHPs have different uses across the five sites. It is, therefore, difficult to establish a trend for installed capacity. Correct sizing of a WSHP is critical for the success of a heating system. If the WSHP is too large, this will lead to cycling, system efficiency will be reduced, and running costs increased. If the WSHP is too small, it will not be able to meet the heat load or will have to produce higher flow temperatures. The latter would reduce its efficiency.

2.7 Refrigerants

The type of refrigerant that a WSHP 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 WSHP 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 carbon dioxide, 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: Common 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 WSHP 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 WSHP 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 WSHP 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 WSHP with a low GWP refrigerant is essential for minimising the system's emissions. Figure 6 shows the full leakage emissions and system output for each of the WSHPs in the 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.

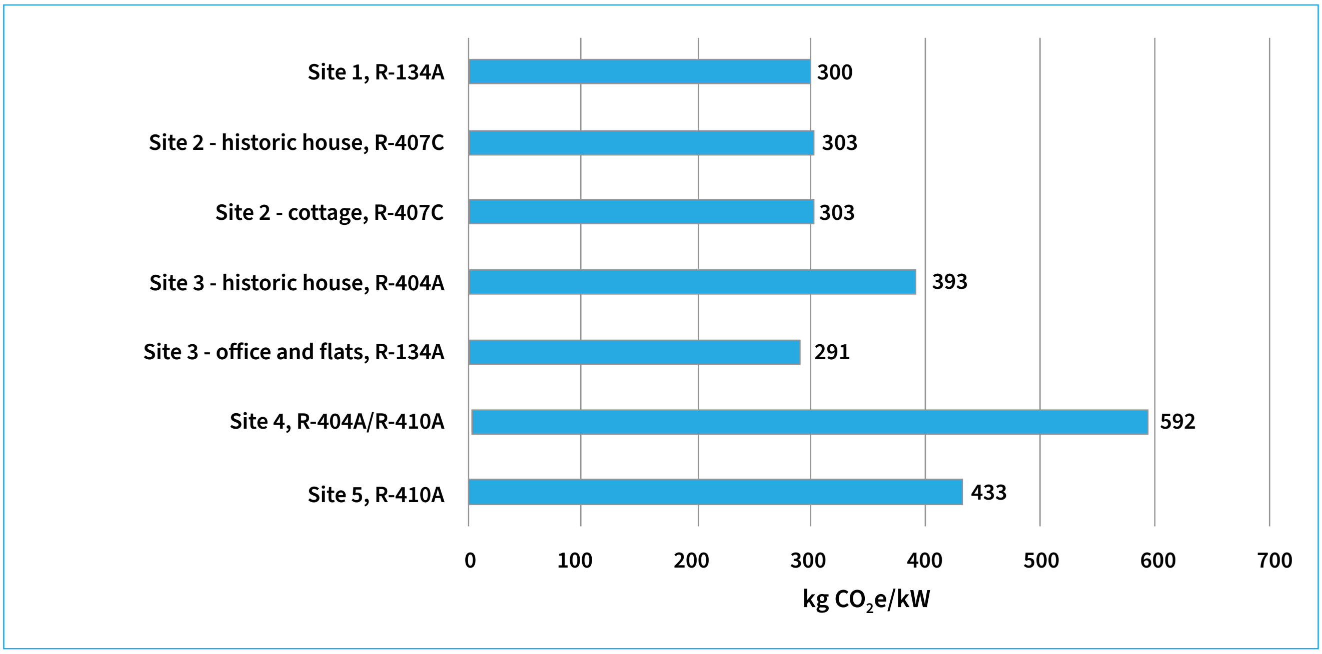


Figure 6: Total refrigerant leakage emissions per kW of installed system output.

System designers should select a low GWP refrigerant WSHP 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 a R-410A WSHP that develops a leak 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 widely used in ASHPs, and has recently started to be used in a limited number of WSHPs.

The choice of refrigerant has a significant effect on the temperatures at which a WSHP can efficiently operate. CO_2 heat pumps can produce high temperature water (~70°C) far more efficiently than conventional heat pumps. Additionally, they require a low return temperature (~30°C) for efficient operation, meaning a high 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 heat pump 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 heat pump, but this may not be the case for other low temperature heat pumps. Using existing pipework can deliver significant cost savings, but CO_2 heat pumps are typically bespoke, so capital costs will be higher. And the low return temperatures that CO_2 heat pumps require are not straightforward to achieve.

A monobloc WSHP typically uses less refrigerant than a direct expansion (air to air) system. The design of a monobloc WSHP 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 WSHP being used.

2.8 Building fabric improvements

There is a common perception that WSHPs do not produce enough heat for older buildings, and so are only viable in new buildings. The sites visited for this report show this is not the case. WSHPs were found to be successfully providing thermal comfort heating and conservation heating to historic buildings 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 WSHP installation, nor were they carried out to improve the energy efficiency of the building. However, they 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 a 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 WSHP, depending on the heating system. Most WSHPs 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 WSHP 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 temperature.

2.9 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.

WSHPs 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 historical fabric and artefacts from damage. This means 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.

When an environmental monitoring system sends a 'heating on' signal, the onboard WSHP 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 that do not have weather-compensated control . Without weather compensation, whenever the environmental monitoring system calls for heat, the boiler supplies circa 80°C water 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 WSHP will provide water at the lowest possible temperature to meet the heat loss. 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 WSHP controller. With only a 'heating on/off' signal from the environmental control system, the WSHP controller is unaware of how close or far away it is from the required setpoint. If the WSHP controller has 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.

It was observed that multiple sites would have benefited from impro ved 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 WSHPs and heating zones will require more complex controls than those with one WSHP and a single branch.

Controlling multiple heat pumps

Lead heat pump rotation

When using multiple WSHPs, 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 WSHP will be the first to be activated. After a set period of time or run hours, another WSHP takes on the lead role. This helps to ensure that all WSHPs have similar run times.

System optimisation

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

A fixed-speed WSHP 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 WSHP to operate for long periods in its optimal steady-state phase. To provide the right amount of heating, the WSHP 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 WSHP is more expensive due to its additional internal components and controls. An inverter allows the electrical signal to the WSHP compressor to be adjusted, and so operate at lower speeds. The WSHP can then modulate its output to match the heat demand, typically down to 30 per cent of its stated maximum.

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

Running multiple WSHPs 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.

2.10 System design

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

The first has separate WSHPs and heating systems for conservation heating and comfort heating areas. The systems share a collector loop. This approach has the advantage of optimising the WSHP for each application, but heat cannot be shared or act as a back-up to different zones. This system is used at Site 3

The second option is to use one or more WSHPs to heat the conservation heating and comfort heating areas through separate heating system branches. Careful consideration should be given to sizing the WSHPs for two different heat profiles. If the WSHPs are undersized or oversized, it can lead to cycling, reduced efficiency or inability to meet demand. However, installing multiple WSHPs in this configuration increases redundancy in the design (a level of resilience in the event of one WSHP not working), as seen at Site 5.

The trade-off between capital and running costs should be considered when designing the system.

3. Case Studies

The following section discusses each site in detail. The WSHP 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 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

This site is a medieval Bishop's Palace first given a permit for construction in the early 13th century. Since then, multiple extensions and additional buildings have been added to the site, including a chapel, great hall, ramparts and moat.

Outbuildings at Site 1 are currently used as an office, plant room for the WSHP, visitor toilets and learning centre. A cafe was constructed in 2012, at the same time as the WSHP was installed. The cafe and visitor toilets are open all year round throughout the week, and the office is occupied during normal working hours.

The WSHP only heats the outbuildings of Site 1. The main palace building, chapel and great hall are not included in this case study.

Figure 7: Site 1, Somerset.

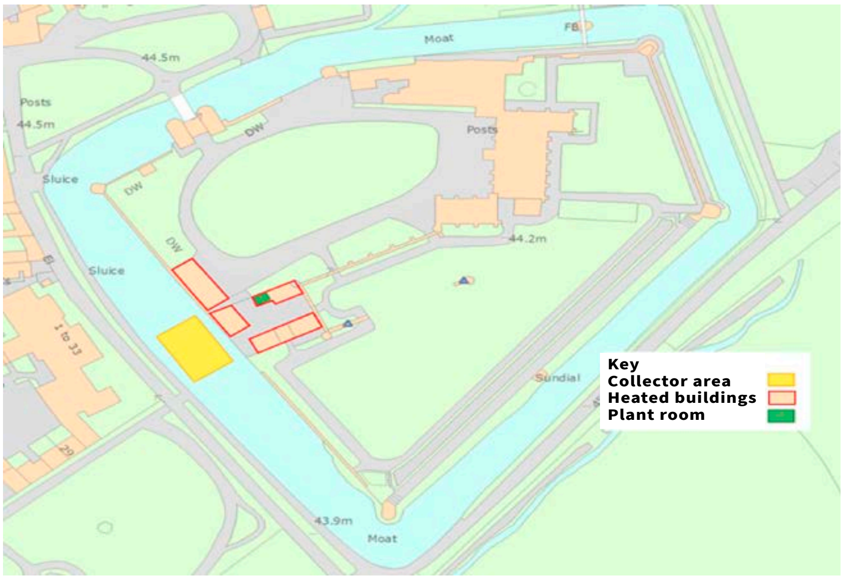


Figure 8: A map of Site 1, showing the location of the buildings heated by the WSHP, the WSHP plant room and the approximate location of the heat collector. © Historic England

Heating system

Site 1 uses a 20kW WSHP to heat the outbuildings. A closed-loop collector placed within the moat on a sunken platform provides the heat source. Underfloor heating is used to heat the toilets, learning centre and cafe, while radiators heat the office.

Photovoltaic panels have been installed on the roof of a newer building , which will produce electricity to run the WSHP and other electrical appliances, thus reducing running costs and the site's CO_2 emissions.

Figure 9: The cafe (left) and learning centre and toilet block (right), heated by the WSHP.

Summary

Property type	Bishop's Palace
Heat pump technology	Dimplex SIH 20TE, with a closed loop collector
Installed heat pump capacity	20kW
Heat pump capacity/m²	46W/m²
Heating system	Underfloor heating in the toilets, learning centre and cafe, with radiators used for the office space
Hot water system	WSHP provides domestic hot water, supplemented by an electric immersion heater in the hot water cylinder
Use pattern	Main site open to visitors all year round
Technology choice	★★ This site has a great advantage in terms of its location because it can use the constant heat source from the moat. Moreover, the unique hydrogeological features of the site ensure a steady moat temperature throughout the year, making it a perfect fit for a WSHP.
Thermal comfort	★☆ A high or appropriate level of thermal comfort in the cafe, office and toilets was reported. There have been some complaints about being cold in the learning centre. The front portion of the learning centre's facade is mainly floor-to-ceiling glass. As a result, it is difficult to heat this building.
System design/ installation quality	★☆ It appears that the system is well designed and has been installed to a high quality. A low COP has been recorded, and the reason for this is unknown.

Internal WSHP observations

- One 20kW WSHP has been installed, with an unknown collector capacity.
- The WSHP uses R-134A, which has a GWP of 1430. The system has a refrigerant charge of 4.2kg.
- The WSHP shows no signs of damage and appears to be well maintained. Some condensate is forming on the pipes containing brine that run to and from the collector.
- The WSHP is mounted on a rubber mat to prevent vibrations from affecting the plant room structure.
- The WSHP is in a dedicated plant room that adjoins the office and a busy visitor walkway. The walls are brick and stone, and single-glazed windows overlook the walkway. There have been no issues with noise.
- The site's electrical capacity was increased because the power kept tripping after the WSHP was installed. A new cafe was built and some outbuildings were renovated at the same time as the WSHP installation, and so the electrical capacity may have had to be increased regardless.

