Open-loop groundwater source heat pumps: Code of Practice for the UK

Harnessing energy for heating and cooling from water in the ground

CP3
2019

Open-loop groundwater source heat pumps:

Code of Practice for the UK

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Note from the publisher

This publication is not intended to be exhaustive or definitive and it will be necessary for users to consult appropriate guidance and to exercise their own professional judgement when applying the standards contained in the Code.

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Foreword

This Code of Practice has been produced as a joint project between the Chartered Institution of Building Services Engineers (CIBSE) and the Ground Source Heat Pump Association (GSHPA) with the backing of the Heat Pump Association (HPA). The work has been supported by the UK Department for Business, Energy and Industrial Strategy (BEIS).

Groundwater source heat pumps (GWSHPs) have huge potential and are an under-used technology in the UK. Harnessing renewable energy from water wells and mine water represents a huge opportunity to provide low carbon heating and/or cooling to buildings. However, if GWSHPs are to form a significant part of our future low carbon energy infrastructure they need to be designed, built, operated and maintained to a high quality to deliver customer satisfaction. This Code of Practice has been produced to help achieve these aims by raising standards right across the supply chain and to encourage adoption of the technology.

Setting minimum requirements (and recommending best practice) should provide greater confidence for specifiers and developers. This Code of Practice can also be included in the tendering/contracting process to specify minimum requirements for a project. The adoption of this Code of Practice by developers could ultimately be used to provide assurance to customers and property purchasers that their GWSHP scheme has followed a set of design, installation and commissioning standards. This Code of Practice should therefore have a significant effect on the GWSHP market by boosting confidence in the technology.

CIBSE, GSHPA and HPA are also working to develop compliance checklists and training to ensure the skills necessary to implement the Code of Practice are available across the sector.

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Units for temperature

Temperatures are described in this Code of Practice as degrees Celsius (°C). However, it should be noted that the Kelvin scale, K (which is the strictly correct SI unit for temperature), is widely used in practice, often interchangeably with degrees Celsius. This substitution is acceptable for these applications because the magnitude of the degree Celsius is exactly equal to that of the kelvin. Subtracting 273.16 K from the temperature of the triple point of water (0.01 °C) makes absolute zero (0 K) equivalent to −273.15 °C.

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Part A: How to use this Code

A1 Introduction

A1.1 Strategic purpose

Open-loop groundwater source heat pumps (GWSHPs), which use groundwater as a thermal resource to provide heating or cooling, will play an important part in the UK's future energy strategy. The 2008 Climate Change Act established the world's first legally binding climate change target; the aim is to reduce the UK's greenhouse gas emissions by at least 80% (from the 1990 baseline) by 2050. Moving to a more energy efficient, low-carbon economy will help to meet this target, reduce local emissions and improve air quality. It will also ensure the UK becomes less reliant on fossil fuels and consequently less vulnerable to energy price rises.

The *Clean Growth Strategy* (BEIS, 2017) states that heating our homes, businesses and industry accounts for almost half of all energy used in the UK and a third of carbon emissions. About 70% of this heat is produced from natural gas. Meeting the target of reducing emissions by at least 80% by 2050 implies decarbonising nearly all heating and cooling used by buildings and industrial processes.

There is a range of low-carbon heating technologies with the potential to support the scale of change needed, including the electrification of the heating of buildings using heat pump technologies, such as GWSHPs, instead of gas or oil boilers.

As electricity generation from fossil fuels, especially coal, is phased out and renewable generation is increased, the carbon intensity of the grid will fall (see http://www.gshp.org.uk/Gridwatch.html). This decarbonisation of the grid, combined with the increasing electrification of heat, will directly reduce the carbon produced by heating and cooling buildings in the UK.

The *Clean Growth Strategy* also sets an ambition to phase out the installation of high-carbon fossil fuel heating such as oil and coal in buildings off the gas grid during the 2020s. This is a sizeable opportunity for decarbonisation and heat pumps will have a key role to play.

This Code of Practice follows on from CP2: *Surface water source heat pumps: Code of Practice for the UK* (CIBSE, 2016), which was published in April 2016 and supported by the Department of Energy and Climate Change (DECC). This Code of Practice (CP3) focuses on open-loop groundwater source heat pumps and has been supported by the Department of Business, Energy and Industrial Strategy (BEIS).

Open-loop GWSHPs have the potential to provide heating and cooling on a large scale and there are an ever-increasing number of examples of open-loop GWSHP systems in the UK, although it is yet to be considered a mainstream technology (see sections B2 and B3).

The strategic aims for the deployment of GWSHP systems are:

(1) to reduce CO_2 and other greenhouse gas emissions

(2) to reduce the overall cost of providing heating and/or cooling.

(3) to use natural resources sustainably

(4) to reduce or replace the consumption of fossil fuels.

This Code of Practice, which has been developed with support from BEIS, is therefore written to:

— improve the quality of feasibility studies, design, construction, commissioning and operation by setting minimum requirements and identifying best practice

— deliver energy efficiency and environmental benefits

— promote long-lasting open-loop GWSHPs in which customers and investors can have confidence

— prevent environmental harm by the introduction of open-loop GWSHPs.

The Environment Agency (EA) is the statutory body for England responsible for regulating open-loop GWSHP installations. The equivalent bodies for the other parts of the UK are the Scottish Environment Protection Agency (SEPA), Natural Resources Wales (NRW) and the Northern Ireland Environment Agency (NIEA). The EA supports the deployment of sustainable, low carbon heating and cooling GWSHP systems. As a result, this means that systems must be designed and operated to protect the environment, with features that mitigate risks of unacceptable impacts on the groundwater environment and to prevent contamination.

Both CP2 and CP3 are written to complement CP1: *Heat Networks: Code of Practice for the UK* (CIBSE/ADE, 2015).

A1.2 What is an open-loop groundwater source heat pump?

Open-loop groundwater source heat pumps utilise groundwater abstracted from an aquifer via a water well as a thermal resource to provide heating or cooling. After use, the water is returned directly to the ground via an injection borehole or soakaway (non-consumptive) or diverted elsewhere for use as a private water supply, to a sewer or a watercourse (consumptive).

The advantage over surface water source heat pumps (SWSHPs) is that groundwater temperatures at 10–15 m below the surface are usually reliable and predictable throughout the year (approximating to the mean annual air temperature at that location) and increase with depth according to the local geothermal gradient (UK average 2.6 °C per 100 m depth). Predictable source temperatures simplify the design process and can enhance heat pump performance.

An open-loop GWSHP is similar to shallow ground source or surface water source heat pumps but set up or modified to maximise the benefit of the reliable and predictable source temperature. Different methods are used by manufacturers to safeguard their units for groundwater use. Integrating a heat exchanger into the source-side pipework being the most common.

A1.3 Why install an open-loop groundwater source heat pump?

Open-loop GWSHPs provide an efficient and low carbon means of using renewable heat from groundwater, i.e. water found underground in aquifers, mines and caverns. There are a number of advantages to using this technology over other heat pump systems, such as reduction in land area required and the reliable and predictable temperature of the groundwater supply, which simplifies the design.

Although heat pump systems can be more expensive to install than conventional oil or gas combustion technology, they can deliver a cost effective return on investment, with significant benefits to the client. Following the requirements in this Code of Practice will help to achieve well-engineered installations that provide lower running costs and carbon emissions.

Economic benefit

In many cases a motivating factor for installing GWSHP systems could be financial benefit through reduced energy bills and other incentives including the following:

— The UK Government's heat strategy identifies an important role for heat pumps and so there are various grants and incentives to encourage uptake of this technology (see Appendix B).

— The increased capital cost of the heat pump system should be compensated by the operating and maintenance cost savings, which can be substantial when accrued over the whole life of the building.

— They can have an indirect economic benefit by delivering least cost compliance with Building Regulations and/or planning requirements.

— Use of a heat pump can bring additional cost savings and some of these are often overlooked. For example, a gas supply and flue are not required.

— As heat pump systems can be used for heating and cooling simultaneously they can be designed to allow thermal energy to be economically re-used within the same system rather than generated or rejected.

— GWSHP systems are usually more compact and may be located in a basement plantroom. The roof space released can be extremely valuable.

Environmental and reputational benefit

Open-loop GWSHPs are a low-carbon alternative to using fossil fuels and so benefit the environment. GWSHPs do not generate local air pollution, therefore local air quality is not impacted as with fossil fuel heat generation technologies. Local authorities are seeking ways to reduce local emissions of NO_x etc. and heat pumps can play a significant role in achieving this.

Heat pump systems are therefore an excellent opportunity for individuals or organisations to reduce their carbon footprint and demonstrate corporate social responsibility, bringing associated reputational benefit. Heat pumps can also be used to decarbonise buildings that are off the gas grid by replacing high-carbon oil or LPG boilers.

Legislative requirements

There is an increasing amount of national and international legislation aimed at decarbonising UK heat supply, such as the *Clean Growth Strategy* (BEIS, 2017), the Climate Change Act 2008, the Energy Performance of Buildings Directive (EPBD), the Renewable Energy Sources Directive (RES), the Climate Change Levy (CCL) and Building Regulations. Heat pumps can play a key role in the decarbonisation of heat and cooling in meeting associated legislation.

The Microgeneration Certification Scheme (MCS) is a nationally recognised quality assurance scheme, supported by the Department for Business, Energy and Industrial Strategy (see https://www.microgenerationcertification.org). The MCS certifies microgeneration technologies used to produce electricity and heat from renewable sources.

Planning regulations often require new developments to include a proportion of renewable technology to reduce carbon emissions. Where developments are near a source of groundwater it presents opportunities for GWSHPs.

A2 Readership and scope of the Code of Practice

A2.1 Readership

The Code of Practice is aimed at owners and developers (referred to as 'the client'), designers, installers and operators of larger GWSHP systems; architects, consultants and engineers specifying larger GWSHP systems; and main and subcontractors involved with installer companies supplying larger GWSHP systems or designs. The Code of Practice should also prove useful to regulatory organisations, such as the Environment Agency, and for anyone considering a GWSHP installation.

Clients can specify the use of this Code of Practice in contracts or tender documents, for entire projects or for specific stages (e.g. construction). It is not necessary to be a technical expert in GWSHP systems to use the Code for procurement or contractual purposes — it has been designed (following extensive industry-wide consultation and in collaboration with BEIS) to give clients and developers confidence that commonly agreed minimum standards are being followed, and to allow clear communication between different parties in the supply chain. Using the Code can provide confidence that:

— a carefully considered design framework will have been followed

— legislative and regulatory requirements will have been identified and should have been met

— reporting and information handover will allow effective oversight of the project.

A2.2 Scope

The Code of Practice is intended to be used for larger scale projects. It is not intended for single domestic dwellings. However, information in the Code may be of interest to those involved with smaller scale projects.

The Code of Practice addresses and supports open-loop heat pump systems that use groundwater as their thermal resource to supply heating and/or cooling or to store heat. This includes water found in mines and caverns as well as aquifers.

The Code of Practice does not address warm water 'geothermal' aquifers, wells and springs.

Information on evaluating the best option for a particular site is addressed at Stage 2: Feasibility (see Objective 2.2).

This Code of Practice is not intended to provide specific design guidance; rather it aims to set minimum requirements for the technical application of GWSHPs. See 'References' and 'Further reading' for information about available guidance documents.

The Code of Practice aims to ensure there is no detrimental impact on the environment.

The Code of Practice does not consider how a heat pump works in any detail (a brief overview is provided in section B1) but focuses on the use of groundwater as a thermal resource and other issues that may have a direct effect on this application. It does not cover surface water, see CP2: *Surface water source heat pumps: A Code of Practice for the UK* (CIBSE, 2016).

A3 Structure of the Code of Practice

The Code of Practice is written to cover all stages of the development cycle from preparation and briefing through feasibility, design, construction and installation, commissioning, operation and maintenance, and finally decommissioning.

The Code of Practice is structured by:

— the typical sequence of a project by stage

— for each project stage a number of objectives are set

— for each objective a number of minimum requirements are defined to achieve the objective.

All of the minimum requirements will need to be met if the project is to fully follow this Code of Practice. It may be used only for a particular stage (and for this reason there may be some duplication between stages), but the greatest value will be gained when it is followed for all stages of the project.

The project stages are outlined in the open-loop GWSHP Plan of Work (see Figure 1) and are colour coded throughout the document. The Plan of Work also shows the key responsibilities (see Figure 1 for further detail) and how these relate to the major themes set out below.

The project stages broadly follow the generic *RIBA Plan of Work 2013* (RIBA, 2013) template (https://www.ribaplanofwork.com). If necessary, to achieve better alignment this may be customised via an on-line tool (see https://www.ribaplanofwork.com/CreatePlan.aspx).

The Code of Practice is designed to be prescriptive and minimum requirements are set to achieve minimum acceptable standards. Best practice has been identified for a number of objectives and should be considered.

The terminology used throughout the Code of Practice follows the ISO International Standards and other normative ISO deliverables, such as TS, PAS, IWA:

— ‘shall’ indicates a *requirement*

— ‘should’ indicates a *recommendation*

— ‘may’ is used to indicate that something is permitted

— ‘can’ is used to indicate that something is possible; for example, that an organization or individual is able to do something.

In section 3.3.3 of ISO/IEC Directives, Part 2: *Principles and rules for the structure and drafting of ISO and IEC documents* (8th edition) (ISO/IEC, 2018), a requirement is defined as an ‘expression, in the content of a document, that conveys objectively verifiable criteria to be fulfilled and from which no deviation is permitted if conformance with the document is to be claimed’.

In section 3.3.4 of the same document, a recommendation is defined as an ‘expression, in the content of a document, conveying a suggested possible choice or course of action deemed to be particularly suitable without necessarily mentioning or excluding others’.

At the beginning of each stage, key support tasks and typical information exchanges are identified. The key support tasks listed are not mandatory. However, they do provide an appropriate level of management and assist in achieving the objectives at each stage. The information exchange provides guidance on information that would typically be delivered at the end of each stage. These tasks are in line with the RIBA Plan of Work.

Each stage of the project will have complied with the Code of Practice when it has been demonstrated that all minimum requirements have been met.

A successful open-loop GWSHP project is often made more difficult by the fragmented nature of the industry and complex procurement processes. It is common to find the feasibility work is carried out by a consultant, the detailed design and construction by a design-and-build contractor and the operation and maintenance by an unrelated facilities management company. The procurement approach adopted should consider the risks involved in this fragmentation and lack of incentives for each party involved to deliver an optimal scheme. Where such separation cannot be avoided, the Code of Practice can assist in achieving a more integrated design that ensures operational costs are fully taken into account in the design/development stages, that the system is correctly commissioned and subsequently maintained and operated by informed and competent engineers.

The client should provide feedback to CIBSE/GSHPA on the operation of the Code of Practice to ensure the Code of Practice may be progressively improved.

A3.1 Themes

The principal ways in which the high-level aims are achieved is through a number of overarching themes, which need to be considered at each stage of the project.

(A) To deliver low environmental impact

Although the principal aim of a GWSHP system is to benefit the global environment and help move to a more energy efficient, low-carbon economy, the impact on the local environment needs to be carefully managed. The relevant environmental agency and other regulatory bodies set requirements which must be followed to ensure the risk of any negative impact is mitigated.