External WSHP observations

- The site has a closed-loop heat collector submerged in the surrounding moat and attached to the moat bed.
- The collector occupies approximately 3 per cent of the available moat area and is located close to the plant room.
- The installation has made no visual impact on the building. The collector is not visible from the moat's edge. The pipes between the collector and the WSHP run under the palace walls and are not visible. Permits from Historic England were needed for the work at this site.
- The collector was visible in the past when the moat was accidentally drained.

Heating distribution system

- Heating is provided by an underfloor heating system in the cafe, learning centre and toilets. The output of the underfloor heating system is unknown.
- The office is heated by wet single-panel radiators.
- The heating system uses a 200l buffer vessel to provide hydraulic separation between the primary and secondary circuits.
- A 500l domestic hot water cylinder has been installed to serve the toilets and cafe .

Environmental permits and surveys

- The site has a closed loop system, so no environmental permits were needed.
- No surveys were conducted.

User interview

- The WSHP installation coincided with other building projects, such as constructing an outbuilding for a cafe. This meant that any disturbance from the WSHP groundworks blended in with the overall construction activity.

- Consent was needed for the groundwork because the collector pipes pass under medieval walls on their way to the moat.
- No one has reported any issues with the temperature in the cafe, office or toilets. The cafe and office are specifically designed to offer comfort for those dressed in indoor clothing. The doors to the toilets are left open throughout the year, and individuals are expected to use them while wearing outdoor clothing.
- Users have reported that the learning centre can feel cold when it is used as an office space and people are sitting still at their desks. One reason for this could be the cold draughts coming from extensive glazed areas.
- The WSHP was programmed to provide space heating and domestic hot water in winter, and domestic hot water only in summer. The staff on site know how to adjust the output of the WSHP, but a very limited control system appears to have been fitted. A new energy monitoring system has been installed on site, to better monitor and control energy usage.
- The WSHP is not noisy because it is in a separate plant room. Even the public area closest to the plant room does not experience any noise.
- The user is currently exploring running costs with the help of an external metering company.
- Annual services are being carried out. However, the building managers are finding it difficult to employ contractors for maintenance and system improvements.

Discussion

Energy usage and COP

After the WSHP was installed, there was little monitoring of its energy usage and no way to determine the energy usage of different systems and different buildings in the palace complex.

The user responded to the rise in electricity costs by implementing an energy monitoring and management system, paired with an energy management contract. An energy management company was hired to evaluate the on-site energy produced by the photovoltaic arrays and to ensure optimal energy consumption.

According to the energy monitoring system, the WSHP was operating at a COP of 0.75. This shows the WSHP was consuming more energy than it was supplying to the heating system, which contradicts its intended function. Assuming the WSHP keeps a constant collector temperature of 10°C and all systems operate correctly, the minimum COP should be 3.0.

The company employed to optimise the energy consumption was able to alter the settings of the WSHP and improve the heating system's performance to achieve a COP of 2.5. This is still lower than expected. There are two primary causes for suboptimal WSHP performance: the WSHP is targeting a high flow temperature, or there is a large temperature difference across the flow and return for the WSHP. During the site visit, recorded flow and return temperatures were 30.3°C and 27.6°C, respectively, which suggests that temperature difference was not the reason for the suboptimal performance. The target return temperature on the WSHP was 37.0°C, which implies it had only just switched on when the temperature was recorded. The WSHP was also used to generate domestic hot water for the kitchen and toilets on site, with a target temperature of 48°C. This higher target temperature could have been the cause for the reduced performance, but it is not clear.

The site has a contract for the WSHP to be serviced annually, but is struggling to find specialist contractors to maintain the WSHP and further investigate its poor performance.

Funding

The project to install a WSHP included renovating the public toilets and learning centre and building a new cafe. The scheme was partly funded by a grant from the National Lottery Community Fund.

Some of the improvements were only possible because they were grant-aided, but this did disqualify the project from receiving funding from the non-domestic Renewable Heat Incentive (RHI) scheme. The RHI scheme is no longer available for new installations, however the Boiler Upgrade Scheme can fund £7500 towards a GSHP up to a maximum thermal capacity of 45kW. Installing heat pumps and renewable energy sources can reduce fuel and electricity bills, but they require capital expenditure. Grants are an excellent way to meet some of these capital costs.

Heat source

The WSHP relies on a moat as its heat source. The moat is highly suitable due to its temperature and location near the plant room.

The moat is especially advantageous because it receives fresh water from springs created by a river emerging from the ground. This constant water supply prevents the collectors from reducing the moat's temperature, which could decrease the WSHP's efficiency. The emerging river benefits from a constant temperature of 10°C throughout the year. As a result, it is not affected by the drop in temperature during winter and does not risk freezing.

Locating the collectors near the plant room helps to minimise the pipe lengths needed for installation. This reduces installation costs because less groundwork is required. It also reduces the embodied carbon of the installation because less material is needed. Minimising the length of pipe in which the brine circulates will reduce the energy required for pumping and, in turn, lead to lower running costs.

At this site, there is a sluice gate that controls the water level in the moat. Originally meant to prevent flooding, it can also be used to drain the moat, which was very helpful when the heat collectors were installed.

Figure 10: One of the springs from the emerging river that feeds the moat.

The availability of a plentiful heat source means that more heat collectors can be added without affecting the temperature of the moat. More WSHPs could, therefore, be installed, which would help reduce the site's overall reliance on fossil fuels for heating purposes.

During the site visit, it was found that new gas boilers had been installed for heating the living quarters and offices in some buildings. It is important to note that these buildings are not owned by the Palace Trust, which currently operates the existing WSHP system. However, it seems like a missed opportunity, because a WSHP is already being used successfully to heat other parts of the same site. The plant room housing the new boilers would have been ideal for a WSHP installation because the moat is directly on the other side of the wall.

The main palace has electrified its heating using direct electric heaters. These heaters respond quickly and can effectively control humidity when operated appropriately. However, they have a COP of approximately 1 and consume more energy than a WSHP to produce the same amount of heat. Running costs are also higher compared to a WSHP or fossil fuel system. Using a WSHP would reduce both energy consumption and running costs compared to the current direct electric system.

3.2 Site 2

Building history and overview

At this site there is a Grade I listed Jacobean-style country house in Cambridgeshire, dating back to 1135. It is now open to the public as a visitor attraction seven days a week for most of the year. In addition to the main house, the site includes extensive gardens, a watermill and a smaller cottage used as a staff office.

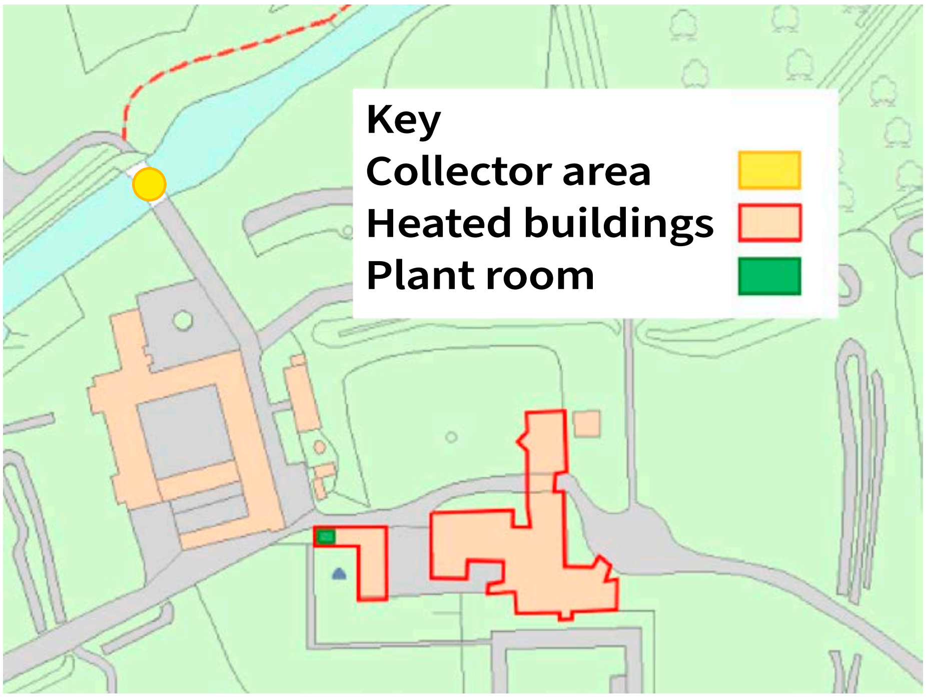


Figure 11: A map of Site 2, showing the location of the buildings heated by the WSHPs, the WSHP plant room and the approximate location of the heat collector. © Historic England

Heating system

In 2018, a 204kW WSHP system was installed to replace the previous oil boiler heating system. The system is open loop, extracting and returning water from a small watercourse, which passes through the site. It provides conservation heating to the main house and comfort heating to the staff cottage. Heat is primarily delivered through existing radiators in the main house and new radiators in the staff cottage, which previously had no heating system. An LPG boiler was also installed to provide top-up heating.

Summary

Property type	**Country house**
Heat pump technology	6 x CTC EcoPart 434 WSHPs, with an open-loop collector
Installed heat pump capacity	204kW: 170kW (5 x 34kW units) for the main house, 34kW for the cottage
Heat pump capacity/m2	72W/m^2 for the main house, 114 W/m^2 for the cottage
Heating system	Radiators
Hot water system	The WSHPs provide domestic hot water to the main house only. Electric immersion heaters top up the main house’s domestic hot water and provide all of the cottage’s domestic hot water.
Use pattern	Open to visitors every day throughout the year
Technology choice	★☆ Considering the proximity of the river to the house, an open-loop water source seems like a good option for this site. However, there have been some significant operational challenges.
Thermal comfort	☆☆ In the first year of operation, the WSHP system was functioning well with no reported issues concerning thermal comfort. The WSHP system has been malfunctioning for almost two years now, so direct electric heaters are being used as an alternative heat source.
System design/ installation quality	★★ Although there are concerns about the effectiveness of the submerged river pumps , the overall installation of the system is of high quality.

Internal WSHP observations

- Six 34kW WSHPs have been installed, providing a total capacity of 204kW,
- The WSHPs use R-407C, which has a GWP of 1774. The system has a refrigerant charge of 34.8kg.
- The WSHPs are not currently operating.
- Some buckets in the plant room are overflowing with discharge from pressure relief valves, indicating problems with the pressurisation of the glycol system.
- There is no visual impact on the buildings. The WSHPs and associated equipment are all in an internal plant room.
- The WSHPs sit on integrated anti-vibration mounts.
- The plant room is in a basement, underneath staff offices. There have been no issues with noise.
- The primary access to the plant room is very tight, with very little standing room.

External WSHP observations

- The WSHPs operate as an open-loop system, using submerged pumps to collect heat from the river water before returning that water to the river.
- The water extracted from the river is circulated through a plate heat exchanger in an outdoor kiosk beside the river. Heat is extracted from this river water using a closed-loop brine circuit between the WSHPs and the plate heat exchanger.