(B) To deliver a high-performance system with a high coefficient of performance

To ensure the GWSHP system is energy efficient, the distribution temperatures should be as low as possible in heating and as high as possible in cooling to maximise performance. In addition, great care shall be taken to ensure all parasitic energy loads, such as circulating pumps, are minimised and the energy source has adequate capacity to cover the requirements of the installation.

(C) To achieve optimum flow and return temperatures

GWSHP systems work most efficiently when the temperature difference (ΔT) between the source and load is minimised. Heat pumps typically have lower ΔT compared to combustion-based systems.

(D) To deliver a practical and compliant system using engineering solutions to overcome technical barriers

The technical barriers to the installation of a GWSHP system include water availability, water quality, ground conditions and pumping distances between the source and load. Space during construction and space for maintenance during operation can

Figure 1 Typical Plan of Work for an open-loop GWSHP project (courtesy of Phil Jones)

also be a major technical barrier. In many cases, an engineering solution can overcome these barriers and examples can be found throughout the Code of Practice.

(E) To deliver a cost effective reliable system with a long life and low maintenance requirements

A cost-effective open-loop GWSHP systems shall be specified to have a long life and require minimum regular maintenance. To ensure this is achieved, the source side needs to be carefully designed and the whole life costs taken into account.

(F) To deliver effective metering/monitoring of the GWSHP

Instrumentation such as flow, temperature and pressure sensors together with associated monitoring hardware and software is required in all open-loop GWSHP installations. This information should be used to monitor and record the performance of the installation and to control the system to ensure optimum efficiency and minimum downtime.

(G) To deliver a safe, high quality scheme where risks are managed

At all stages of the scheme safety, quality and risk need to be addressed and the adoption of national and international standards is required, including:

— BS ISO 9001 (BSI, 2015a) for quality management

— BS EN ISO 14001 (BSI, 2015b) for environmental management

— BS ISO 45001 (BSI, 2018a) for occupational safety

— BS ISO 31000 (BSI, 2018b) for risk management

— BS ISO 55000 (BSI, 2014a) for asset management.

A3.2 Responsibilities

A typical project involves several parties who need to work together. The responsibilities of the parties should be made clear for each stage of the project. The Code of Practice should be adopted by all involved in the project and should not be a contractual requirement limited to just one party.

Although each project will be different, Table 1 (below) describes the typical responsibilities that may be carried out by each party. Please note some roles may be combined.

Table 1 Typical roles and responsibilities

Organisation	Responsibility
Central and local government	Central government sets overall policy, develops appropriate incentive mechanisms and works to remove barriers. Local government promotes the strategic vision and develops and implements supporting policies at a local level including planning approval and the enforcement of building regulations.
Environment Agency (EA), Natural Resources Wales (NRW), Scottish Environmental Protection Agency (SEPA), Northern Ireland Environment Agency (NIEA) and statutory bodies	Responsible for: • groundwater quality and resources • conservation and ecology • aquifer capacity • contamination prevention • pollution monitoring • regulation of the use of groundwater Other statutory bodies have powers and responsibilities for specific site locations, such as Natural England for designated conservation sites and species. See Appendix C for further details.
Client (or in some cases referred to as Owner/Developer) The Owner is the entity who holds legal title to the property. The Developer is the entity responsible for the project. Either could be an individual, a local authority, a private or public limited company, a charity, housing association, building management organisation, a private sector Energy Service Company (ESCo), a public-private partnership or a community energy company.	Arranges finance, sets performance objectives and prepares the project brief. Appoints: • feasibility study consultant • project team including: ◦ project manager ◦ planning and legal advisor ◦ principal designer ◦ designer ◦ construction specialist ◦ maintenance contractor The Developer may be responsible for just the construction phase or also for operation.
Feasibility study consultant	Carries out a clear and accurate lifecycle feasibility study in line with the Code of Practice and other relevant standards and guidance. The feasibility study should cover environmental, technical and economic aspects.
Project manager	Responsible for overall coordination and delivery of the project and ensures that the project team works together effectively.
Principal designer	Should be a Chartered Engineer or other suitably qualified equivalent for all aspects of system design. The Principal Designer shall have experience in relevant heat pump and building services systems designs and be familiar with GSHPA requirements. The Principal Designer advises and assists the client and project team with their responsibilities under health and safety legislation.
Designer	Prepares the detailed design of the heat pump and source side installation and interface with the load. The Designer shall have experience in relevant heat pump and building services systems designs and shall take advice from specialist hydrochemists and hydrogeologists on all groundwater matters.
Heat pump supplier	Should be involved as early as possible so that they can confirm the suitability of their unit and any functions or features which are relevant to the project.
Planning and legal advisor	Advises on planning and regulatory compliance and applies for consents and permits as necessary. Commissions environmental reports. Negotiates with adjoining land owners and other parties for access to water source where required.

Table continues

Table 1 Typical roles and responsibilities — *continued*

Organisation	Responsibility
Construction contractor	Is responsible for the construction of the GWSHP systems using specialist suppliers and subcontractors. Specialist activities may include: • heat pumps • abstraction and injection well drilling and construction • pumps and controls • water quality monitoring and treatment • groundworks and pipe laying • metering • heat pump system control to ensure coordination with and successful integration into the Building Management System
Commissioning specialist	Develops commissioning procedures and a commissioning plan to ensure the design intent is realised and the plant operates correctly.
Operator and maintenance contractor/facilities manager	Maintains plant room and equipment in accordance with planned maintenance schedule and should operate the system in accordance with the design. However, the operator and maintenance contractor will follow instruction from the client, which may differ from the design intent. Operator training and specialist maintenance may be sub-contracted to the GWSHP supplier.

Part B: Challenges and opportunities

B1 The heat pump

When heating, open-loop groundwater source heat pumps (GWSHPs) operate by extracting low grade heat from groundwater and upgrading it to a suitable temperature for use in local heat networks or single buildings to provide a low-carbon source of renewable heat. Open-loop GWSHPs can also be used for cooling by absorbing heat from a building or other similar load and rejecting it into the aquifer. This rejected thermal energy can be stored and used to supplement the ground heat and returned to the building for use in space or domestic hot water heating. This process is known as aquifer thermal energy storage (ATES), see section B4.6.

An ATES system reduces the load on the aquifer and increases the system seasonal performance factor (SPF), which is the key measure of overall system performance, see Table 4 (page 22) and Appendix D.

In the Code of Practice, the groundwater is referred to as the 'source' and the building or other use as the 'load'.

B1.1 Types of heat pump

This Code of Practice does not assess in detail the advantages and disadvantages of the different types of heat pump. However, some understanding is necessary, even at feasibility study stage, to ensure a machine with the correct functionality and performance parameters is selected. Table 2 shows the various types of heat pumps and where they may or may not be used. Table 3 refers to the simple notations used to aid understanding within the heat pump community.

Table 2 Heat pump types and typical applications

Heat pump type		Typical application	Considerations
Vapour compression	Low temperature heat pump, less than or equal to 55 °C.	Space heating with low temperature heat emitters able to operate effectively with a low incoming water temperature of 35 °C or even less.	Domestic hot water (DHW) storage temperatures below 60 °C will need *Legionella* disinfectant strategy.
	High temperature heat pump (e.g. cascade with or without dual refrigerant; (R744) CO_2, (R717) ammonia vapour injection, desuperheater).	Space heating with ordinary or high temperature heat emitters and domestic hot water. Can also be used to supply heat networks (district heating) and existing buildings designed to operate at historically high distribution temperatures, normally 82 °C flow, 71 °C return.	Suitable for existing distribution temperatures. Efficiency may be impaired for lower temperature space heating applications without DHW. Health and safety implications of the refrigerant.
Absorption	Gas absorption, e.g. lithium bromide/water.	Off electricity grid, or where the electricity supply is constrained. May be used to create cold from heat in tri-generation applications. More efficient when heating than conventional gas boiler. Hot water output temp: > 80 °C Chilled water output temp: > 8 °C	Still requires small electrically driven circulation pump. Can be driven by almost any heat source including 'free' waste heat, geothermal, solar or from fuel cell cooperation. Higher maintenance cost.

Table continues

Table 2 Heat pump types and typical applications — *continued*

Heat pump type		Typical application	Considerations
Adsorption	Gas adsorption, e.g. zeolite/water	Off electricity grid or where the electricity supply is constrained. Works well with solar 'combi' heating and cooling applications	High reliability and long life (30+ years) as few moving parts. Uses non-toxic working fluids with zero GWP and zero ODP.
		Hot water output temp: > 50 °C	New, still improving, technology.
		Chilled water output temp: > 3 °C	Output temperature more stable across range.

Table 3 Heat pump notations

Notation	Source	Delivery medium
A/W	Air	Water
W/A	Water open loop	Air
W/W	Water open loop	Water
B/W	Brine closed loop	Water

Note: A W/W heat pump is one specifically designed and/or modified to work directly with groundwater. It will usually contain additional parts and systems to protect key components. A heat pump designed for B/W operation should not be used with an open-loop groundwater heat source without the manufacturer's specific written authorisation.

Most heat pumps found in open-loop GWSHP applications use a vapour compression cycle in which the compressor is driven by a motor, usually an electric motor. Vapour compression cycle heat pumps can be 'tuned' for different applications and even situations, primarily by using dissimilar refrigerants or combinations of refrigerants that perform differently according to their operational temperature range(s). Recent climate legislation has resulted in many changes to the refrigerants available, but suitable alternatives are rapidly evolving. There are also some 'add on' devices that may be used to enhance or modify performance, e.g. desuperheaters and hot gas injection.

Heat pumps using a 'sorption process (i.e. absorption or adsorption) are becoming increasingly popular. These use heat as the primary motive energy; they are usually gas-fired but may also use oil, electricity or recovered heat. There are two types:

— *Absorption*: transfers heat by using the changing temperature/vapour pressure relationship between two substances that can chemically combine and be separated again (e.g. lithium bromide/water or ammonia/water) .

— *Adsorption*: transfers heat by using the changing temperature/vapour pressure relationship between two substances that do not chemically combine (e.g. water/zeolite).

B1.2 Heating and cooling

This Code of Practice refers to heat pumps used for the space heating and cooling of buildings and/or domestic hot water (DHW).

The term heat pump applies to many devices, some of which are used primarily for cooling (for example, a refrigerator or automotive air conditioner) and some for heating. In operation, the machine simply pumps thermal energy from one side of the machine to the other, so the same device always has a cold side (the evaporator) and a hot side (the condenser) at the same time. Whether it is for heating or cooling, will depend on which side is selected.

If both sides are used simultaneously in a configuration that delivers heating and/or cooling from both sides of the heat pump (as shown in Figure 2) the benefits can be even greater, e.g. heat recovered by cooling a data centre may be re-used directly to provide heating (or DHW) elsewhere in the building.

Simultaneous systems are inherently efficient and require a new metric to reflect the performance increase. This is the Total Efficiency Ratio (TER), being the ratio between the delivered heat power plus the delivered cooling power, divided by the electrical power input. The system reaches its maximum TER value when the loads are balanced.

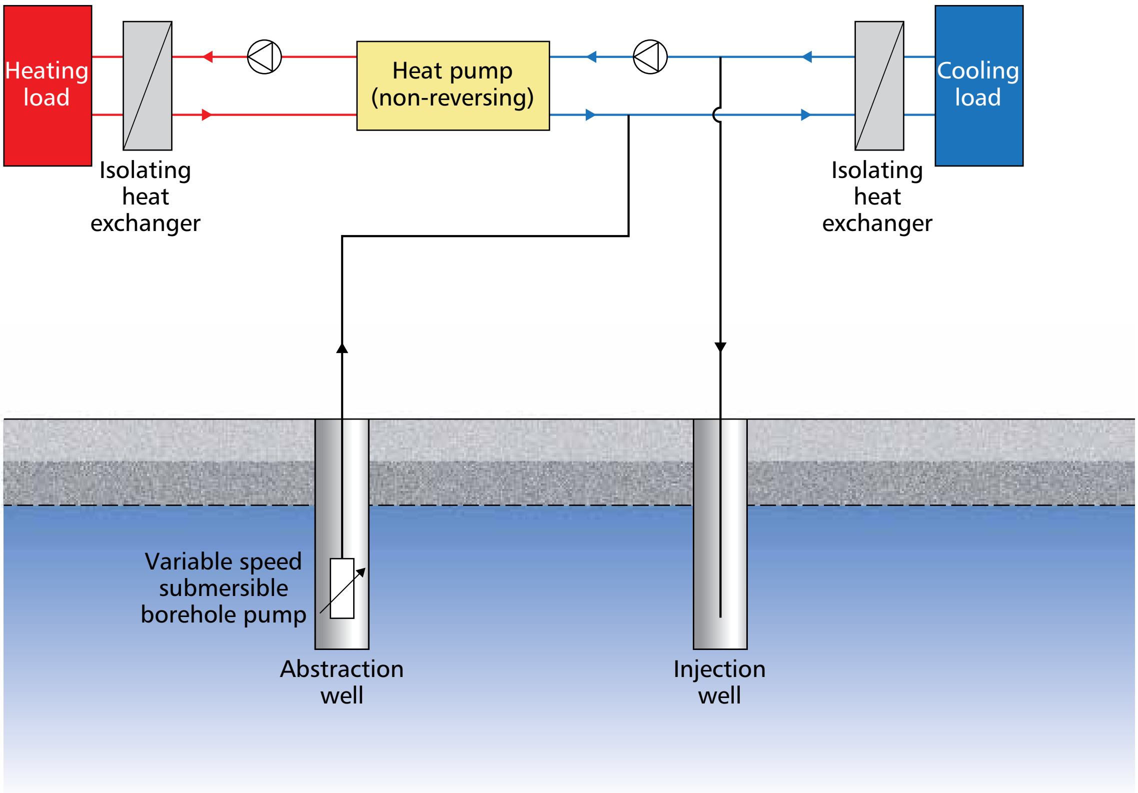


Figure 2 Simultaneous heating and cooling being supplied by a non-reversing heat pump (schematic, for illustrative purposes only)

It is also possible to pair heat pumps so that the thermal energy rejected by one heat pump while providing cooling is used subsequently provide simultaneous heating, see Figure 3. Heat is only collected from, or rejected into, the source when the loads become unbalanced.