- The river water is cooled by around 5°C before being returned to the river.
- The submerged pumps are located underneath a footbridge to minimise visual impact.
- The inlet for the collector is placed upstream of the outlet to avoid any recirculation of cooled water.
- The distance between the inlet and outlet is approximately 5m.
- The submerged pumps are visible from the riverbanks but are not obvious. Some pipework is visible near the edge of the river.
- During the visit, it was observed that the submerged pump was consuming 1.4kW of power. However, the water meter indicated zero flow, possibly due to an airlock in the pipework between the submerged pump and the riverbank. This was evident from the fact that the pipework was floating on the river's surface.
- There is a build-up of debris beneath the bridge near the pumps. This area is especially susceptible due to the narrowing of the waterway caused by the bridge. The inlet to the pumps appeared to be submerged underneath the debris and possibly the riverbed.

Heating distribution system

- Heating is mostly provided by existing cast iron radiators in the main house and modern triple-panel radiators in the staff cottage.
- The heating system uses two 300l buffer vessels for the main house and one 300l buffer vessel for the cottage.
- A 300l calorifier has been installed as part of the main house's domestic hot water system, heated by the WSHPs. A 300l storage cylinder has been installed as part of the cottage's domestic hot water system, heated by an electric immersion heater.

User interview

- The design engineer created a performance specification for the WSHP system. However, during construction, design modifications were made outside the design review process and were not recorded which has caused problems.
- The LPG boiler was installed as an either/or system, meaning that when the LPG boiler is on, the WSHPs are always off (known as switch mode). The LPG boiler is only 67kW, and so cannot provide the full heating load.
- The system is reported to have functioned as designed for 12 to 18 months. The end user believes that a combination of a lack of river maintenance, personnel changes during the COVID pandemic and lapsed system maintenance led to the submersible pumps and filtration system frequently failing and defaulting to the LPG boiler having to be used all of the time during two heating seasons. Small electric heaters are being used to provide heat, but the spaces are not comfortable.
- The client's initial brief asked for the WSHPs to be installed without altering the plant room access. The entrance to the plant room is very restricted, accessed via a narrow staircase. As a result, 6 smaller WSHPs were installed. However, these smaller WSHPs still needed to be disassembled to be moved into the plant room.
- Due to the prolonged system downtime, the main house is beginning to show signs of damage caused by mould growth and building movement. Many historic buildings rely on their heating systems to help protect the historic fabric and collections.

- There was a concern that the installer did not adequately communicate the necessary maintenance instructions for the system, specifically regarding the open-loop pumps submerged in the river.
- The client was aware that the submerged pump filters would need to be cleaned, but it has been difficult to put this into practice.
- The decision to place the pumps underneath the bridge came from the client, because they wanted to minimise the visual impact of the system. In hindsight, they have realised that this has made maintenance particularly difficult and they would prefer to put the pumps in a more accessible location.
- In future, at other properties , the client would use a closed-loop water source system to avoid the problem of blocked filters.
- The client is interested in the possibility of converting the current open-loop system to a closed-loop one.
- There have been no noise problems.
- Running costs were not an issue when the system was operational.
- Finding an appropriately skilled contractor to fix the system has been difficult.

Environmental permits and surveys

- An abstraction licence was required from the Environment Agency for the extraction of river water. The Environment Agency assesses applications to abstract water against local water availability.
- The abstraction licence at this site is valid until 2027.
- As the river is classed as a main river, construction work required an environmental permit for flood risk.
- Further details and discussion can be found in the environmental permits section of this report.

Discussion

Handover information

The user guide for the system is well designed and helpful. It contains customised content and clearly labelled photographs of the installation. The guide also includes instructions for users to optimise the WSHP system’s efficiency by adjusting the ‘heating curve’. It is commendable that the building owner has access to this information because they are best placed to make these minor changes most effectively.

The user guide needs more details about the submerged pumps, which are a unique and important aspect of this system. The maintenance team would have benefited from instructions on how to clean the filters and how to identify when they need to do so. A clear method statement for performing these tasks safely would also have been helpful.

Heat collector type

This site is the only one in this report that has an open-loop configuration. Here, the open-loop system pumps water from the river and passes it through a plate heat exchanger to transfer heat to the thermal transfer fluid (or brine) that circulates through the WSHPs. The water is then returned to the river approximately 5m downstream.

Closed-loop systems have a closed thermal transfer fluid loop submerged in a body of water. The water is used as a heat source, but the water itself remains undisturbed.

One benefit of using an open-loop system is that it does not require long thermal transfer fluid coils to be installed in the water. This should save time and money, particularly on larger projects, but the pros and cons of both systems should be evaluated on a case-by-case basis.

The risk of thermal transfer fluid leaking and contaminating the source water is very low in an open-loop system, because the plate heat exchanger is typically located in a separate plant room and is, therefore, less susceptible to mechanical damage. The submerged coils of a closed-loop system are vulnerable to damage from activities such as dredging.

In an open-loop system, there is a strong possibility that the submerged pumps and plate heat exchanger will become fouled (partially or wholly blocked). As water from the water source passes directly through them, fine filters are needed to prevent debris from blocking the narrow channels of the plate heat exchanger. To avoid a decrease in flow rate , the filters need to be cleaned and replaced regularly.

At Site 2, the submerged pumps have been running constantly but delivering no flow rate through the plate heat exchanger. This has likely damaged the pumps and wasted energy. During the site visit, the water extract pipework was floating on the surface, indicating that there is air in the system. It is not known if the zero flow in the river loop system was caused by blocked pump filters or an airlock in the pipework.

Once pump filters become blocked, the pipe's flow rate decreases. The water's velocity also decreases, and the slow-moving water is unable to dislodge any air bubbles that are forming. As the air bubbles collect, the flow in the pipe decreases further, and the filters become more blocked. Eventually, there will be zero flow in the circuit. At Site 2, automatic air vents have been installed at high points in the kiosk pipework to remove air trapped in the system. However, in this instance, the likely airlock occurs before the automatic air vents and so the vents cannot alleviate the issue.

The pumps' location in the middle of the river and under the footbridge, makes maintenance very difficult. Examining the installed pumps and the image of the pump assembly shown in Figure 12, it appears that some parts of the screened inlets are covered by debris on the riverbed. This will reduce the flow available to the system. A full risk assessment must be undertaken to safely carry out pump maintenance.

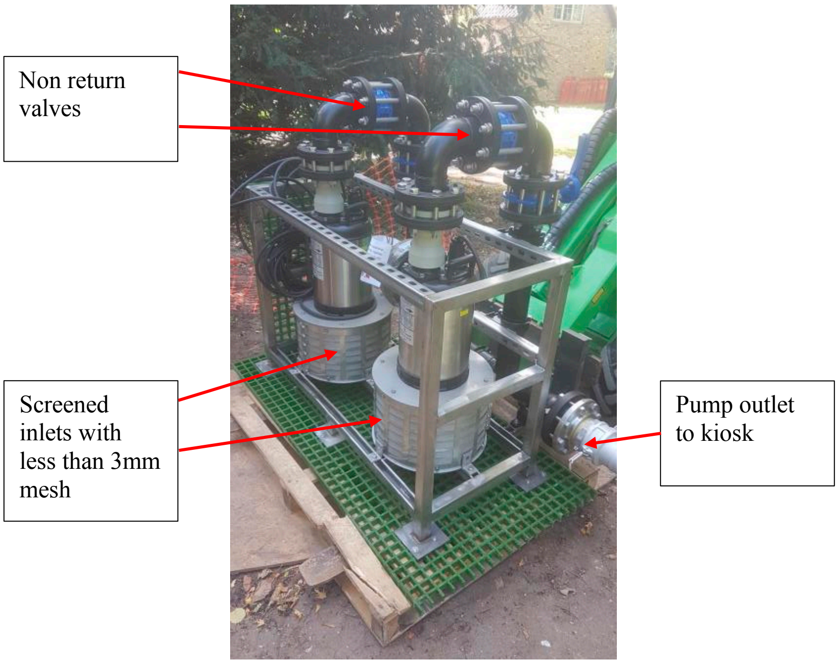


Figure 12: Extract from the installer's handover document, showing the pumps before they were installed in the riverbed.

Closed-loop systems require no maintenance in most cases, and the site owner has expressed an interest in converting to a closed-loop system in the future. All the other sites in this study have yet to carry out any maintenance on their closed-loop collectors. However, a closed-loop system requires significantly more space in the river than an open-loop system, because long runs of coils are needed to extract the necessary heat. At Site 2, the river is relatively narrow, and so a larger length of the river would be required for heat collectors if a closed-loop system were used.

Plant room planning

The WSHPs are located in a plant room in the basement of the cottage, which previously housed an oil boiler. The space is very restricted, with little standing room and densely packed equipment. Using the existing basement reduces the likelihood of noise from the WSHPs and means that space is not lost on the ground and other floors. However, access to this basement is down a narrow stairway with a 90-degree bend, shown in Figure 13.

Figure 13: Cottage plant room door, located at the bottom of a staircase.

The client asked for the WSHPs to be installed without altering the plant room access, and so six smaller WSHPs were selected.

The required WSHP capacity was divided until each individual WSHP unit was small enough for it to be manoeuvred into the plant room. This may have increased the capital cost of the equipment, compared to installing fewer larger units. Installation expenses were also higher due to increased labour costs and more plumbing and wiring connections being required.

The smaller WSHPs still had to be disassembled to fit through the doorway and then reassembled inside the plant room. This increased the risk of damaging the units and voiding manufacturers’ warranties.

Reusing a small basement space as a plant room may seem like a good idea, but it can cause problems when installing, maintaining, repairing and replacing plant. Pros and cons should be considered on a case-by-case basis.

Environmental permits

With an open-loop system, water is both abstracted from and discharged into the local river. Separate environmental permits may be needed for abstraction and discharge, and there is a combined application form available from the Environmental Agency. Additional permits may be required for flood risk activity, and additional approval may be needed from the local authority, depending on the site.

It is advisable to begin discussions with the Environmental Agency and relevant local authority early, before you apply for any environmental permits. There is a free basic pre-application advice service and an enhanced paid-for one.

The basic service gives advice on:

- the type of permit you need
- which application forms you should use
- what guidance you must follow
- application charges
- any standard rules that are relevant to your activities and if you meet the criteria for them
- risk assessments you may need to complete and send with your application
- administrative tasks the Environment Agency may need you to do as part of your application.

The enhanced service gives additional advice on:

- complex modelling
- preparing risk assessments
- parallel tracking for complex permits with planning applications
- specific substance assessments
- monitoring requirements (including baseline)
- complex application charge questions
- public engagement plans for high public interest applications
- requirements of nationally significant infrastructure projects.

For sites that will discharge less than 1,000m^3 a day, a standard rules discharge permit can be used. This is often quicker to obtain and may cost less than a bespoke permit. However, the site must comply with all the conditions of the standard rules discharge permit. If this is not possible, a bespoke permit must be used.

When applying for, or renewing, an abstraction licence, an application charge must be paid and there is also an annual subsistence charge. An environmental permit for discharge can be applied for at the same time using the same form, or separately. An application fee must be paid for a standard rules discharge permit. An annual subsistence fee must be paid for the duration of the permit. However, the fee is reduced if a thermal heat exchanger is used between the water source and the WSHP.

A permit for flood risk activity is needed if there is any construction work:

- in, under, over or near a main river, including if the river is in a culvert
- on or near a flood defence for a main river
- in the flood plain of a main river
- on or near a sea defence

The location of main rivers in England and Wales can be checked here environment.maps.arcgis.com/apps/webappviewer/index.html?id=17cd53dfc524433980cc333726a56386

You do not need a flood risk permit to work on ‘ordinary watercourses’ (non-main river, streams, ditches), but you should contact the local authority to check if any other consent is needed. For example, if the water source is covered by another organisation responsible for managing bodies of water (such as the Canal and River Trust), additional permission may be needed from them. Early engagement is advised to help ensure timely consent is granted for the project.