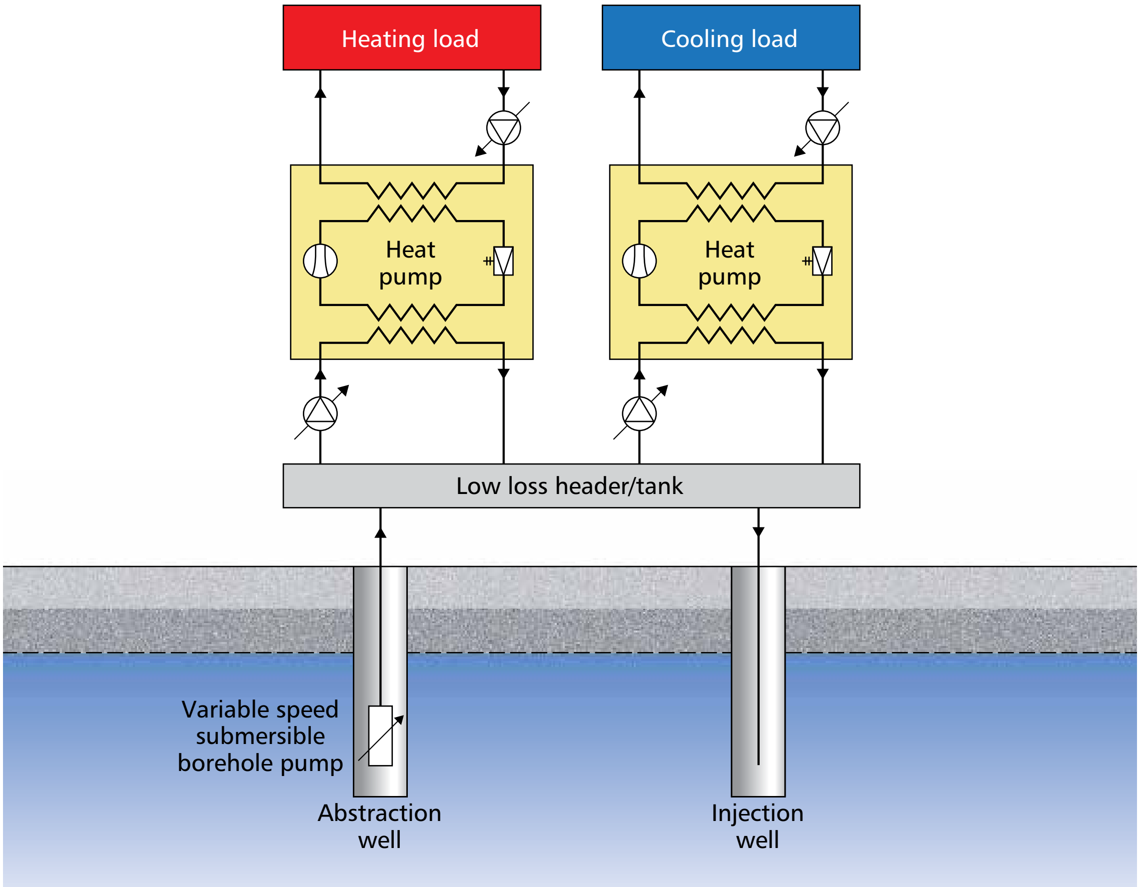


Figure 3 Simultaneous heating and cooling provided by paired non-reversible heat pumps with a low loss header or similar sharing arrangement

Another variant uses the cold water produced after the evaporator of a heat pump while heating to provide cooling, see Figure 4. This technique is sometimes employed to moderate the injection temperature to ensure it remains within prescribed limits.

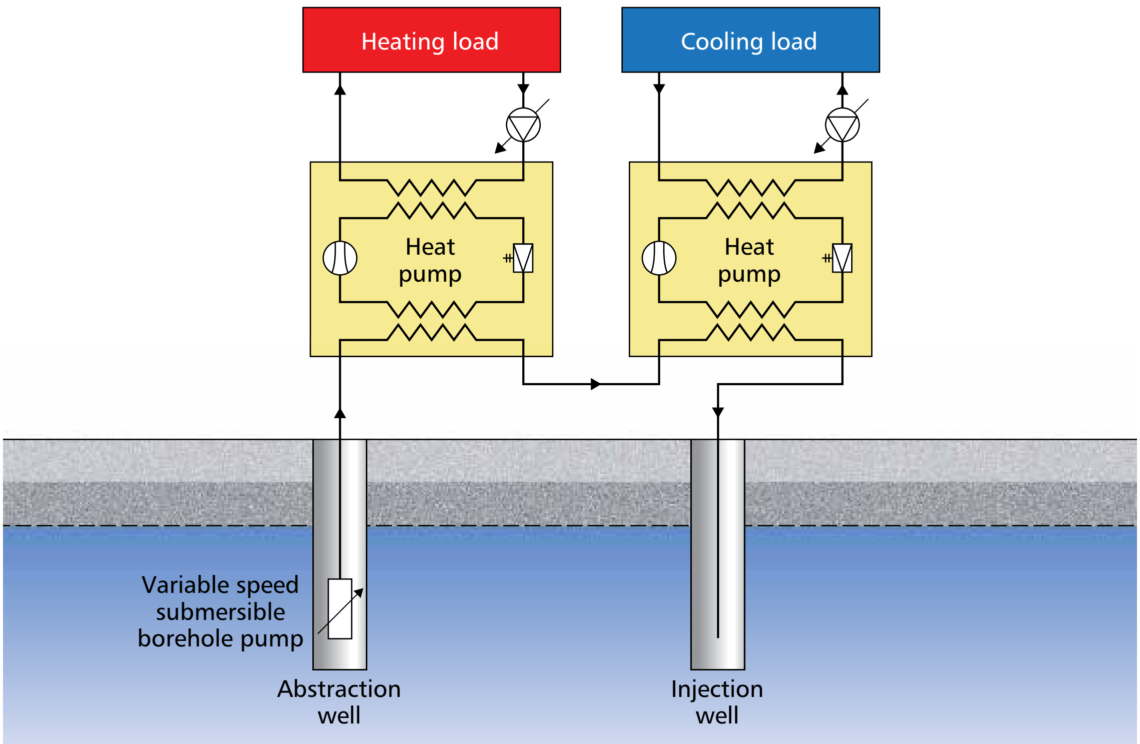


Figure 4 Heat pump arrangement using the cooled water after the evaporator for cooling

Reversible heat pumps work differently; they have a dedicated reversing mechanism fitted internally so the function of the evaporator and condenser can be exchanged to enable the unit to supply either heating or cooling. Air conditioning units designed for use in temperate climates are often reversible, meaning one device can heat or cool the building simply by flicking a switch, see Figure 5.

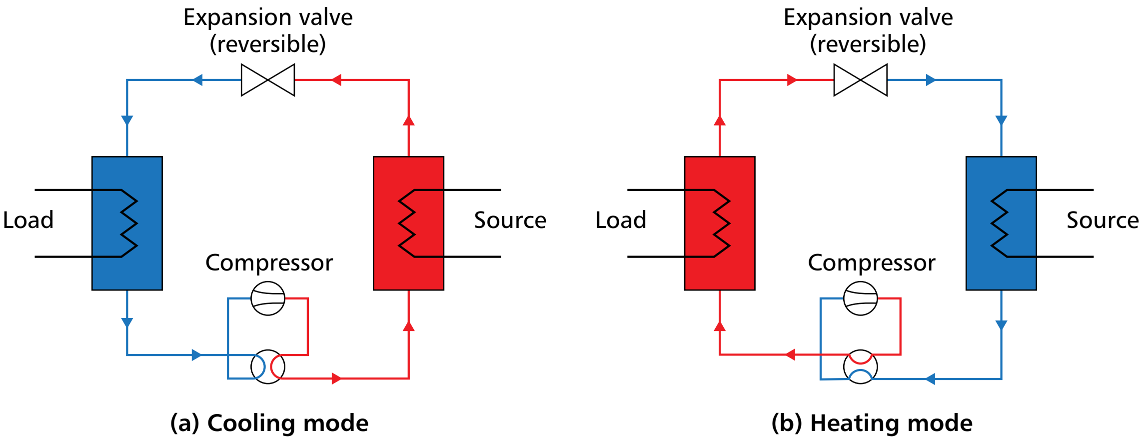


Figure 5 Heat pump arrangement using a reversing valve

B1.3 Key design issues

The Code of Practice primarily looks at the source side of an open-loop GWSHP installation, it does not address air or hydraulic distribution systems on the load side in any detail since, whatever heat generator is to be installed, the load side will use broadly the same design, construction and maintenance procedures.

However, sensible hydraulic design is a crucial component of the overall system performance and heat pumps have some characteristics which, when taken into account, can increase efficiency as well as deliver other benefits:

— For open-loop doublet schemes, especially large installations on a limited building footprint, it is very important to try to achieve a thermal balance between net heating and cooling loads over an annual cycle.

— The closer the source and load temperatures (i.e. the smaller the ΔT) the more efficiently the heat pump will operate. Therefore, low input temperature heat emitters should be specified so heat can be produced and delivered at the lowest possible temperature. Similarly, high temperature cooling can also enhance performance, see Objective 2.5.

— Where existing emitters are designed to operate at historically high distribution temperatures (normally 82 °C flow, 71 °C return), rather than replace the entire distribution system a high temperature heat pump may be specified. These may use a multivalent system, cascade arrangement or alternative refrigerants.

— Pressure drops must be designed to be as low as possible to reduce the energy required to drive the external pumps. This parasitic pumping load can compromise the performance of the entire installation. Injection wells will require regular preventative maintenance and occasional reconditioning as will submersible pumps, especially when they are installed in a deep aquifer.

— Different refrigerants may be used for a particular application and/or to take into account refrigerant Global Warning Potential (GWP) and toxicity levels.

— Heat pump evaporators and condensers frequently have flow, pressure and temperature constraints/parameters, which must be observed to prevent damage and ensure optimum efficiency.

— Short cycling should be avoided as it risks reducing the heat pumps life. The District Network Operator (DNO) may also impose a limit of 3 or 4 starts per hour. The hydraulic arrangements will need to allow for this.

— A buffer tank is often used to provide short-term thermal energy storage to smooth the output from the system and overcome any peaks or troughs. Buffer tanks can be of 2- or 4- or more pipe design; they can assist with reducing cycling but can also reduce efficiency by increasing flow temperature.

Historically, single stage heat pumps were either 100% off or 100% on, but advances in pump and compressor technology mean that more multistage and modulating (inverter or variable speed drive) heat pumps are available. Other strategies that enable multiple units to automatically switch in or out to load match (sequence control) or 'sliding' header arrangements are also employed. The ability to balance output and load simplifies design and improves system performance.

Heat pump sizing

When calculating the load to be satisfied by the heat pump the design should consider building thermal mass, internal and solar heat gains, and any other loads present, for example swimming pools or data centres, where appropriate. As with all heating/cooling installations, establishing the peak power accurately is important to ensure that sufficient heating/cooling is available to keep the premises comfortable on both the hottest and coldest of days.

If the heat pump is sized to cover the entire peak heat load itself it will be a monovalent system, but the heat pump may be sized to provide only the base load when additional heat generators are used to satisfy the peaks. These are bivalent or multivalent systems (see Objective 2.5).

In addition to peak power, accurate annual energy demand profile information is critical for design. However, GWSHPs are more forgiving than a closed-loop vertical or horizontal ground heat exchanger, because the ground needs time to recover. When an open-loop system is adopted, the design can be more flexible as the flow rate or flow duration through the evaporator can be varied to match the load, always ensuring it is within the permitted levels agreed for the abstraction licence and discharge permits.

It is essential that the annual energy demand profile as well as peak power is accurately calculated. This is required for modelling thermal performance of the aquifer and to determine the maximum hourly, daily, monthly and annual source-side flow volumes, as required by the relevant environmental agency.

Consideration should also be given to the likelihood that the building usage pattern may change in the future, for example a school opening for evening classes. Designers must be aware that the 'as built' peak power and energy demand may differ significantly from the initial design calculations. Seasonal commissioning and optimisation of the installed heat pump system should be considered.

Parasitic energy loads

A significant, but often overlooked issue affecting the operating efficiency and economic benefits of a GWSHP system is parasitic energy consumption. The energy used by abstraction pumps sometimes exceed the energy consumed by the heat pump since, unlike circulation pumps in closed loop systems, these pump against an absolute head so energy consumption increases significantly with depth. This energy use can be substantially reduced through good design, such as:

— minimising the depth below ground level of the submersible pump, see Figure 6

— installing a porter shroud, see Figure 25

— using buffer tanks to run at more optimal loads and for longer periods of time

— using high efficiency motors and variable speed drive controls

— reducing flow rates to match demand (within operating design limits)

— minimising pipework pressure losses

— minimising reinjection pressure

— avoiding flow restricting fittings

— switching off unnecessary loads.

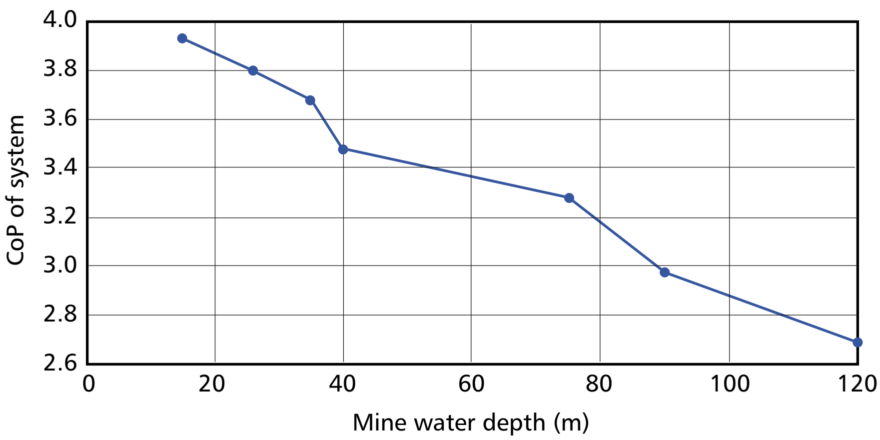


Figure 6 Relationship between depth of water in a coal mine and coefficient of performance of the system (source: Athresh et al. (2015); courtesy of Prof. Amin Al-Habaibeh and Dr Anup Athresh, Nottingham Trent University)

To obtain a realistic estimation of the performance of the installation it is essential that a calculation or measurement of efficiency takes into account the energy consumption of the entire system and not just the heat pump itself.

Pump performance factor (PPF) as a measure of source pump(s) performance can be useful to compare system performance and thus efficiency:

$$\text{PPF} = \frac{\text{pump(s) power consumption (kW)}}{\text{heat pump output (kW)}} \times 100$$

Note: It is important not to confuse the heat pump thermal output (kWt·h) with the electricity supply requirement (kWe). While the precise figure will depend on each unit’s CoP, the heat pump’s power requirement will always be less. For example, a 300 kWt·h output heat pump with a CoP of 3 will require only a 100 kWe supply (other variables must also be taken into account, such as starting current and minimum CoP). Erroneously specifying a 300 kWe supply will substantially increase capital expenditure and can result in an otherwise viable scheme being abandoned.

Assessment of system performance

Various methods can be used to calculate (during feasibility and design) and measure (during commissioning and operation) the efficiency of heat pump systems. The methodologies recommended in this Code of Practice are summarised in Table 4, and further details on system boundaries in Appendix D and Figure 7. Figure 49 in Objective 3.9 demonstrates typical metering arrangements and calculations.

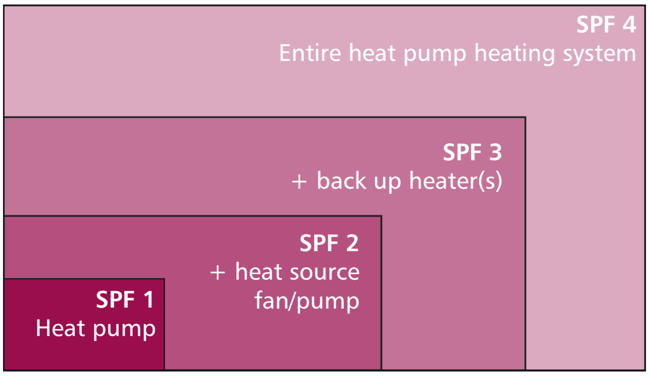


Figure 7 Boundaries used for calculations of system efficiencies (as defined by the SEPEMO project; see Appendix D for further details)

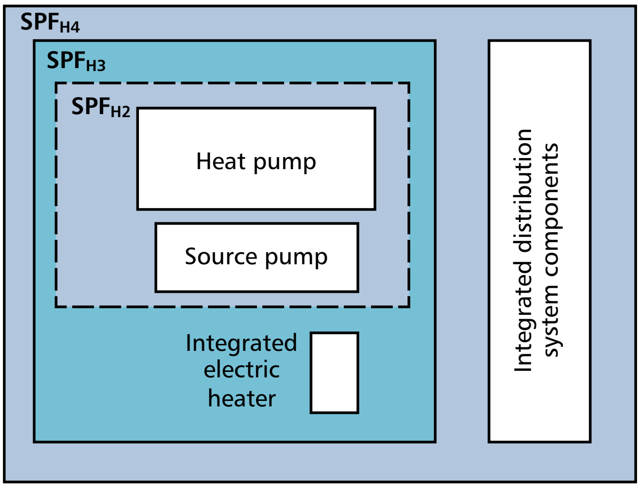


Figure 8 Heat pump boundaries for electrical input measurements (reproduced from section 8.36 of *Ofgem Non-Domestic Renewable Heat Incentive (RHI) Guidance Volume 1* (Ofgem, 2015))

Table 4 Methodologies for measuring and calculating heat pump system efficiency as used in this Code of Practice (see also Appendix D and Glossary)

Methodology (see note 1)	Type	Definition	Stage	Objective	Why this is important?	Typical system boundary
Coefficient of performance (CoP)	Calculated	Heat output/electrical power input. An expression of the efficiency of a machine in heating mode, at a selected source and load temperature. It is an instantaneous figure rather than an average. CoP always quoted with a source and sink temperature, e.g. ASHP CoP = 3.1 @ A7/W35 or GSHP CoP = 3.5 @ B0/W35. Without source and sink temperatures, it is not a CoP. All others (SCoP, SPF, etc.) are estimated, calculated or measured averages of seasonal CoP, and so do not feature temperatures.	Feasibility, design, commissioning	n/a	To help select an appropriate heat pump and monitor. It may also be that these figures are required to demonstrate compliance for government regulations or financial incentives. its performance.	SPF_1 (see note 3)
Seasonal coefficient of performance (SCoP)	Calculated	Method for calculating SPF (see below) at design stage, as defined in BS EN 14825 (BSI, 2018c) using data and test methods derived from BS EN 14511 (BSI, 2018d).	Design	3.8.2	To update calculations made at feasibility stage based on more accurate specifications	SPF_3 or (see notes 2 and 3)
			Commissioning	5.3.4	To check the predicted system performance at against calculations made at design stage. Remedial action might be taken if predicted is likely to be less than originally expected.	SPF_4 (see notes 2 and 3)
Seasonal performance factor (SPF)	Calculated	Annual total heat out/total annual system electrical power in. A ratio expressing the average seasonal efficiency of a heat pump by describing heat output over the season. Calculation method defined in BS 15316 (BSI, 2017a) using data derived from BS EN 14825 (BSI, 2018c).	Design and/or pre-commissioning	3.8.2 5.3.4	To provide a more accurate prediction of total system energy efficiency. It may also be that these figures are required to demonstrate compliance for government regulations or financial incentives.	SPF_4

Table continues

Table 4 Methodologies for measuring and calculating heat pump system efficiency as used in this Code of Practice (see also Appendix D and Glossary) — *continued*

Methodology (see note 1)	Type	Definition	Stage	Objective	Why this is important?	Typical system boundary
Seasonal performance factor (SPF)	Measured	Annual heat out/annual electrical power in. A ratio expressing the in-use efficiency of a heat pump system by describing heat output over the season.	Operation and maintenance	6.4.7	To monitor and report on actual system performance and ensure that performance is maintained over time.	SPF_4

Note 1: Methodologies for determining efficiencies are shown for heating applications. For cooling, the equivalent efficiency metrics are as follows:

- Energy efficiency ratio (EER) is the cooling efficiency coefficient over a very short period and is hence comparable with CoP for heating.
- Seasonal energy efficiency ratio (SEER) is the cooling equivalent of, seasonal coefficient of performance (SCoP), which must be calculated or measured over a period of 12 months to be truly 'seasonal'. When calculated, SCoP and SEER use typical average climate data. When measured, SCoP and SEER will be affected by any climatic deviations from the mean over the 12 month period and hence corrections may be needed to represent 'average' seasonal conditions.

Note 2: SCoP is NOT strictly the same as SPF, therefore when calculating a predicted SCoP the boundary will be generally in accordance with one of the SEPEMO boundaries. However, SCoP for GWSHPs does not normally include the energy used by the abstraction pump, which means it would not be truly accurate from SPF_2 through to SPF_4, since SPF_2 should include all the energy required to circulate/pump fluid around/from the source.

Note 3: Coefficients are ratios of the same metric and when multiplied by 100 become percentages. Ground source heat pumps have coefficients in excess of 1 and hence appear to have efficiencies well in excess of 100%, typically 300–400%. However, the overall fuel input to heat output should be considered and for electrically driven heat pumps this will be based on primary generating efficiency. With a primary energy factor of 40% (40% electricity generation for 100% fuel input) the overall typical efficiency would be 120–160%.

B2 Groundwater sources and their characteristics

The idea of using groundwater to provide heating and/or cooling for living spaces to improve human comfort is not new. Gently sloping underground water channels (qanats) many of which are 3000 years old have been used in the Middle East to provide cooling. Naturally occurring geothermal springs have been used historically for heating, for example the thermal baths in Bath. Heat pumps now provide new opportunities and applications.

The starting point of every project is to investigate the resources available, in particular the underlying geology and hydrogeology. In the UK, information can be obtained from the British Geological Survey (BGS) (https://www.bgs.ac.uk) and the Geological Survey of Northern Ireland (GSNI) (https://www.bgs.ac.uk/gsni). This can include site-specific hydrogeological reports or an initial assessment of subsurface suitability for large-scale open-loop installations. These provide an excellent starting point but do not remove the requirement to employ a suitably qualified hydrogeological expert.

B2.1 Aquifers: the occurrence of groundwater in the subsurface

Aquifers are bodies of porous, permeable rock or sediment that can provide a useable quantity of groundwater. Groundwater is formed from, and replenished by, rainwater that has flowed from the surface through pore spaces in the soil and downward into underlying rock formations. Where an aquifer intersects the surface groundwater will emerge as a spring or seep.

Major aquifers in the UK include chalk, sandstone and limestone formations while shallow sands and gravels associated with some river and/or glacial deposits can also form productive aquifers, see Figure 9.

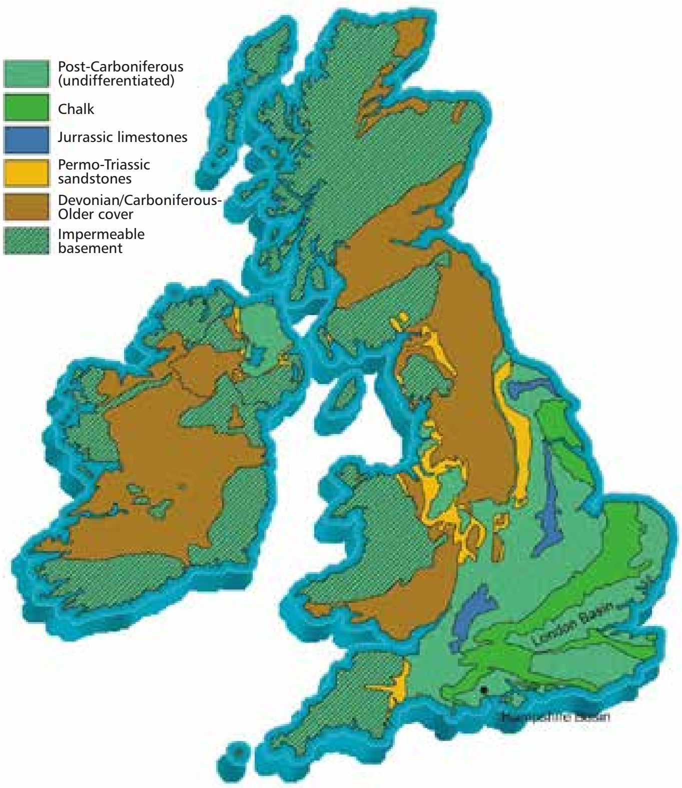


Figure 9 Geological map of the principal aquifers of Britain and Ireland (courtesy of the British Geological Survey)

The temperature of shallow groundwater (<50 m depth) is often close to the average air temperature of that location and varies with latitude. For example, an open-loop borehole in London would produce water at a temperature of over 13 °C. In upland areas of the north of Scotland or Northern Ireland the temperature is closer to 8 °C.

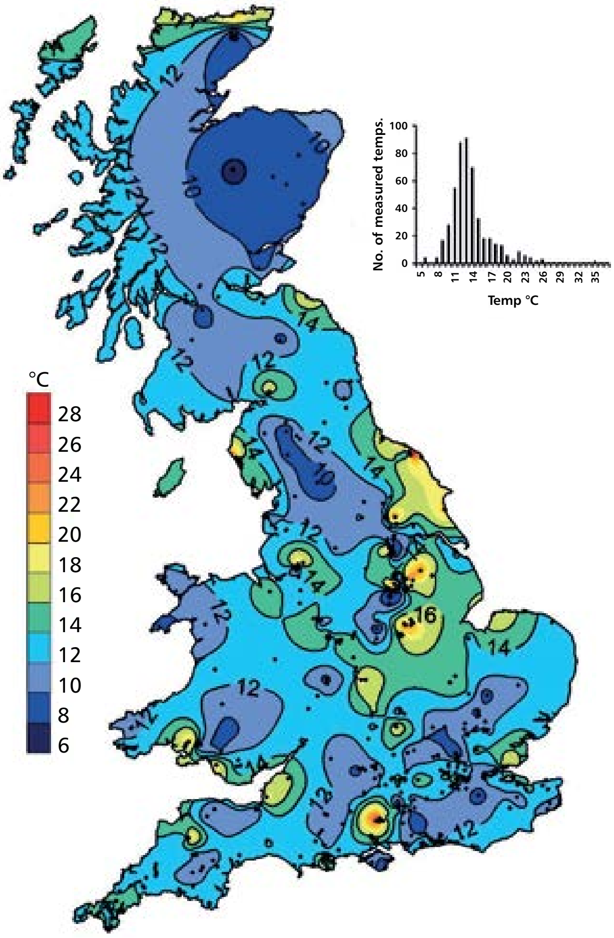


Figure 10 Measured temperatures at 100 m depth below ground level. Measurement locations are indicated by the black dots (reproduced from Busby et al. (2011), courtesy of the British Geological Survey)

In some circumstances artesian flow can occur. An artesian flow is where water emerges from the borehole at the surface under natural pressure, see Figures 11 and 12.

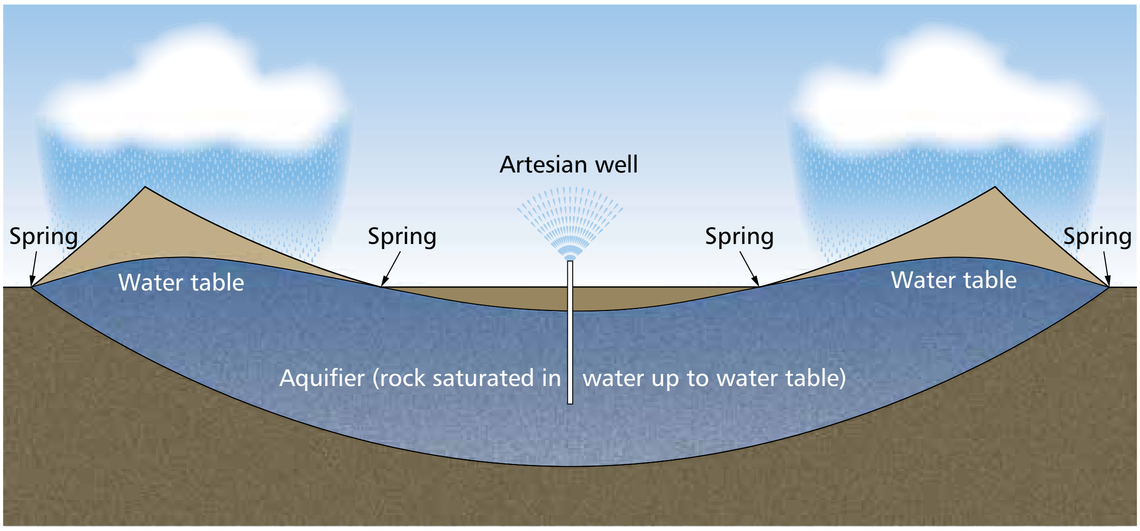


Figure 11 Artesian flow

Figure 12 A temporary borehole wellhead on an artesian open-loop abstraction borehole drilled into Carboniferous Artesian Millstone grit in Yorkshire (courtesy of Carbon Zero Consulting Ltd.)

Table 5 The key variables that need to be considered when assessing the viability of a groundwater resource to supply heating and/or cooling

Variable	Considerations
Yield	Is there enough water available from the underlying aquifer for the proposed heat pump installation?
Accessibility	How easily can this yield be obtained, i.e. what is the degree of complexity and cost of an open-loop borehole system? Is the site footprint large enough to accommodate the boreholes required for abstraction and injection?
Quality	What are the risks or corrosion, incrustation, bacteria and presence of particles and dissolved gases? Is the groundwater contaminated?
Discharge	What happens to the water afterwards?
Interference	Will the proposed scheme conflict or interfere with other groundwater users?

Some groundwater may be contaminated by agricultural practices or by historical industrial or mining activity. This may make it unsuitable for potable purposes but it can still provide heating and/or cooling. However, if the thermally spent groundwater is subsequently re-introduced into the ground, legal or regulatory issues may have to be satisfied as the discharge of many forms of contamination is strictly controlled.

There are examples where contaminated groundwater has been used for an open-loop GWSHP installation. For example, in Holland, water contaminated with chlorinated hydrocarbons has been remediated at the same time as using it as a groundwater source in an aquifer thermal energy storage system (Sommer et al., 2013).

When drilling into an area where the groundwater or land is known to be contaminated, early consultation with the relevant environmental regulator is recommended to ensure that the required environmental permission can be obtained.