For more information on applying for open-loop WSHP permits, see: gov.uk/guidance/open-loop-heat-pump-systems-permits-consents-and-licences#standard-rules-water-discharge-permits-for-surface-water-systems

The ‘Surface water source heat pumps: Code of Practice for the UK’, published by CIBSE in 2016, recommends that an environmental survey is conducted before all WSHP projects, to establish a baseline against which the environmental impact of the WSHP can be measured throughout its lifetime. This is especially important for an open-loop configuration because of the risks of fouling within the system, contaminating the water source, and debris blocking the abstraction pipes. There is also the risk of the water abstraction being affected by seasonal water levels and ecology of the river .

It is unclear whether an environmental survey was done at the Site 2. The handover document does not make any reference to debris and fouling. It mentions the approval of abstraction and discharge permits but makes no reference to an environmental survey.

Project update following our investigation

Two years on from our site visit, the end user has provided the following project update.

A new 120kW electric boiler has been installed to replace the LPG boiler. This electric boiler is now providing the heating and in the longer term, it is intended that this boiler will be backup plant when the WSHPs are operational. The controls have been configured with automatic switchover to provide backup heating via the electric boiler. The end user also reports that the pressure relief valves have been replaced along with other plantroom defects.

The submersible pumps suffered severe corrosion due to mild steel components being used in the pump body rather than stainless steel, and this was not discovered until the pumps had completely failed and they had subsequently been inspected. The river intake has been redesigned to remove any mechanical components from the water. The river will be de-silted over a 10 metre section to improve depth, flow and reduce the risk of debris collecting around the intake pipe. The intake pipe will be fitted with a basket strainer which will be positioned in the middle of the river for the best flow and an automated backwash filtration system installed. This will remove debris before the intake water reaches the plate heat exchanger.

3.3 Site 3

Building history and overview

The construction of this historic house dates back to 1570, and the building has been modified and expanded over time. In the 1920s and 1930s, the house underwent significant renovations and extensions when it changed owners.

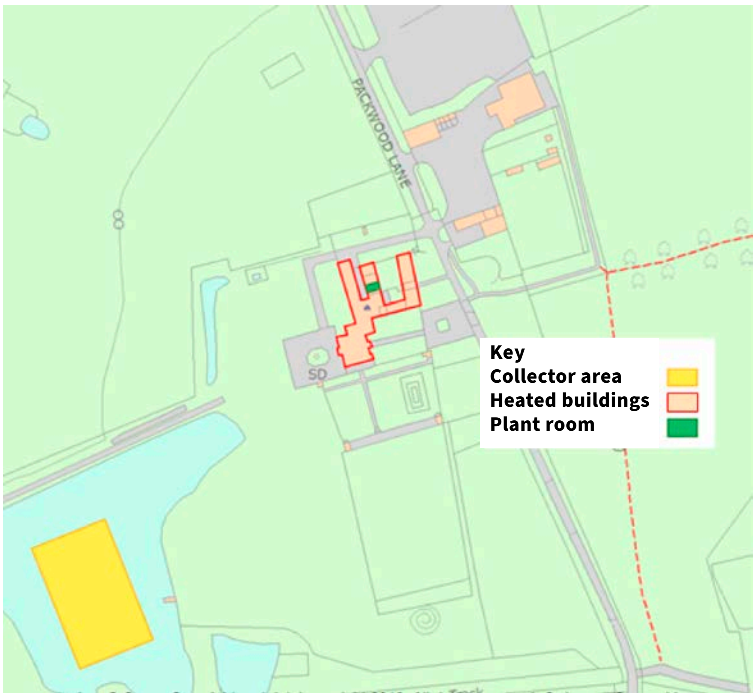


Figure 14: A map of Site 3, showing the location of the buildings heated by the WSHPs, the WSHP plant room and the approximate location of the heat collector. © Historic England

Heating system

Three Dimplex WSHPs heat the main house, office accommodation and flats at Site 3. All three are connected to a shared closed-loop collector on a sunken platform within the lake next to the house.

A single 75kW WSHP and a 1,000l buffer vessel provide conservation heating to the main house, which uses the existing historic radiators to deliver heat.

Heating for thermal comfort is provided on separate circuits to the office accommodation and flats, powered by a 40kW and a 20kW WSHP, sharing a 500l buffer vessel. The offices and flats use modern radiators to deliver heat. Oil boilers have been retained to provide back-up heat to these areas.

Figure 15: Dimplex WSHPs in the plant room.

Summary

Property type	Mansion house
Heat pump technology	3 Dimplex WSHPs of various model types, shared closed-loop collector
Installed heat pump capacity	135kW: 75kW for the house, 60kW (40kW + 20kW units) for the offices and flats
Heat pump capacity/m2	65W/m^2 for the house, 85W/m^2 for the offices and flats
Heating system	Exisiting radiators in the house, modern radiators in the offices and flats
Hot water system	No hot water provided to the main house. Point of use heaters used in the offices and flats
Use pattern	Main house is open every day, all year-round for visitors; flats are continuously occupied
Technology choice	★★ The site is ideal for a WSHP because it is near a lake, and there is a straightforward route between the lake and the plant room. In this case, a WSHP system is likely to be cheaper and quicker to install than a GSHP system using a borehole or ground loop collector.
Thermal comfort	★☆ High thermal comfort levels were reported in the offices and one of the flats. The occupant of the other flat complained about being cold. However, this is likely caused by the heat distribution system rather than the WSHPs. The main house is heated for conservation heating rather than thermal comfort. Portable electric radiators have been added to assist the wet radiators because some areas are not receiving enough heat. Again, this is a heating system issue, rather than a WSHP issue.
System design/ installation quality	★☆ The system appears to be well designed, with adequate thought given to buffer vessels to extend the run time of the WSHPs and reduce mixing. Comparing what has been installed in the plant room to a schematic of the design, a non-return valve appears to be missing. This reduces the heating system flow temperature by allowing some return water to mix with the outgoing flow.

Internal WSHP observations

- Conservation heating is provided to the main house by a single 75kW WSHP with a 1,000l buffer vessel.
- Heating for thermal comfort is provided on separate circuits to the offices and flats, powered by a 40kW and a 20kW WSHP, sharing a 500l buffer vessel.
- Oil boilers have been retained to provide back-up heat to the offices and flats.
- All three WSHPs are connected to a shared closed-loop collector on a sunken platform within the lake next to the house. The collector consists of 5km of pipe sunk within the water source.
- The heat pumps use R-134A, which has a GWP of 1430. The system has a total refrigerant charge of 26.5kg.
- The plant room and WSHPs seem to be well maintained and tidy. Some condensation forms on the pipes containing brine running to and from the collector.
- There is no visual impact on the building or gardens. The WSHP plant room is located in a separate outbuilding.
- Rubber mats have been placed under the WSHPs to reduce vibration.
- The plant room is located away from all public areas. The entrance to the plant room is more than 5m away from the nearest offices.
- The closest public area is behind a high gate around a corner. Staff offices are around a corner in a separate building. The WSHPs are not audible at either location.
- Additional circuit board upgrades were made at the same time as the WSHP installation. Staff members on site assume that the capacity for the grid connections has also increased.

External WSHP observations

- The WSHP system uses closed-loop coils attached to a sunken platform in a nearby lake to collect heat for the WSHPs.
- The collector coils were spaced apart on the rigid platform, floated out and sunk towards the lake’s centre.
- Three poles mark the coils’ location. This helps to minimise the possibility of them being damaged during activities such as dredging. The poles are not visually intrusive.
- The coils are not visible, even when water levels are low.
- The pipes between the coils and the plant room are run underground and are not visible.

Heating distribution system

- Existing historic radiators provide heating for conservation in the main house.
- Modern double-panel radiators are used in the offices and flats.

Environmental permits and surveys

- As it is a closed-loop system, no environmental permits were needed.
- No known surveys were conducted.

User interview

- The individuals interviewed at the site did not participate in the design and installation of the WSHP system and have limited knowledge of the process.
- The design appears to have been carefully planned. There are separate WSHPs for thermal comfort and conservation heating.
- The offices and one flat have high thermal comfort levels, but the second flat struggles to reach the required temperature. The cause is thought to be poor hydraulic balancing or blockages in the existing pipework.
- The installation is generally high quality, with the pipes insulated and well supported. However, there is a missing valve in the plant room. It is not known if this is an installation error or an undocumented design change.
- No issues have been reported with the noise level. There is no noticeable noise in any part of the building or external public grounds. The hum of the heat pumps and water circulation pumps is audible when standing directly outside the plant room. However, this area is an exterior walkway between back-of-house areas.
- The WSHPs have reduced the running costs by £23,000 per year compared to the oil boilers they replaced as part of a plan to decarbonise.
- The WSHPs use the existing heating system and pipework, reducing the capital cost and installation time. However, the issues currently experienced with inadequate heat distribution will require maintenance to be carried out. This work is likely needed regardless of the heat source.
- There were limited controls seen on site. It appears that the control strategy is that the WSHPs maintain a set buffer vessel temperature. The heat distribution pumps are probably activated by a demand signal that originates from a remote thermostat, time clock or humidity sensor in the relevant area of the building.
- Having separate WSHPs and systems for the main house and the flats and offices allows for greater control and efficiency when different areas require independent heating for conservation and thermal comfort.
- Annual services have been carried out. However, finding a contractor for more detailed service and repairs was difficult.

Discussion

Unintended system recirculation

A schematic of the heating system is displayed in the plant room. The main house schematic shows low temperature hot water flows from the WSHP to the bottom of a two-pipe buffer vessel. The top of the buffer vessel is connected to the primary house heating circuit to distribute the heat to the heat emitters. A simplified version is shown in Figure 16.

Bypass legs are in place on either side of the buffer vessel. The bypass on the left of the buffer vessel allows the heating circuit to circulate water through the buffer vessel when the WSHP is not running. Without this bypass, the main system pump (P.2) would have to push water through the inactive WSHP. The non-return valve (NRV.1) on this bypass is essential. Without it, the heat pump flow would short-circuit around the bypass, with little flow being pushed through the buffer.

To guarantee that minimum operating flow rates are available to the WSHP at all times, including when P.2 is inactive, a second bypass is fitted to the right-hand side of the buffer vessel. The non-return valve (NRV.2) on this bypass is also essential. Without it, some heating system return water would flow through the bypass, rather than make its way back through the buffer vessel or heat pump.

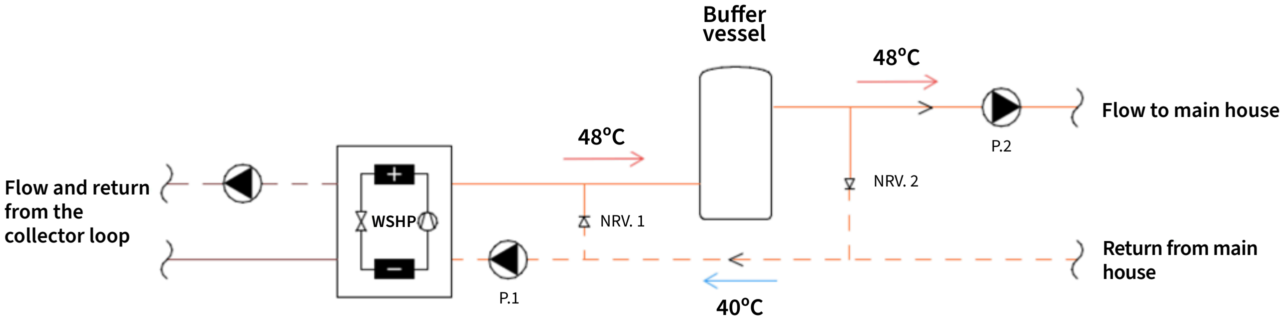


Figure 16: A schematic of how the two-pipe buffer vessel and bypass legs should have been installed according to the schematic found during the site visit.