Open-loop GWSHP schemes require detailed understanding of water quality and its implications. Initial investigations should therefore include a minimum set of on-site measurements and laboratory analysis and the adopted measurement and sampling procedures must follow standard protocols. Poor understanding of water quality can lead to several types of problem, including:

— clogging or incrustation of wells, pipes, filters, heat exchangers or soakaways with chemical precipitates, biofilm or particulate matter, see Figures 13 and 14

— clogging of pore spaces around injection wells with bubbles of exsolved gas

— abrasion or corrosion of components

— risk of subsidence due to pumping of particulates

— saline intrusion

— liability for contamination.

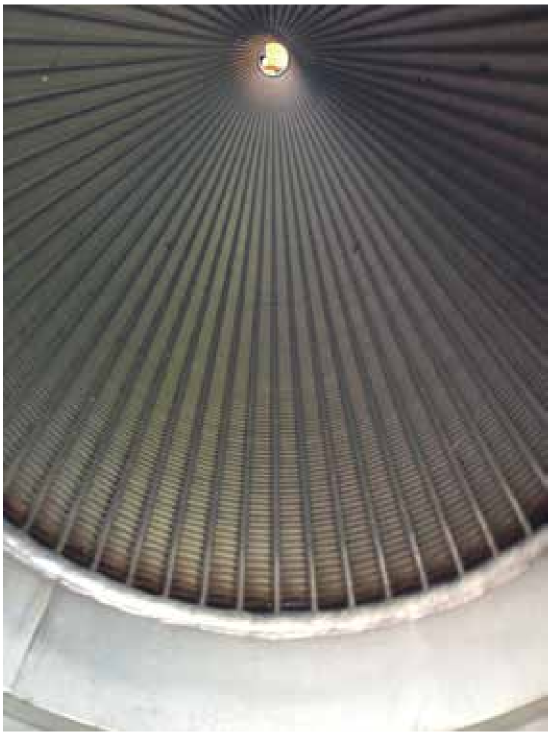


Figure 13 A clean wellscreen (courtesy of Carbon Zero Consulting Ltd.)

Figure 14 A clogged wellscreen (courtesy of Carbon Zero Consulting Ltd.)

B2.2 Water wells and boreholes

A water well is an excavation or structure created by digging, driving, boring or drilling to access groundwater in aquifers. A borehole is a small diameter hole drilled into the ground for any purpose, which can include water abstraction or injection.

The Water Resources Act 1991 requires that borehole logs for water wells of greater than 15 m depth are submitted to the British Geological Survey (BGS). Similarly, the Mining Industry Act 1926 requires that borehole logs of mineral exploration boreholes of greater than 30 m depth are also submitted to the BGS. Other borehole logs should also be submitted to BGS to aid their geological survey work. Logs can be labelled as confidential if required, to prevent dissemination to third parties.

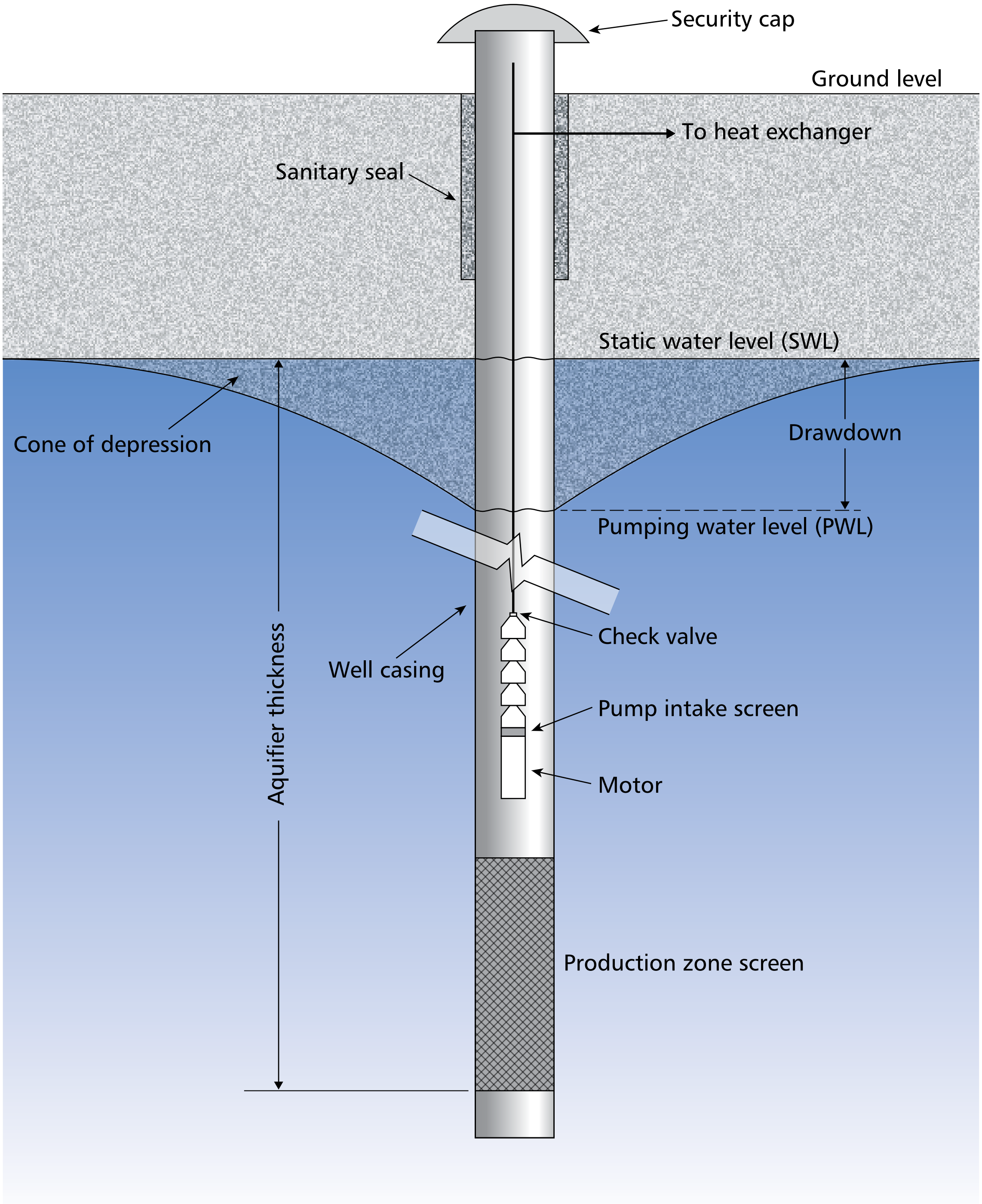


Figure 15 Example of an abstraction well (adapted from Kavanaugh and Rafferty (2014); courtesy of ASHRAE)

Borehole-based water wells are constructed to a design, depth and diameter to suit the geology and the size (diameter) of the pump that will supply the required flow of water. Modern boreholes are designed to accommodate an electrical submersible pump. Typical submersible pump diameters for use with open-loop systems vary, commonly between 100 mm for smaller systems and 200 mm for very large flow requirements.

The yield of a water well is controlled by the nature of the aquifer and borehole design. Borehole diameter has a relatively minor impact on sustainable yield. The design of a borehole is critical to the success and longevity of a borehole water supply and requires a suitably qualified hydrogeological expert from an early stage of feasibility and design.

B2.3 Groundwater from flooded mines and quarries

Caverns, tunnels or mines frequently contain large bodies of water that can be employed to provide renewable heating and/or cooling. In the UK this has been used to a limited extent for heating and cooling and a number of techniques to tap into this asset have been developed and tested.

Great care must be taken when using mine water because it may contain high concentrations of naturally-occurring dissolved or suspended chemicals that can be harmful to the environment. The effects of impurities on a heat pump installation must be considered during design, operation and maintenance procedures as they can compromise the efficiency or longevity of a system.

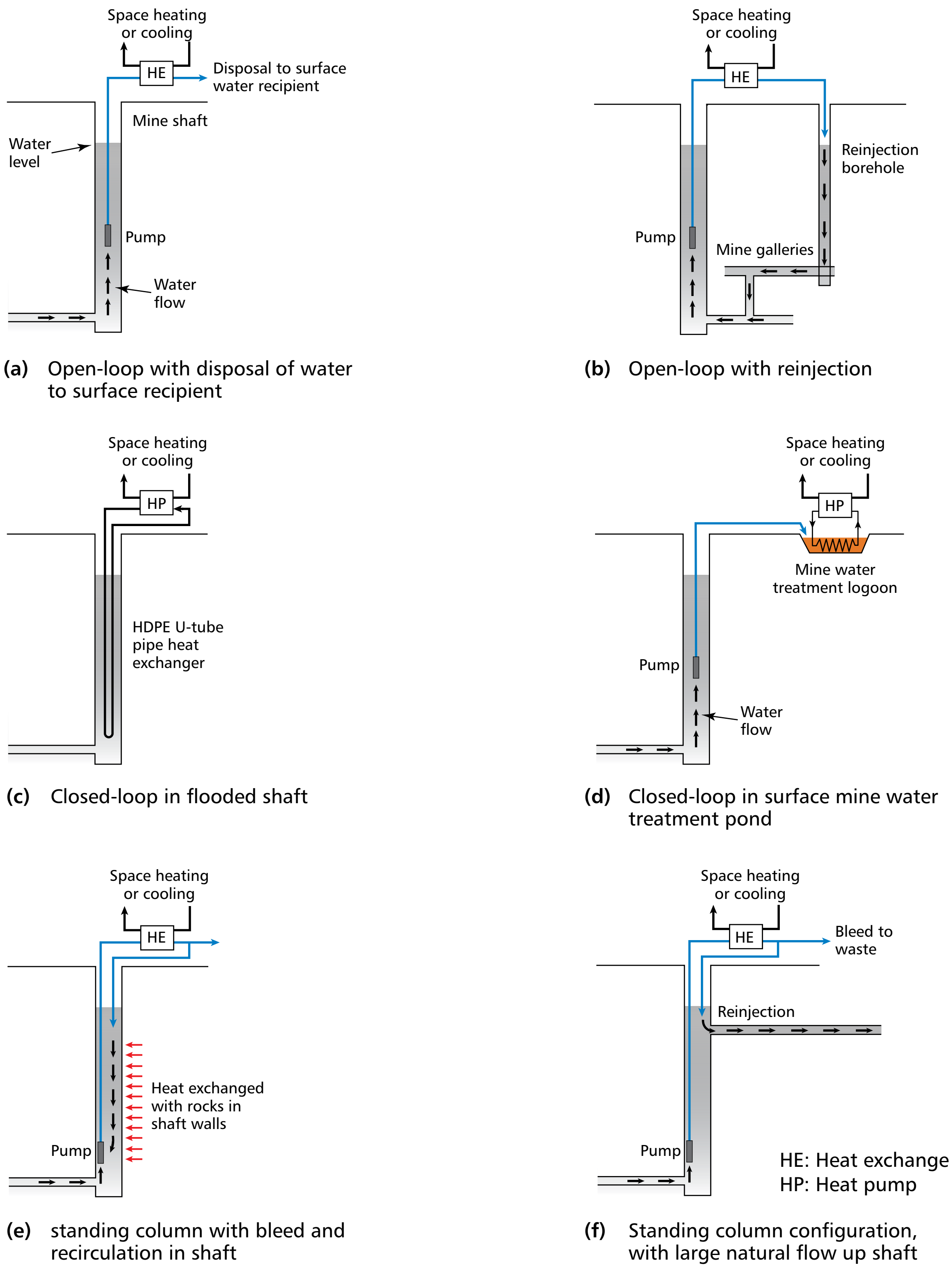


Figure 16 Different modes of heat extraction from/rejection to abandoned, flooded mines (reproduced from Banks D, Athresh A, al-Habaibeh A and Burnside N (2017) by permission of David Banks; © David Banks)

It is estimated there are over 1000 mine shafts and related boreholes in the UK that may be suitable for open-loop GWSHP installations. Many of these mines are the responsibility of the Coal Authority, a non-departmental public body which oversees the legacy of the former British coal industry, see Appendix C.

To prevent pollution, the Coal Authority already pumps and/or treats in excess of 100 billion litres of mine water every year, which equates to over 3000 litres per second. Its use for low-carbon heating and cooling allows it to be transmuted into an environmental and economic asset.

Much of this mine water is warm, ranging between 12 °C and 20 °C, with little or no seasonal temperature variation, making it an ideal source for low-carbon heating or cooling.

Figure 17 Mine water treatment scheme at Caphouse Mining Museum, near Wakefield (© David Banks; courtesy of David Banks)

The Coal Authority estimates that 66 MW of heat energy is currently lost to atmosphere from mine water treatment schemes. The total thermal energy that is available stored within coal mines is estimated to be 2.2 million gigawatt-hours.

In Shettleston, Glasgow, a social housing development was constructed in 1999, comprising 16 apartments, see Figure 18.

Figure 18 The Glenalmond Street housing development in Shettleston, Glasgow, heated by a coal mine water-sourced heat pump scheme (© David Banks; courtesy of David Banks)

Water is pumped from a borehole penetrating abandoned, flooded coal mine workings and is passed through a heat pump array of approx. 65 kW nominal capacity, supplying water at about 55 °C to a thermal store. This supplies space heating and supports domestic hot water provision to the residents at a low annual cost. The thermally-spent mine water is directed to a shallower reinjection borehole.

Elsewhere in Europe one of the largest mine water projects is at Heerlen in the Netherlands, where a low-temperature district heating system was launched in October 2008 (Figure 19). This was upgraded in 2013 to a ‘thermal smart grid’ with decentralised heat pump stations that can both consume and supply heat. These enable the mine water reservoir to be used to store thermal energy that would otherwise be wasted.

The system is currently used to heat and cool 200 000 m^2 of buildings and will be extended to a further 10 000 renovated dwellings over the next 5 years (Mijnwater, 2014) (see https://www.mijnwater.com/?lang=en).

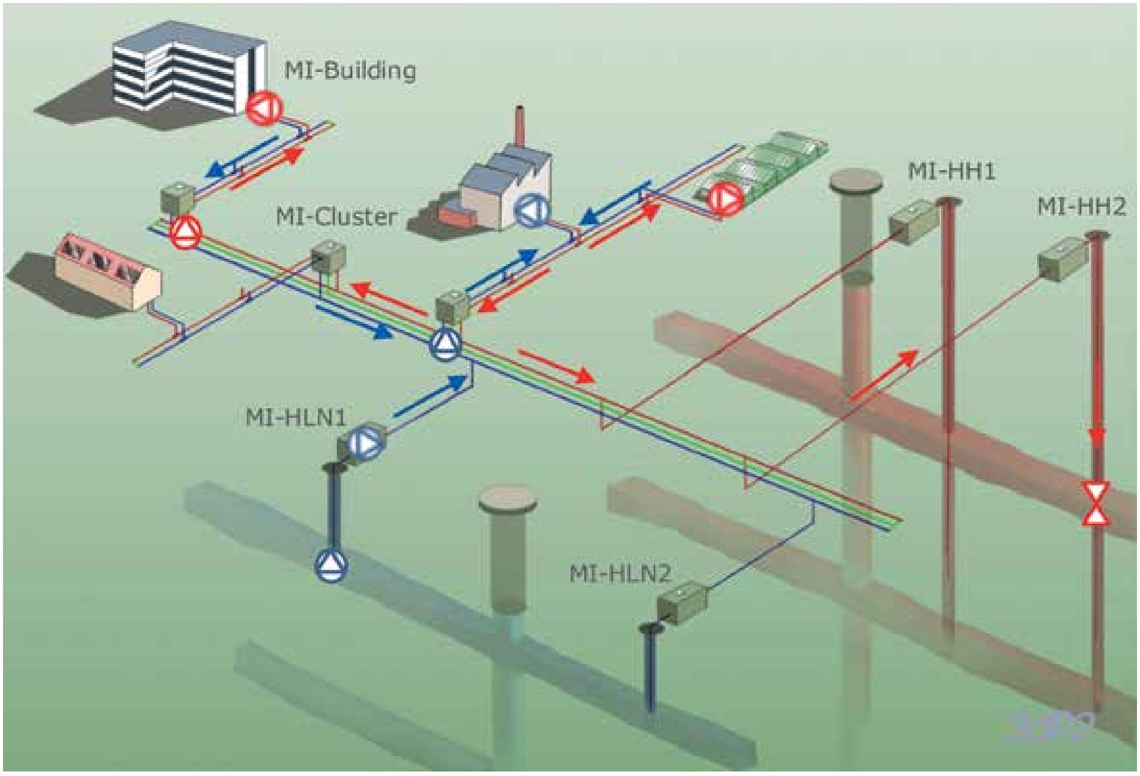


Figure 19 The mine at Heerlen (courtesy of Mijnwater BV)

B3 Types of installation

Groundwater can be accessed as a heating or cooling resource using either open- or closed-loop systems. The choice of technology will depend on the specific site circumstances. This Code of Practice specifically considers open-loop GWSHP installations.

Open-loop systems remove water from the source and physically pass it through a heat exchanger inside or very close to the heat pump so the unit exchanges heat with the water as directly as practicable, see Figure 20.

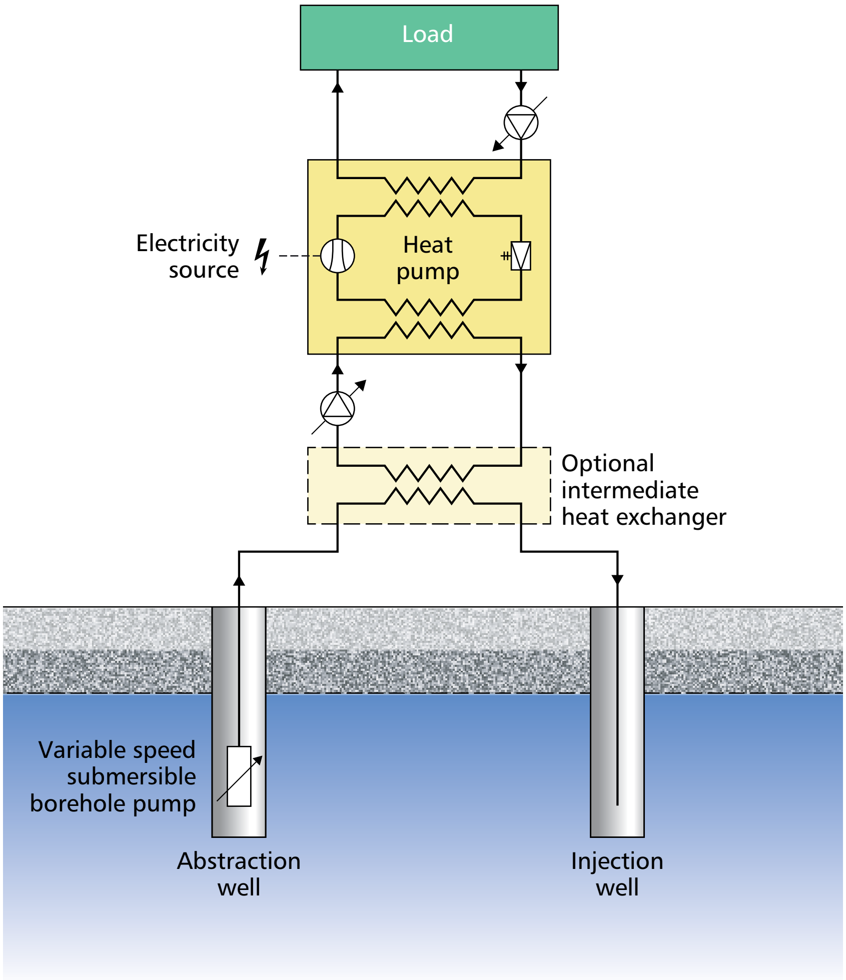


Figure 20 Simplified schematic showing optional heat exchanger

Open-loop systems may be used alone or in association with other technologies and in some cases may be configured to provide underground thermal energy storage (UTES), more commonly termed aquifer thermal energy storage (ATES) for open-loop applications.

The following examples demonstrate some of the challenges and opportunities surrounding open-loop systems and how the technology can be harnessed.

B3.1 Open-loop doublet systems: abstraction with injection to aquifer

Most groundwater open-loop systems involve abstraction wells, taking the water from the ground, and injection wells, returning water to the ground. By returning all the water to the same aquifer the scheme is termed 'non-consumptive', i.e. there is no net effect on the aquifer other than temperature change (although the introduction of heat to the ground can be regarded as a polluting activity and may affect the water quality). Non-consumptive systems make licencing of the project more straightforward and can allow projects to proceed where otherwise they would not.

In some cases, systems need multiple wells to meet the flow rate required to satisfy the building's heating and cooling requirements. Although it inevitably increases installation costs, this approach improves resilience and avoids the risk of failure associated with a single abstraction well. Injection wells will require regular preventative maintenance and occasional reconditioning to ensure injection rates do not decline significantly.

The separation between the abstraction and injection wells is a key consideration. This is always site specific and will depend on the geology and detailed properties of the aquifer and requires thermogeological modelling. The presence and direction of groundwater flow will influence the separation requirement, injection should always be made downstream of the abstraction well.

The typical separation required between abstraction and injection wells is around 100 m. If there are multiple abstraction wells, typical separation between each well is around 25 m, see Figure 21. These spacings are only indicative and a suitable professional must be engaged to assess the groundwater gradient and appropriate separation requirement at each location.

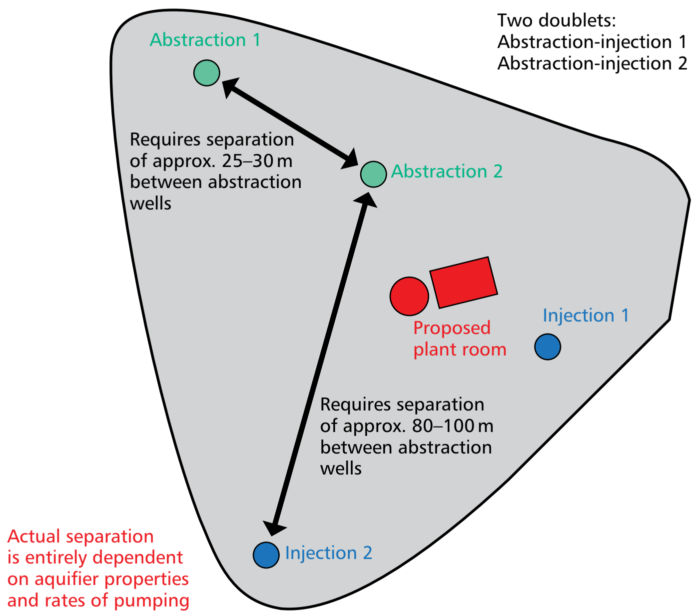


Figure 21 Example of well separation

If the wells are too close together 'thermal breakthrough' (recirculation) can result, see Figure 22 below. This means that the water temperature in the abstraction well is affected by the injection well, either increasing or reducing the undisturbed groundwater temperature. As a consequence, some sites may be too small to accommodate an open-loop doublet system. In many cases a degree of long-term thermal breakthrough can be tolerated as part of the design although excessive thermal interaction should always be avoided. The likelihood of thermal breakthrough may be minimised by ensuring that the heating and cooling loads are thermally balanced over an annual cycle. It is also possible to manage operational temperature gradients by 'bleeding off' a proportion of the total flow of water and discharging it elsewhere.

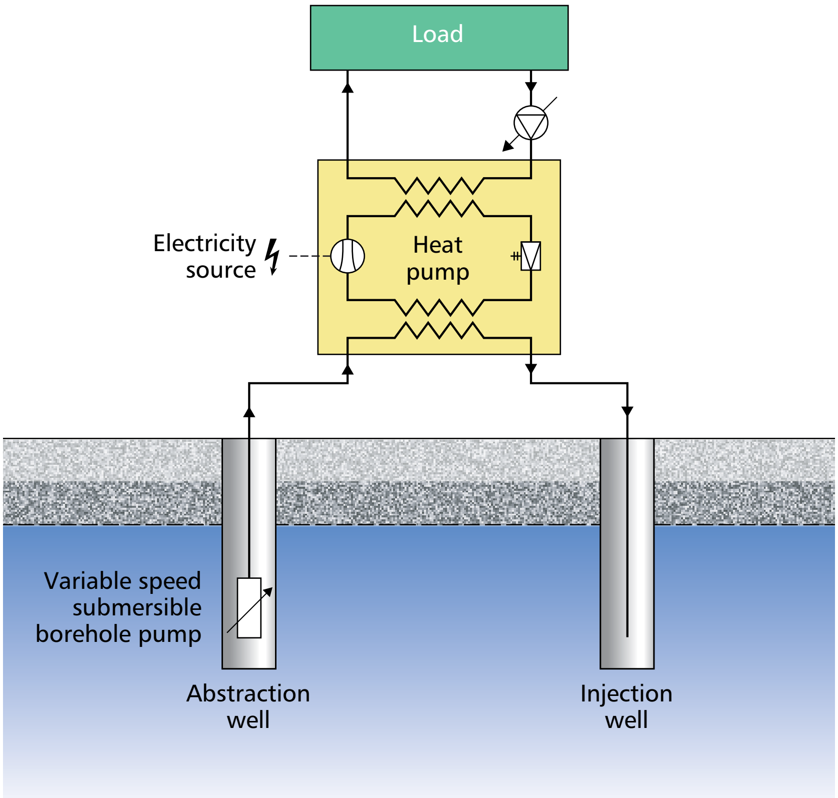


Figure 22 Thermal breakthrough (recirculation) schematic example

If two separate aquifers are available beneath the site, it may be possible to use one for abstraction and the second for injection (Figure 23); however, this would be considered 'consumptive'. In these situations, the spacing between the wells can be significantly reduced. It is important to understand the properties and the hydraulic connection or separation of the two aquifers in detail. It is also important to obtain advice from a hydrogeologist and the relevant environmental agency regarding potential issues with such schemes.

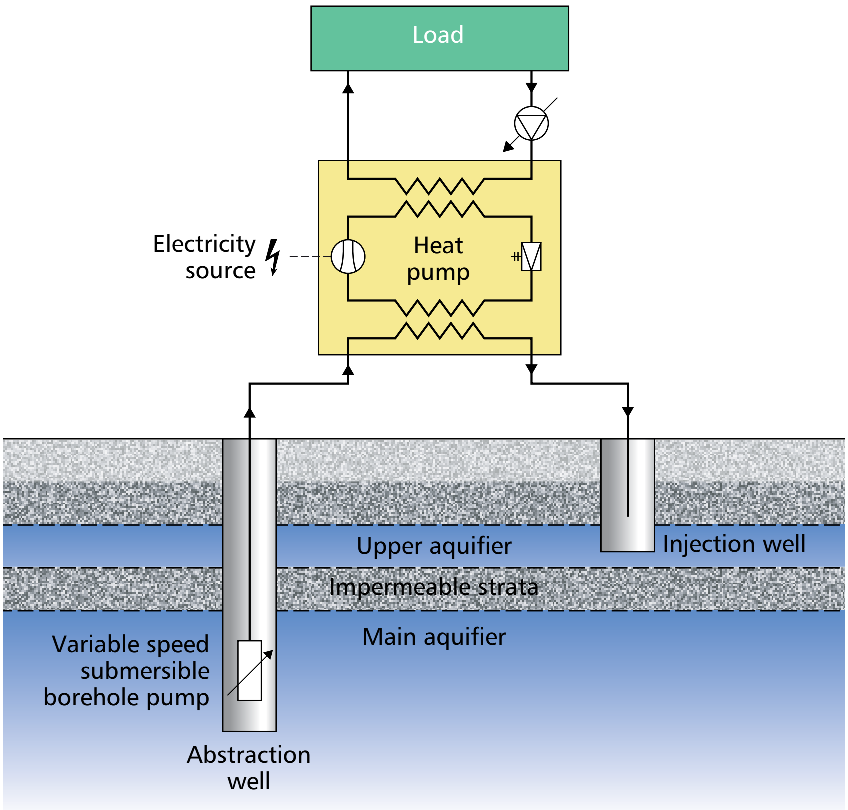


Figure 23 Schematic of vertically separate aquifers

Special considerations

The majority of open-loop GWSHP systems use one or more doublet pairs or 'dipole' for abstraction and injection of the water. A doublet arrangement is non-consumptive, i.e. all water that is abstracted is returned to the same aquifer, albeit at a slightly higher or lower temperature.

When heating, an open-loop GWSHP cools the groundwater returned to the aquifer and vice-versa. It is important to understand any significant environmental effects of changing the groundwater temperature and so the risk can be managed effectively. This may be mitigated, see Figure 4, or used beneficially, for example in an ATES system, see section B4.6.

The relative position of abstraction and injection boreholes is constrained by site boundaries, and other building construction or access issues, see Figure 21, but the following are important:

— Abstraction and injection borehole locations will normally be as far apart as possible to minimise interference between the 'cone of depression' caused by abstraction, and the resulting 'cone of uplift' formed in the level of groundwater within the injection borehole.