A visual inspection of the installed system revealed that NRV.2 is missing. The temperature gauges on the flow and return legs on either side of the buffer vessel and bypass legs support this theory, as unintended mixing of the hotter flow and colder return is occurring.

This has reduced the flow temperature leaving the plant room to the heat emitters. As a result, the heat emitters are cooler than intended.

Feedback from the site confirmed that some areas of the building are not receiving enough heat. It is unclear whether the problem is caused by the mixing of the heating system's flow and return, which lowers the flow temperature, or if another issue is restricting the flow to these spaces.

Whatever the cause, the system will be less efficient if there is a reduction in temperature between what the WSHP is producing and what is being delivered to the heating system.

Figure 17 shows the temperatures observed during the visit. The WSHP could improve its efficiency by approximately 15 per cent if it produced 42°C water instead of 48°C.

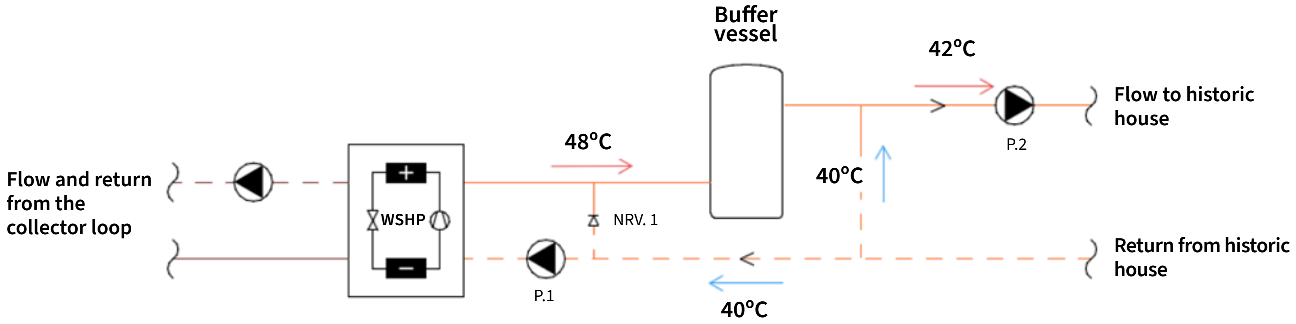


Figure 17: A schematic of the two-pipe buffer vessel arrangement that was installed on site, with readings taken from temperature gauges on site.

Using existing heat emitters

The WSHPs on site were connected to the existing heating system within the historic section of the house. The heat emitters in the main house were supplemented by electric oil radiators, which were controlled by humidity sensors.

The additional electric radiators were installed because the wet heating system radiators were not providing adequate humidity control. There are several possible reasons for this, including:

- reduced WSHP flow temperature caused by uncontrolled mixing
- issues with the hydraulic balancing of the existing heating system
- the heating system being designed with an insufficient heating capacity.

The radiator system would benefit from some maintenance work, because blockages may be reducing the heat output or stopping heat from reaching some areas altogether. For example, there are two staff flats. Both flats have similar thermal performance and heating systems, but one is comfortable and the other is cold. During the site visit, noise was heard in the flow pipes in the plant room, indicating air within the system. Draining and flushing the pipework and balancing the radiators may improve the situation. However, the exact pipework configuration is unknown and assessing the pipework routes would be intrusive.

The current heating system was not part of the original building. It was installed as part of renovation works during the 1920s and 1930s. Some radiators are well hidden, as shown in Figure 18, but others are more visible. The radiators used in the old heating system are large cast iron models. They were originally designed to provide thermal comfort, but the building is now heated for conservation purposes. The heating system should, therefore, be able to meet the heat output requirements for conservation, using the lower temperature generated by WSHPs, without any fabric improvements being made to the building. There are several advantages to this approach. First, it helps decrease the carbon footprint associated with installing a new heating system. Second, if the necessary heat output is achieved with lower flow temperatures, this avoids any negative impact on the WSHP's performance that may result from running it at high temperatures. Third, it reduces the installation work required, resulting in lower costs and fewer modifications to the historic building.

Figure 18: Historic radiators underneath a window sill.

Heating for conservation and thermal comfort

A heating system designed for thermal comfort will probably require different flow temperatures and 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 during the summer. Conservation heating usually requires heat throughout the year to control the relative humidity. If a single WSHP is used for both conservation and comfort heating, it may be oversized for conservation heating during the summer. This may lead to cycling and reduced efficiency. Using separate WSHPs 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 WSHP to operate at the lowest possible temperature, thus maximising its efficiency.

This site has two heating systems that share the closed-loop lake heat collector. The first is dedicated to conservation heating for the historic house, while the second provides thermal comfort for the staff offices and flats. Alternatively, the areas heated for conservation and thermal comfort could be connected to the same WSHP, 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 WSHP 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.

Generally, it is advisable to separate the thermal comfort and conservation heating circuits, similar to the system at Site 3, shown in Figure 19 below.

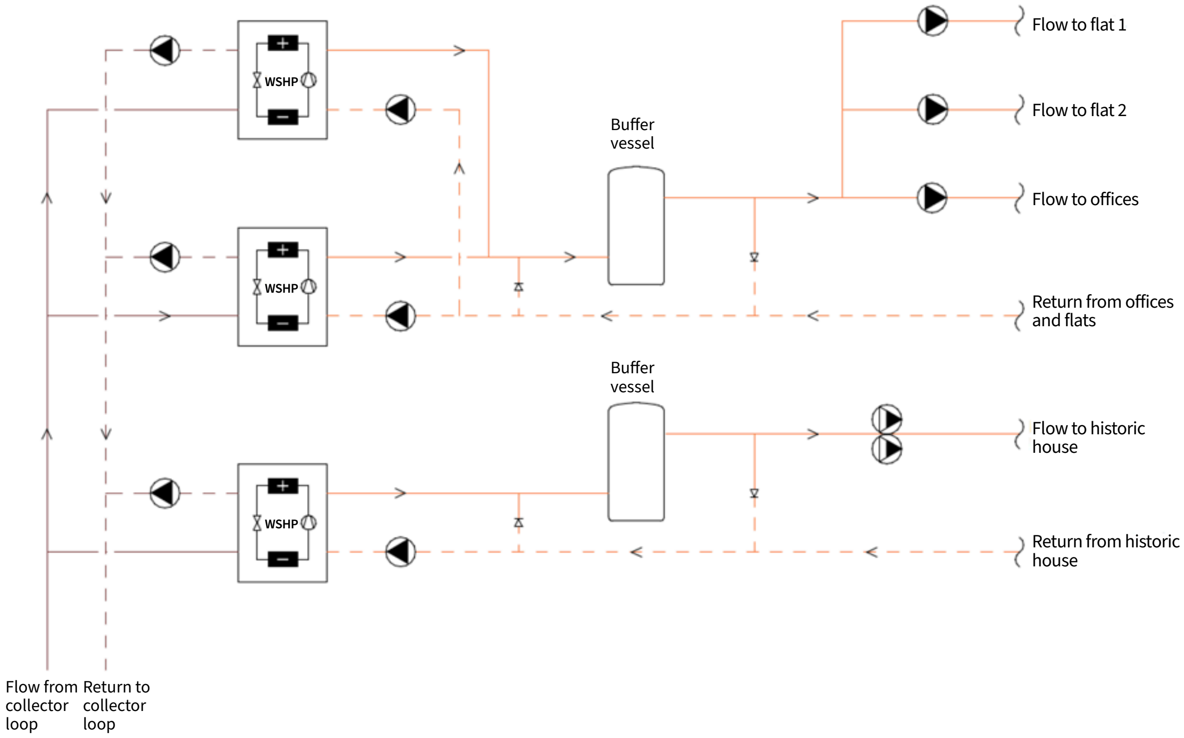


Figure 19: A simplified schematic of the heating system at Site 3, using separate WSHPs for conservation heating and thermal comfort.

3.4 Site 4

Building history and overview

This is a stately home within a wider estate, consisting of gardens, monuments, outbuildings and farm buildings. Construction of the house began in 1699, and it was largely completed in the 1750s. The long gallery was completed in 1811. After this time, additions were made in the 19th century, and extensive restoration was carried out after a fire damaged nearly a third of the house .

Figure 20: Site 4, North Yorkshire.

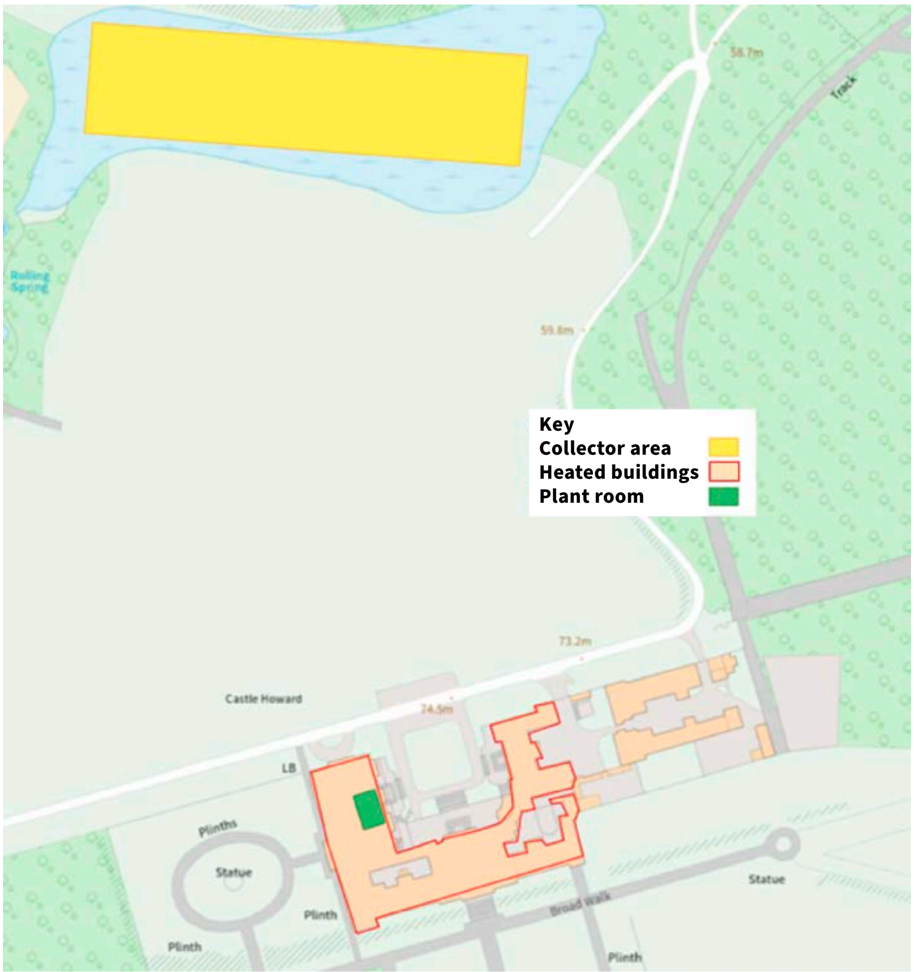


Figure 21: A map of Site 4, showing the location of the buildings heated by the WSHPs, the WSHP basement plant room and the approximate location of the heat collector. © Historic England

Heating system

In 2009, two 144kW WSHPs were installed, which use a closed-loop collector system to collect heat from the sizable Dairy Pond. They provide heating to all the heated areas of the main house and hot water to the west wing.