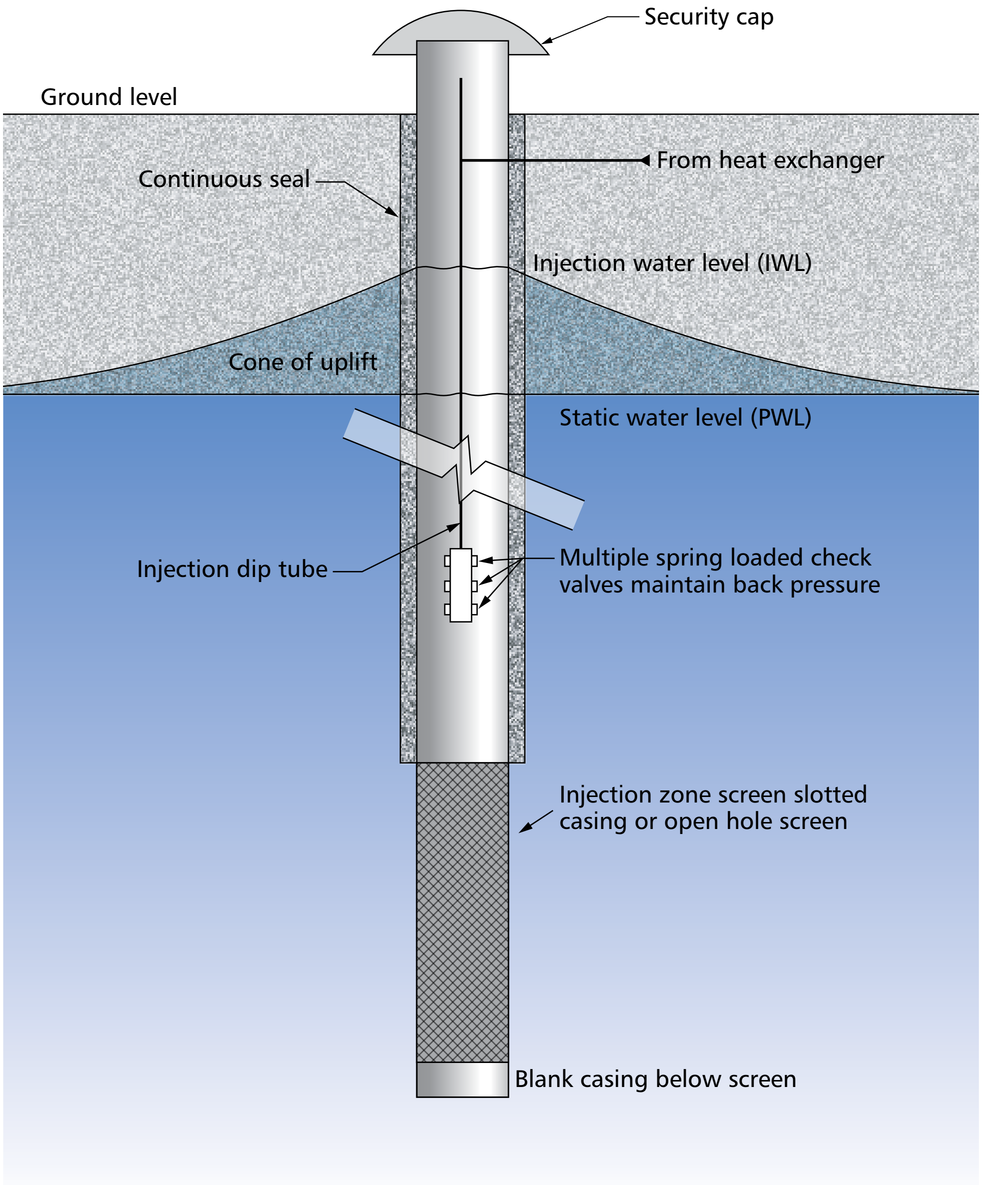


Figure 24 **Example of an injection well** (adapted from Kavanaugh and Rafferty (2014); courtesy of ASHRAE)

— The location of abstraction and injection should take into account the regional hydraulic groundwater gradient.

— The impact of nearby existing abstractions (for water supply or other GWSHP systems) as these could be modifying local groundwater conditions.

— In some cases (ATES, see section B4.6) the function of the abstraction and injection boreholes is reversed interseasonally.

— The depth below surface of groundwater (the 'rest' water level, or 'water table') must be known. A rest water level very close to the surface might impact on the ability to return the water to the aquifer. In an unconfined aquifer, this could cause flooding if the groundwater level within the injection borehole and aquifer rises above surface. In a confined aquifer, this effect can often be managed by suitable design of casing depths within the injection borehole.

B3.2 Open-loop systems: abstraction only with discharge to surface water or sewer

In some cases, it can be easier or more cost effective to drill an abstraction well to supply the required flow of water, with the spent water discharging to a sewer, waterway or surface water body. This is termed a 'consumptive' system as there is a net loss of water from the aquifer. Although there is a saving to be made by not drilling an injection borehole, other costs might be involved that outweigh this advantage. This form of GWSHP is only acceptable when regulatory requirements allow.

If the water is discharged into a waterway or surface water body, permission will be required from the relevant environmental agency and in the case of most rivers and canals, the owner/operator. Charges may apply, particularly discharge into a sewer and will be charged per unit volume of water. The cost can sometimes be considerable so should be quantified as early as possible.

An example is the Bank of Kuwait, Baker Street, London. The site footprint is too small to accommodate an abstraction and injection borehole pair and so a single abstraction borehole is used to provide the water, with discharge to an adjacent sewer.

B3.3 Standing column wells: abstraction and injection to the same well or shaft

Originally developed in the north east of the United States in the 1970s to utilise the legacy of water wells found in that area, standing column wells (SCWs) were primarily used to provide heating for domestic scale installations.

The technology has subsequently been further developed in North America and can now be found in much larger commercial geothermal heat pump systems where hydrological and geological conditions are suitable. It is also successfully employed in some mine water schemes.

A standing column well can be advantageous during the design phase as the performance can be predicted more accurately without an extensive hydrogeological study, therefore saving time and testing and design fees.

Under normal operating conditions, all water extracted from the source is circulated through the heat pump system and returned. However, if the source temperature diverges too much, it can be returned closer to the far-field temperature by bleeding off some of the water, this induces fresh groundwater inflow. This effect can be utilised to protect against freezing, improve performance and increase the heating or cooling capacity.

Standing column well systems allow significant reductions in borehole depth compared to closed-loop systems. It has been shown that, compared with single U-tube vertical closed-loop systems, without bleed, borehole depth reductions between 25% and 65% are possible (O'Neill et al., 2006). The same authors show that, with bleed, reductions in the range of 49% to 78% can be achieved. Therefore, as a result of this significant reduction in borehole depth, significant reductions in capital cost and life-cycle cost are possible.

The normal arrangement is for water to be extracted from the bottom of the borehole, well or shaft and injected back at the top (Figure 26).

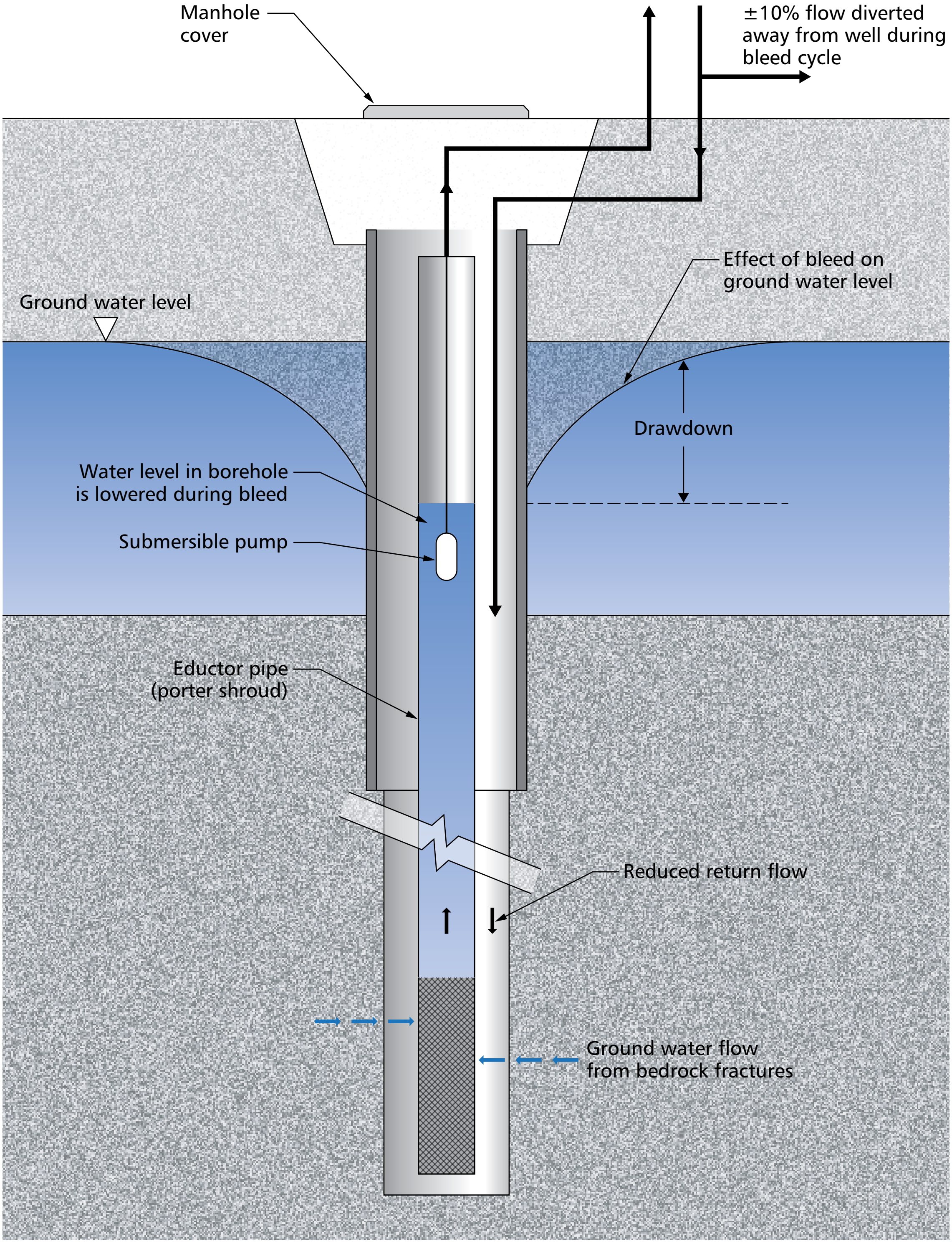


Figure 25 Diagram of a typical standing column well system

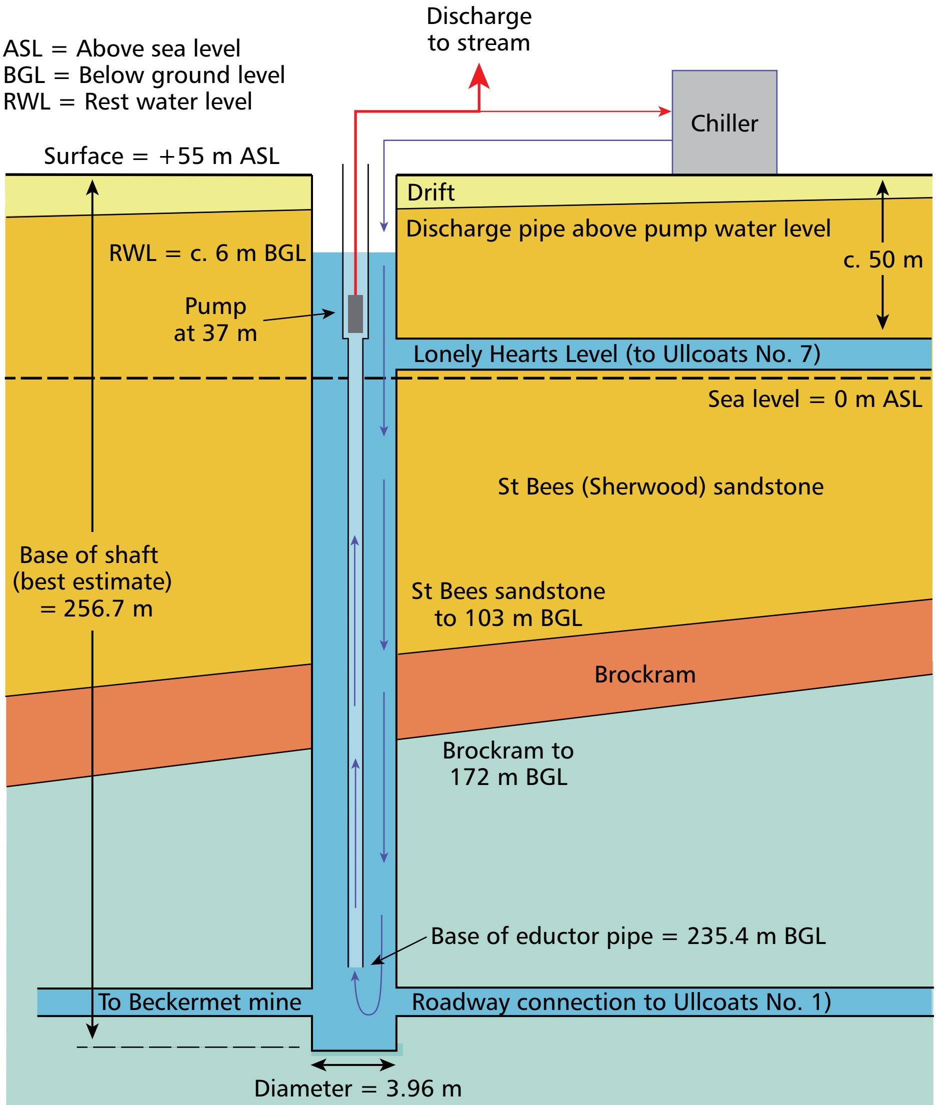


Figure 26 Standing column well test at the abandoned haematite mine, Egremont in Cumbria; a combined pumping test and heat extraction/recirculation trial in an abandoned haematite ore mine shaft (reproduced from Banks D, Steven S, Berry J, Burnside N and Boyce A (2017) by permission of the authors; © the authors)

It is important to return it below the water level to avoid oxygenating the water as this may encourage unwanted mineral deposition and bacterial growth. This method creates a direct path for the water to travel between the injection point and the pump and so an eductor pipe, often called a ‘Porter Shroud’ is often employed. This is a plastic pipe, usually of small diameter, with a louvred or perforated section near the bottom, which extends to the base of the well to force the water to take the longest possible path before returning to the pump. Another significant advantage of using an eductor pipe is that it reduces the pumping head and thus load and pumping input energy. This relatively low-cost modification significantly improves the seasonal performance factor, see Figure 7.

If the geology is suitable standing column wells are an option worth considering, especially where land area is limited. There are only a few SCWs in the UK but several dozen SCWs have been installed in the New York City (NYC) area, and hundreds throughout New England (all US states east of New York State).

An SCW has been installed in St Patrick’s Catholic Cathedral (Figure 27) in NYC to replace its system of steam radiators and 1960s-era air conditioning. The system generates 850 kW·h of cooling and/or 940 kW·h of heating for the 7060 m^2 building. It is designed to cool and warm simultaneously in different areas. It has operated since February 2017 and, compared to the original HVAC system, it saves around 30% of input energy, reduces CO_2 emissions and takes up 40% less space.