In 2020, two 73kW WSHPs were installed to provide heating to additional areas of the west wing and to accommodate the installation of more hot water appliances.

Additional pond collector capacity was required for the 2020 WSHP installation. The disruption was minimised because the below-ground pipes between the plant room and the pond had been installed in 2009. New collector loops were added to the Dairy Pond, and a new manifold and manifold chamber were installed on the pond's banks.

The majority of the building is heated for thermal comfort. Heat is delivered by both historic and new radiators, with portable oil radiators used when heat is required in rooms without heating.

Figure 22: Dimplex SI 75TU WSHPs in the basement plant room at Site 4.

Summary

Property type	Historic house	
Heat pump technology	2 Dimplex SI 100TE WSHPs installed in 2009, and 2 Dimplex SI 75TU WSHPs installed in 2020, sharing closed-loop radial collectors	
Installed heat pump capacity	434kW: 288kW (2 x 144kW) from the 2009 installation, 146kW (2 x 73kW) from the 2020 installation	
Heat pump capacity/m2	97W/m^2	
Heating system	The main house is heated by the WSHP system. Where possible, existing wet radiators were kept in place. New wet radiators were installed in areas that were previously unheated or used direct electric heating.	
Hot water system	The WSHPs supply domestic hot water to the west wing. An oil boiler provides the domestic hot water to the east wing.	
Use pattern	The east wing is occupied throughout the year. The lower-level bedrooms and dressing rooms in the west wing are occupied intermittently by overnight guests. From April through to January, the west wing and south front rooms are open to visitors.	
Technology choice	★★	The site has several bodies of water that could be used as a heat source. The pond closest to the plant room was chosen. It is not the deepest or largest available, but it was deemed large enough by the system's designers. The distance between the plant room and the pond is approximately 250m. Ample areas around the main building would suit boreholes or ground loop collectors for a GSHP. However, installing a ground loop would be more disruptive to the historic gardens and hidden archaeology than the chosen system.
Thermal comfort	★☆	The occupants were satisfied with the refurbished areas, which have newly installed radiators. However, there were varying opinions on the level of comfort in areas that use the existing radiators.
System design/ installation quality	★☆	The system appears to be well designed, with ample space for installation and maintenance activities in the dedicated plant room. The pipework is well insulated. However, the insulation has been damaged in some places and is falling away from the pipes. This will lead to heat loss from the heating pipes and an increased risk of condensation forming on the ground collector pipework.

Internal WSHP observations

- The SI 100s have a maximum capacity of 144kW each, while the SI 75s have a maximum capacity of 73kW each. A total capacity of 434kW has been installed.
- The capacity of the heat collector is unknown.
- When the initial heat collector was set up, it was designed to allow for more collector loops to be added in the future. This was a wise decision.
- The SI 100s use R-404A refrigerant, and the SI 75s use R-410A, which have a GWP of 3922 and 2088, respectively. The system has a refrigerant charge of 20.5kg of R-404A and 23kg of R-410A.
- Both pairs of WSHPs seem to be in good working order. However, one heat pump was not working during the visit and was undergoing planned maintenance.
- It appears that the pipework insulation has been damaged in various places and has not been fixed. Repairing the vapour barrier on the ground collector pipework is imperative to prevent condensation on the pipes. Prolonged condensation can cause rapid pipework corrosion, which could eventually cause leaks.
- There is no internal visual impact on the building, as the plant room is in a cellar. Pipes to the collector are visible in a light well leaving the building (covered in black insulation), but they have a minor visual impact compared to the above ground drainage, see Figure 23. The light well is not visible to the general public.
- The WSHPs appear to be mounted on rubber mats to reduce vibrations.
- The basement plant room is far from any noise-sensitive locations.
- The plant room has a stone ceiling and walls that effectively suppress plant noise.
- There is a visitor area and kitchen above the WSHPs, and no noise can be heard from the plant room in these areas. Any noise originating from the plant room would likely be masked by the noise of the kitchen ventilation system.

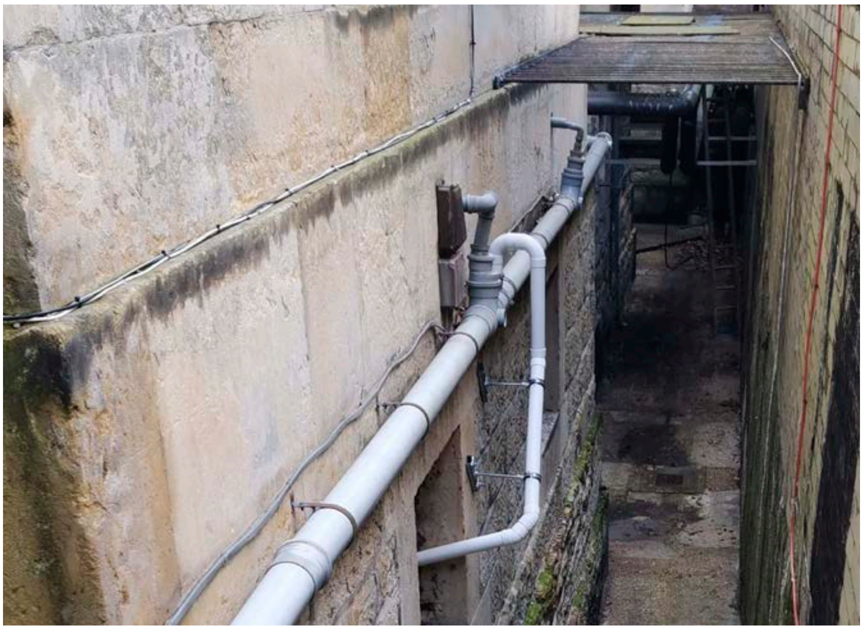


Figure 23: Black pipework that connects the lake heat collector to the plant room in the background.

External WSHP observations

- The WSHPs use a closed-loop collector system.
- Multiple pipe loops are submerged in the Dairy Pond.
- The loops are placed at least 2m apart and located in an area of approximately 200 x 50m.
- The multiple loops are gathered in a collector manifold in a below-ground chamber, close to the pond's edge.
- For the collector, coils were chosen over flat loops.
- The area where the collector is buried can be seen against the surrounding landscape, see Figure 24.
- Some pipes are visible in the pond. The pipe that runs out to the collector manifold has caused minor visible differences.

Figure 24: The raised ground around the manifold collector chamber.

Heating distribution system

- The radiators and pipework in the hallway and larger rooms have been retained and reused.
- Reusing existing pipework has limited the system's zoning capabilities.
- In 2022 , new radiators and pipework were installed in renovated rooms that did not previously contain a wet heating system, as part of a major reservicing project.
- The renovated rooms combine wet radiators and direct electric radiators. Guests can use the latter if they need higher temperatures.
- The heating system uses two buffer vessels of 500l each.
- The system installed in 2009 uses two 500l domestic hot water storage cylinders, serving the commercial kitchen and some existing accommodation.
- As part of the 2020 renovation project to update the west wing and create guest accommodation in the east wing, a 1,000l domestic hot water storage cylinder was installed.

Environmental permits and surveys

- No environmental permits were required due to the system being a closed loop.
- No known surveys were conducted.

User interview

- In 2022, as part of a site master plan, more rooms were added to the central heating system, and some rooms were renovated. A new WSHP system was designed and installed in 2020 to accommodate the additional heating needs of the new rooms. The new system was designed and installed by a different designer than the 2009 works. At the same time, modifications were made to the existing WSHP system to make it RHI-compliant.
- Additional pond collector capacity was required for the 2020 WSHP installation. External disruption was minimised because spare below-ground pipes had been installed between the plant room and the pond in 2009. New collector loops were added in the Dairy Pond, and a new manifold and manifold chamber were installed on the pond's banks.
- Installing pipes between the plant room and the future manifold location next to the pond in 2009 meant that the 2020 installation was quicker, thus lowering costs and minimising disruption.
- There were some challenges in getting the new WSHPs into the plant room, and the external casing sustained some damage. However, this has not affected the WSHPs' performance.
- During the site visit, staff expressed greater satisfaction with the temperatures in the refurbished areas, which have newly installed radiators. There were varying opinions on the comfort level in areas that still use the existing radiators.
- No issues with noise were reported. Building occupants are more likely to hear noise from commercial kitchen ventilation fans above the plant room.
- Although more rooms are now being heated, electricity usage has not increased. This is because the wet radiators connected to the WSHPs have replaced the direct electric radiators.
- The WSHPs are not connected to a building management system. They run constantly for the heating season, targeting a set return temperature. This control method is seen as adequate. The WSHPs have weather compensation controls, which have caused some issues due to the building's thermal mass , resulting in a significant lag between the external and internal temperatures. For example, the weather compensation control can turn the WSHPs off or very low even when the internal temperature remains low. The weather compensation has, therefore, been disabled.
- No maintenance was carried out on the WSHPs between 2009 and 2019. Bi-annual services have now been scheduled. General repairs have been carried out throughout the life of the WSHPs, with some parts replaced.

Discussion

Groundwork

When the WSHPs were installed in 2009, spare pipework was added between the plant room and the pond. This meant that less groundwork was required when the additional WSHPs were installed in 2020. It also reduced the installation costs and minimised the disruption. The pipe run from the plant room to the water source is approximately 270m, and it crosses a well-used path. An additional manifold and manifold chamber, plus more collector loops had to be installed in 2020.

Figure 25: The manhole for one of the collector loop manifolds, with the historic house in the distance.

Replacing oil boilers

Before 2009, the site used oil boilers for heating and domestic hot water. A three-year study was conducted to determine if WSHPs would be a suitable replacement. During the study, the set point of the oil boilers was lowered from 75/80°C to 55°C, and heating was provided 24/7 without a timer. This led to a reduction in fuel consumption of between 20,000 and 30,000l per year, depending on the severity of the winter. The house remained comfortable despite the lower flow temperatures, even during cold spells. The study also found that running the heating at a constant lower temperature provided greater control. The room conditions fluctuated less, which was beneficial for sensitive historic building fabric and artefacts. Additionally, running the boilers at a constant lower temperature reduced the maintenance required.

The study showed that WSHPs were a viable and effective solution for reducing oil consumption at Site 4.

When the initial WSHPs were installed in 2009, an old oil boiler was kept as a back-up. It was never used. In 2020, additional WSHPs were installed, and the oil boiler was removed. The redundant oil tank was removed in 2022.

Before installing the new WSHPs, an external consultant was hired to assess the heating system and decide how best to increase the number of heated rooms. The consultant recommended replacing the existing WSHPs with boilers because they believed the pond was too shallow to be used as a heat source, and the collectors were not receiving sufficient heat for additional rooms. However, a staff member who has experience with similar projects consulted a company that specialises in the design and installation of heat pump systems. It proposed an alternative plan to keep the WSHPs. This plan was selected because it aligned with the site's wider sustainability strategy.

The first stage of the alternative plan was to review the existing WSHP installation. The WSHPs were found to be running for long periods at maximum output and they were not registered on the RHI scheme. The WSHP system was made RHI compliant and was registered on the scheme. RHI payments then became an additional income source for the site, highlighting the cost benefits of WSHPs over boilers.

The second stage saw the installation of additional WSHPs to reduce the load on the existing ones. The new WSHPs were to accommodate the additional heat demand as more areas were added to the central heating system. The new WSHPs use collector loops from the same lake as the original heat pumps, and there are no issues with the heat supply.

The plan has been successful, with high thermal comfort levels reported. There has been no noticeable increase in running costs despite more rooms being heated to higher levels of thermal comfort. This is because the direct electric radiators previously used are more expensive to run.

Heat emitters

The existing radiators were used wherever possible. However, new ones were installed in areas with no previous heat emitters or those heated by direct electric radiators. Many of the old radiators are historically significant but using them has presented some challenges on site. Debris was found in the existing pipework. This problem was particularly relevant in the garden hall's historic underfloor heating system. Despite multiple attempts to flush the pipes, debris remained in the system. As a result, the underfloor heating system was disconnected and the room left unheated. To alleviate the problem, strainers (a filter to capture particles) could be fitted to the underfloor heating manifold if there is sufficient pumping capacity.

The historic radiators have also been leaking. This has occurred in the chapel , and the radiators have been isolated to prevent further harm. As a result, no heating is currently provided in the chapel. The cost of repairing and refurbishing these radiators is substantial. They have historic value, and replacement parts and materials are difficult to source. Another historic radiator has failed in the long gallery, causing significant water damage to the rooms below.

Using existing heat emitters may save money initially, but there may be significant repair costs in the future, which should be budgeted for. Historic England recommends that the refurbishment of historic radiators should include painting, flushing and pressure testing to help mitigate this issue.

Figure 26: Historic radiators within the chapel.

The heating system is limited by the current pipework configuration, which controls the temperature for the entire building as one zone. However, different areas – residential, showrooms and guest accommodation, for example – have different occupancy and temperature requirements and would benefit from independent control. Unfortunately, changing the pipework system would be disruptive and difficult. The building services team do not consider it to be a worthwhile investment at this time.

In some areas, installing a wet heating system was impractical and too disruptive. This was often due to a lack of pre-existing pipework or the presence of delicate historic floorboards that could not be lifted. Unfortunately, some rooms were left without heating or had to rely on direct electric plug-in radiators for warmth.

The heat loss calculation suggested four radiators were needed in the refurbished areas. The decision was made to add two wet radiators and one direct electric radiator per room, with connections added for an additional direct electric radiator if required. Since then, it has been found that two wet radiators provide enough heat for thermal comfort, suggesting that the heat loss calculation overestimated the heat required.

Some rooms in the east wing have been reported to have low thermal comfort levels. This was initially thought to be caused by insufficient heating water circulating through the radiators, because the rooms are located at the end of the circuit. Additional direct electric radiators were installed, and a wood fire is often lit in winter to help achieve thermal comfort. It is understood that some radiators were purposefully undersized to match the aesthetics and proportions of the rooms.

Domestic hot water

In addition to heating the space, the WSHPs supply hot water to most of the building. The hot water supply for the east wing is provided by LPG boilers . The distance between the WSHPs and the east wing is too great: it would require a long length of distribution pipework, which would affect the final water temperature and pressure.

Both the 2009 and 2020 heat pump systems were designed to provide domestic hot water. The 2009 system produces domestic hot water via coils in a calorifier, while the 2020 system uses a plate heat exchanger to feed the hot water cylinder. At the time of the visit, the 2009 hot water cylinder had been isolated and was not producing hot water, but the owner has since reported that both systems are now operating.

A calorifier with an integrated coil is a cost-effective and space-saving option compared to having a separate plate heat exchanger. However, it may result in uneven heating within the cylinder, because the coils do not cover the entire cylinder height and colder water, therefore, settles at the bottom. This reduces the effective storage volume of the hot water cylinder.

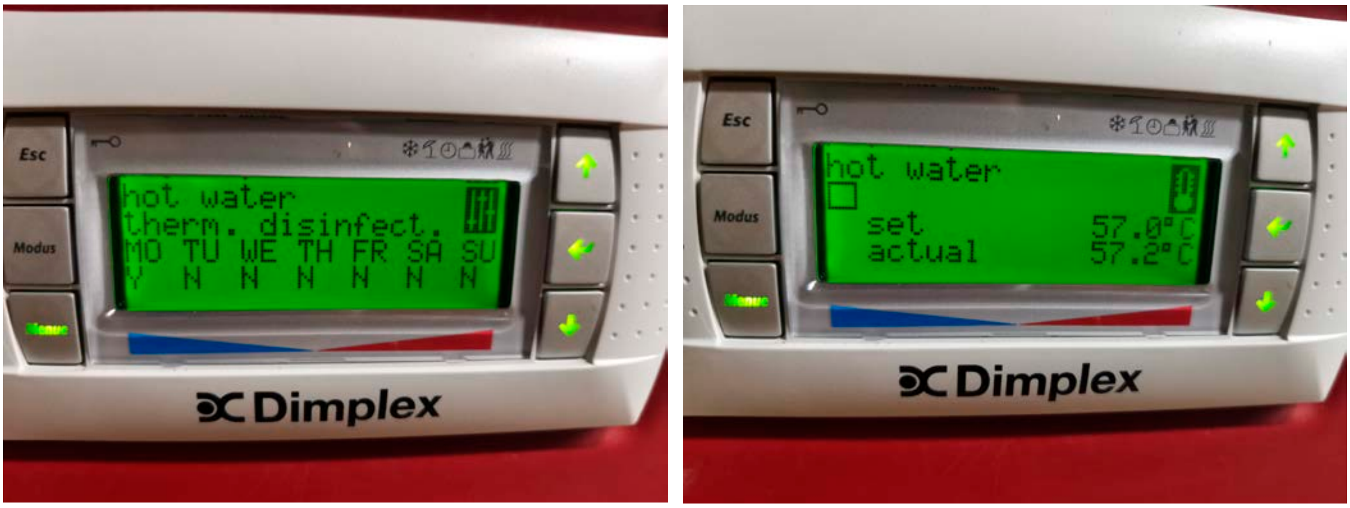
Using a plate heat exchanger will allow for more even distribution of heat in the cylinder. Cold water can be drawn from the base of the cylinder and then passed through the plate heat exchanger to reach the desired water temperature. This effectively increases the storage volume, and so a smaller cylinder 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. The external plate takes up additional space and will likely be more expensive to install and operate.

For systems providing domestic hot water, there is a risk of legionella. The risk is increased in larger distribution systems, such as the one at Site 4. To reduce the risk of legionella bacteria growing to an unsafe level, hot water should be stored above 60°C or heated to 60°C for at least one continuous hour a day.

When using a WSHP for domestic hot water, water is sometimes stored at less than 60°C because the WSHP's efficiency decreases as it produces hotter water. In this case, the temperature of the water in the cylinder should be increased to 60°C daily and circulated to reduce the likelihood of stratification and the development of legionella at the tank's bottom.

The system has a targeted storage temperature of 57°C. A thermal disinfection cycle is programmed to take place every Monday, as shown in Figure 27, with a set temperature of 60°C.

The domestic hot water cylinder for the 2020 WSHPs was installed with two 12kW immersion heaters. These heaters will be able to heat the hot water to a higher temperature than the WSHPs can achieve, and they will supplement the WSHPs. The controls for the heaters are linked to the WSHP control panel. There is a risk of the less efficient immersion heaters taking over the heating of the hot water, which will greatly increase running costs. As the immersion heaters are directly controlled by the WSHPs, they should only operate when required. The heat pump has recorded the run time of the immersion heaters to be 451 hours.



```
hot water
therm. disinfect.
MO TU WE TH FR SA SU
Y  N  N  N  N  N  N
```

```
hot water

 set              57.0°C
 actual           57.2°C
```

Figure 27: The WSHP control panel for the thermal disinfection cycle (left) and the hot water temperature (right).

Modern WSHPs can efficiently heat water for domestic use without needing an immersion heater top-up. However, if a WSHP is limited to a 55°C flow temperature, it can still effectively heat a domestic hot water cylinder from 10 to 50°C with a COP of approximately 4.2. To achieve a storage temperature of 60°C, an immersion heater with a COP of 1 can be used to raise the temperature by 10°C: the WSHP provides 80 per cent of the heat and the immersion heater provides 20 per cent. This combination results in an overall COP of 3.6. Although most modern WSHPs can heat a domestic hot water cylinder to 60°C without an immersion heater, the heat pump's efficiency decreases as it produces hotter water. The overall COP of heating water from 10 to 60°C using a modern WSHP is approximately 3.9, an improvement over the WSHP and immersion version. However, since the WSHP still provides 80 per cent of the heat, the overall impact on efficiency and running cost is somewhat diminished.

3.5 Site 5

Building history and overview

This is a Grade I listed stately home in Norfolk, dating back to the 1600s. The estate is now open as a visitor attraction seven days a week for most of the year. The house contains dressed showrooms, staff offices and accommodation.

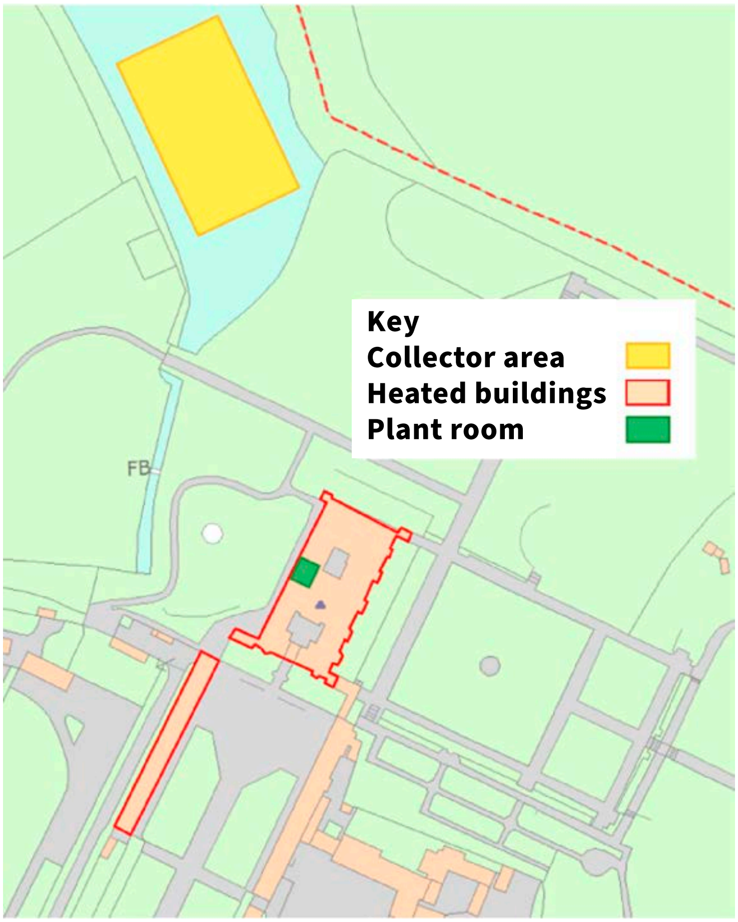


Figure 28: A map of Site 5, showing the location of the buildings heated by the WSHPs, the WSHP basement plant room and the approximate location of the heat collector. © Historic England

Heating system

In 2016, two WSHPs were installed with a combined capacity of 205kW. Extracting heat from the nearby lake via a closed-loop system, the WSHPs provide conservation heating to the visitor areas of the main house and comfort heating to the staff offices and accommodation. Heat is delivered through a variety of historic radiators, which were previously powered by an oil boiler. The staff offices contain some modern twin-panel radiators. In addition to the WSHPs, there is also an LPG boiler that serves as a back-up in case the WSHPs fail.

Figure 29: Lake at Site 5, with manifold chamber cover.

Summary

Property type	**Historic house**
Heat pump technology	Dimplex SI 130 and SI 75TU WSHPs, with a closed-loop collector
Installed heat pump capacity	205kW (130kW + 75kW units)
Heat pump capacity/m2	50W/m^2
Heating system	Wet radiators and direct electric heaters
Hot water system	The site is open to visitors every day throughout most of the year
Use pattern	★★ The proximity of the lake to the house makes the water source an excellent choice for high-efficiency heating with minimal visual impact on the site.
Technology choice	★★ The staff and volunteers have consistently reported feeling comfortable, even in the main hall, which is primarily heated for conservation purposes.
Thermal comfort	★☆ The installation quality is high, but there is a significant lack of control over zoning of heat.

Internal WSHP observations

- One 130kW and one 75kW capacity WSHP have been installed in the plant room that previously housed the oil boiler.
- The WSHPs use R-410A, which has a GWP of 2088. The system has a refrigerant charge of 42.5kg.
- The WSHPs appear to be well maintained and in good working order.
- The 75kW WSHP had a reported compressor run time of 2 hours, while the 130kW WSHP had a compressor run time of 32,006 hours. This indicates that the 75kW WSHP is not used very often. However, the control panel of this WSHP had been replaced, likely resetting the run time counter to zero.
- There is no visual impact on the building. The WSHPs are all internally housed.
- The WSHPs are mounted on anti-vibration mounts.
- The brine pumps are mounted directly onto the stone wall , without anti-vibration mounts. This transmits vibrations into the building structure.
- The WSHPs are in a dedicated plant room, which acts as a noise barrier.
- The main house and west wing have not undergone any fabric improvements to accommodate the WSHP installation.
- A 150kW LPG boiler, converted from an oil boiler, provides full heating back-up.

External WSHP observations

- The WSHPs use closed-loop coils as a collector system, with a total collector length of around 5.6km.
- The collectors do not make a significant visual impact on the site. Only the initial 10m of the collector pipes can be seen beneath the surface of the lake.
- A small manifold chamber panel is the only visual sign of the collector loops.
- The lake is approximately 90m away from the plant room.

Heating distribution system

- Wet radiators of various sizes and ages provide heating. No radiator upgrades were made as part of the WSHP project.
- Existing pipework has been reused in many places.
- The heating system uses a 1,000l buffer vessel.
- The new WSHPs and buffer vessel interface with the existing heating system in the plant room. Several outgoing heating circuits serve different areas. No means of measuring or balancing the outgoing flows has been provided. This may have been outside the scope of the WSHP project. The facilities team use the isolation valves on each branch of the heating system in an attempt to control the amount of heat being delivered to each zone. Isolation valves are not designed to balance a system, so only crude control is possible.

Environmental permits and surveys

- No environmental permits were required due to the system being a closed loop.
- No known surveys were conducted.

User interview

- The consensus is that the system has exceeded expectations and initial challenges have been resolved. However, there is room for improvement.
- An oil leak in an underground supply pipe prompted the switch from oil to WSHPs. This incident highlighted the potential environmental hazards of storing oil on the premises.
- An initial assessment of the electrical capacity at Site 5 showed that the existing supply would be adequate for the WSHPs. However, this assessment failed to account for the start-up currents of the WSHPs, which are much higher than the running currents. This is because compressors draw a lot of power on start-up. As this was not accounted for, an upgraded electrical supply was required. These works needed planning permission and delayed the project by more than a year.
- A boat was used to manoeuvre the heat collector pipe loops into their final position in the lake.
- Installing the pipes connecting the collector to the WSHPs was disruptive. The landscaping has now been restored, and the pipework route is completely hidden.
- An archaeologist was employed to monitor the construction of the pipe trench between the mansion plant room and the lake. There were no archaeological issues reported during the works.
- Freezing has never been a problem at the lake, even though the collector loops are situated in a shallow part. The pipe loops are filled with antifreeze, which prevents the thermal transfer fluid from freezing even if the lake itself freezes.
- The shallow end of the lake has been known to dry out over the summer. However, there have been no reported incidences when the WSHPs could not run when required for conservation heating in the summer (The WSHPs do not provide domestic hot water, so they are only used to provide heat to control humidity).
- Shortly after installation, some pipe loops floated to the lake’s surface. The contractor flushed out any trapped air and weighed them back down. This issue occurred a few times, soon after the installation, but has not happened since.
- Good comfort levels were reported by staff working in the offices and the main house.
- Staff living in the flats have reported being cold at times. The existing heating pipework layout allows only crude balancing of the heating circuits. This makes it difficult to increase the heat delivered to the flats without impacting the heat delivered to the main house.
- There were no complaints about noise coming from the WSHPs. The WSHPs are placed on anti-vibration mats to reduce noise and vibrations.
- Despite being two floors away from the flats, the sound of the main thermal transfer fluid circulation pumps starting up can still be heard by the flat’s occupant. There appeared to be no vibration dampening between these pumps and the building structure.
- Thanks to the RHI payments, the energy running costs are considered low. However, running costs have yet to be benchmarked, or the WSHPs’ efficiency analysed.
- Weather compensation of the system flow temperature is achieved by manually adjusting the flow temperature in 1 to 3°C increments, based on feedback from occupants.

- The site organisation felt that the handover process was a bit light, and more information on system control could have been provided.
- No maintenance contract is currently in place.

Discussion

Heating plant

The WSHPs are backed up by a 150kW LPG boiler, shown in Figure 30. This was originally one of the old oil boilers and was adapted for LPG use. It was determined that retaining an LPG boiler as a back-up heat source was a worthwhile additional cost. LPG is also favoured over oil due to the reduced environmental risk in the event of a fuel leak.

Figure 30: Existing oil boiler, which was repurposed to LPG.

The LPG boiler has rarely been required. On one occasion, a power surge tripped the WSHPs' power supply, and the LPG boiler kicked in to provide heat to the site. The transfer happened automatically, and staff were unaware of the change of heat source until the LPG supply ran out and the heating stopped working. If the LPG had not taken over, the team would have been aware of the issue earlier and could have switched the WSHPs back on. An alarm to identify when the WSHP power supply trips would help prevent unnecessary use of LPG. Other than this one instance, the WSHPs have always been able to meet the heating requirements of the site. Now that the WSHPs have proven reliable, the need for a back-up heat source is not seen as critical.

At the time of the visit, the 75kW WSHP had a total compressor run time of 2 hours, while the 130kW WSHP had a total compressor run time of 32,006 hours . However, the control panel on the 75kW WSHP had been replaced, likely resetting the run time counter to zero. If a fault were to develop with the lead 130kW heat pump, the 75kW heat pump could provide back-up heating, albeit at a reduced output. Although the 75kW WSHP has not been required, when two or more WSHPs are installed together, sharing the load evenly between them is preferable. This maximises the lifetime of the WSHPs and provides a better level of resilience throughout the system.

Controls

The heating system provides conservation heating to the main house and comfort heating to the staff offices and flats in the west wing. Each space requires different amounts of heat at different times of day, thus increasing the need for good controls.

The original design had separate heating zones for the main house, each flat and the staff offices. Branching off from a low-loss header, each zone was supposed to have its own WSHP and three-port valve for controlling the heat delivered to the space. Only the branch serving the offices seems to have this set-up. As a result, there are limited options for controlling the amount of heat delivered to the main house and staff accommodation at different times.

Thermostatic radiator valves are present, but they are old and most of them are no longer operational in the main house. The flow rate to the main house is manually altered in the plant room by adjusting the position of isolation valves. When the relative humidity in the main house is too low, the flow rate is reduced to limit the heat input, and vice versa. There is also no way of measuring the flow rate in each zone, so the process is driven largely by guesswork. At the time of the visit, all the valves were in the same half-open position. This crude method of relative humidity control requires a lot of staff time. Relative humidity control and running costs could be improved by implementing an automated system driven by in-room relative humidity sensors.

The west wing offices are controlled in three heating zones, based on time clocks and internal air temperature. Thermostatic radiator valves on each radiator control the room temperature. The flow temperatures required to provide comfort conditions in the west wing offices dictate the system flow temperature to the main house and staff flats.

The WSHPs can be monitored remotely. However, issues with the network firewall mean that off-site access has never been possible for maintenance engineers.

Radiators and distribution

The main house heat emitters, shown in Figure 31, have been reused. They would have been sized to provide comfort heating at an oil boiler flow temperature of around 82°C. The installed WSHPs are not capable of this temperature, and at the time of the visit, the flow temperature was set to 45°C.

The staff at the main house reported that the new system, which focuses on conservation rather than comfort, was surprisingly more comfortable than the previous oil-fired system. In contrast to the oil boiler's short bursts, the consistent operation and lower flow temperatures of the WSHP likely contributes to this improvement.

Figure 31: Cast iron radiator at Site 5.

Comfort has been achieved in the offices and staff accommodation without radiator upgrades. The original radiator design probably focused on combating cold draughts from windows and was not based on a heat loss calculation. The original designer placed a double-panel radiator under each window. This common strategy often means there is far greater radiator capacity than is required to counter a room's steady-state heat loss. Therefore, the existing radiators are able to provide comfort at the lower WSHP flow temperature of 45°C.

The new WSHPs are connected directly to the existing system. A system flush was recommended before they were added. The site team deemed it too risky to flush the existing system in the main house because they were worried it might cause a leak. Given the age of the building and the unknown pipework layout, fixing a leak in the system could be very disruptive and damaging to the building. The west wing heating system was flushed because it is a newer installation.

The system designer provided a good-quality operation and maintenance manual showing how to clean out the system filters. It recommends this is done every three months.

4. Conclusions

These case studies show that closed-loop WSHPs 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 WSHPs 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 WSHPs for conservation heating.

Many historic stately homes are located close to a body of water, as would have been a priority when they were built. WSHPs are, therefore, particularly suited to these buildings. When a body of water is available nearby, a WSHP system can be a more discreet solution than an ASHP system and a more straightforward installation than a GSHP system.

The visual impact of the WSHP systems was found to be minor, although it was reported that the groundworks were disruptive during the installation. Frequently, the sole indication of a submerged heat collector is the presence of manifold chamber covers near the water's edge. In fact, more could be done to draw public attention to this low carbon technology and promote the positive impact that it is delivering for historic sites.

The manifold chambers appeared well sized for access and maintenance, with adequate light and drainage.

The components of a WSHP that create noise are the pumps and compressors located within the heat pump housing. WSHPs are generally installed inside a plant room, and noise reduction measures are, therefore, more readily available than they are for ASHPs, which are located outside. WSHPs 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.

The system design of the WSHP is crucial to its success. While an open-loop heat collector requires less area in the water, at the scale of these projects (20 to 288kW), a closed-loop heat collector was the preferred option. The latter system has fewer maintenance requirements, contractors are more familiar with closed-loop systems and environmental licences are not generally required. Maintenance was particularly challenging across all the sites because there seems to be an ongoing shortage of suitably skilled contractors.

As WSHPs are very efficient at low flow temperatures, they are ideal for conservation heating systems that require slow internal changes in the environmental conditions. Existing radiators sized for high temperature comfort heating can be used for low temperature conservation heating. Where WSHPs are providing both comfort and conservation heating, system separation could lead to improved performance.

Issues reported were often not a direct impact of the WSHPs 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 minimise return temperatures to the WSHP. In a number of cases, users had a limited understanding of how to adjust the controls, which significantly affected the system's efficacy.

When attention is given to the details of system design and control, a WSHP is an excellent means of decarbonising the heating of a historic building.

5. Acknowledgements

Contributors

The authors would like to thank the end users 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

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Historic England

6. Endnotes

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

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

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