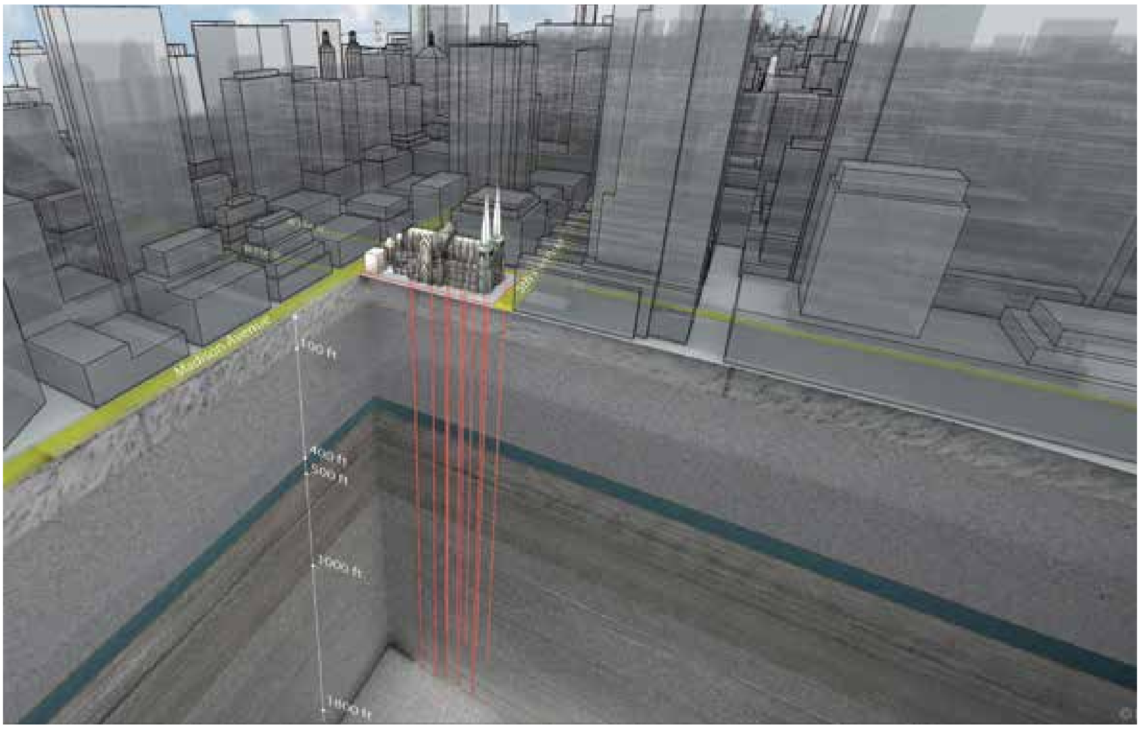


Figure 27 The standing column wells under St. Patrick's Cathedral; 200 mm diameter wells were bored into the Manhattan Schist bedrock. They range from 180 m to 675 m in depth and tap into a vast reservoir of thermal energy in the form of fractured rock and groundwater at a stable temperature of about 13 °C (© MBB Architects; courtesy of Murphy Burnham & Buttrick Architects)

B3.4 Hybrid and mixed technologies

In some cases, the groundwater yield is insufficient to meet the entire building heating and cooling load. Under these circumstances a hybrid approach can be employed that can often enhance efficiency and resilience of the systems.

It is often preferable to base a hybrid ground source system on a closed-loop source side network (SSN), which can act to recover and share heat in the short, medium and long term. Open-loop systems may then be used to augment the closed loop as it reaches capacity.

By employing a hybrid approach the building energy management system (BEMS) can actively manage the closed loop or SSN temperature and therefore maximise system efficiency and minimise the energy consumption of the individual components. For example, in a cooling dominated system a dry air cooler can be employed on a closed ground loop to moderate the temperature and therefore reduce the borehole numbers otherwise required. If the borehole system is sized such that it can handle the peak load on a summer's day and the dry cooler is run overnight, then the efficiency of the cooling process can be greatly enhanced.

An example of this is One New Change, London. The project brief was to achieve sufficient on-site energy generation to satisfy the planning requirements. The base load is covered by a closed loop in the building piles, which is then tempered by using a pair of reversible open-loop wells. Further heat can be added to the load side of the system by gas boilers and can be rejected by conventional cooling equipment, e.g. a dry air cooler. By actively managing the thermal transfer fluid temperature in the closed loop circuit the BEMS can maximise heat pump efficiency in both heating and cooling mode thereby minimising system operating expenditure (OPEX).

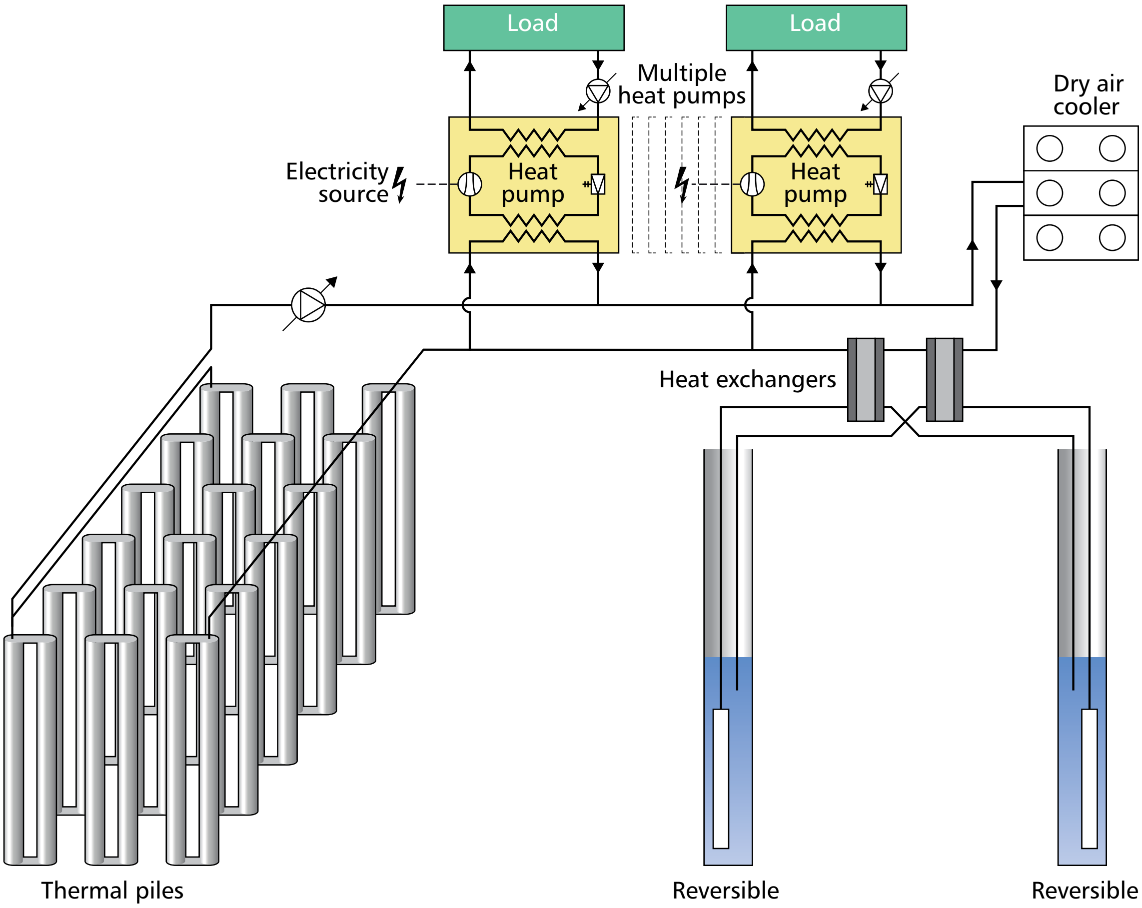


Figure 28 Schematic of system at One New Change

Figure 29 One New Change, the view from St Paul's Cathedral
(© Ben Fitzpatrick; courtesy of Ben Fitzpatrick)

B4 Challenges and opportunities

The following examples demonstrate how different projects have used GWSHPs to provide heating and/or cooling for a selection of applications.

B4.1 Heat networks (load side)

Load-side heat networks use an energy centre to deliver hot water to buildings via highly insulated pipework. This approach employs a large centralised plant to feed many buildings. Cooling can be added although this will require a second insulated network. A mix of technologies, such as open-loop GWSHP and CHP can often extend the benefits of this system architecture, as discussed in B4.3 below. See CP1: *Heat Networks: A Code for practice for the UK* (CIBSE/ADE, 2015) for more detail.

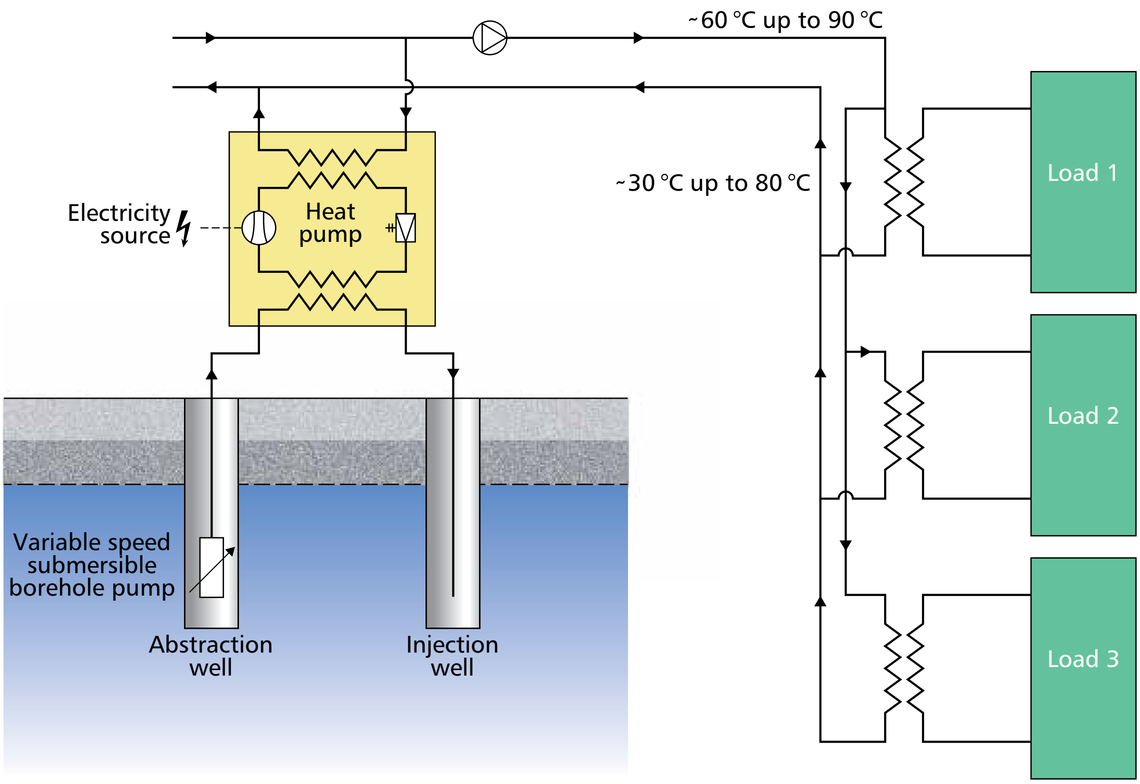


Figure 30 Example of a conventional open-loop heat network

B4.2 Source side networks (SSNs)

The concept of ambient or source side networks (SSNs) are relatively new but have many cost and operational advantages over their load side equivalent. In these systems a central low temperature loop feeds individual heat pumps in the buildings. This core network is connected via a heat exchanger to the open-loop wells, which modulate groundwater flow to maintain loop temperature within the range of maximum heat pump efficiency and minimise the need for insulation to prevent condensation or heat loss.

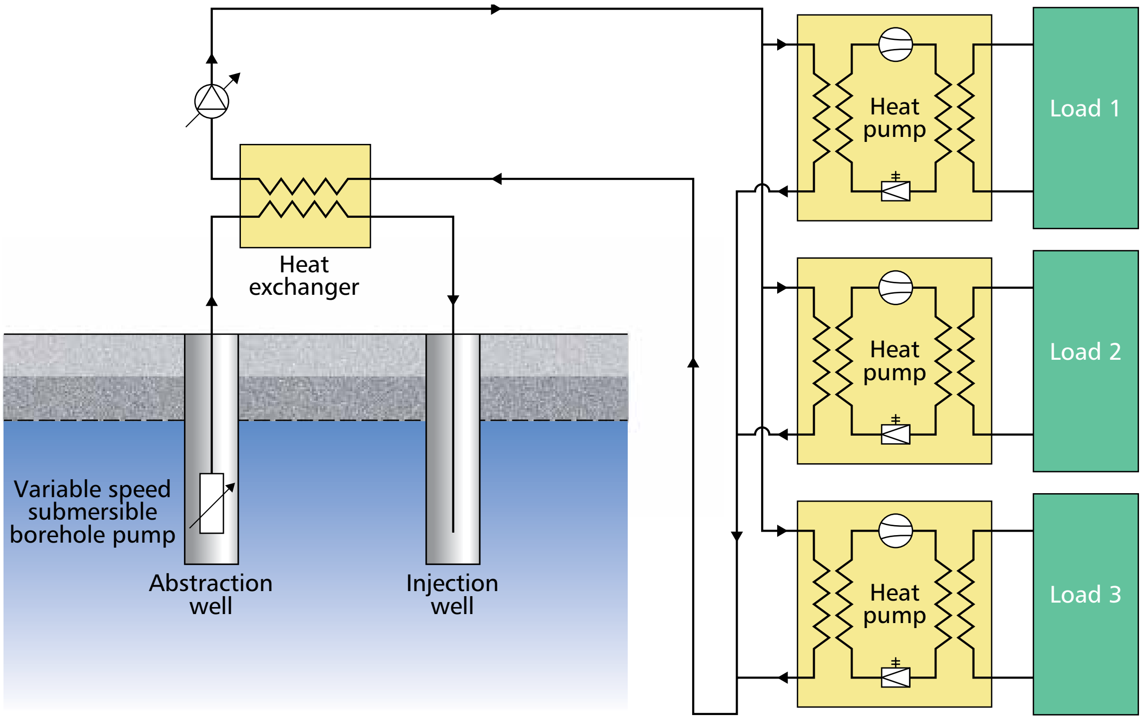


Figure 31 Example of an open-loop source side network (SSN)

The greater the diversity of the loads on the network the more efficient the system. In an ideal situation the water well pumps will not be required or can run at minimum speed as the building heating and cooling loads will balance. For example, a supermarket refrigeration system can run very efficiently on an SSN, which not only provides cooling to the freezers and refrigerators but the recovered heat can be used as space heating to the shop and to homes and businesses nearby.

The advantages of this approach include the following:

— Insulated pipe is not required for the network, therefore pipework costs are reduced.

— Heat losses in the network are minimal.

— Heat pump plant, and the temperatures they produce, can be selected to suit the individual buildings rather than across the entire network. For example, older buildings may require higher distribution temperatures than new buildings.

— Low-grade thermal energy can be injected or removed at any point along the network.

— A central energy centre can often be eliminated.

— Central running costs can be minimised or eliminated.

B4.3 Multivector and multivalent systems

In many circumstances a project can benefit from a multivalent or multivector system where different heating, cooling and electrical generation technologies complement each other. For example, as consumers of electricity heat pump systems sit well beside on-site electrical generation from solar photovoltaics, wind or combined heat and power. Other heat generation technologies can also be of benefit, for example by providing higher temperature water than the heat pumps can deliver efficiently.

Strategies

The system integration and operational control strategy adopted has many, often subtle, implications. Consequently the optimum solution will differ from project to project.

However, in most cases the heat pump(s), will be sized to provide the heating (or cooling) base load 100% of the time with other technologies providing the peaks. This top-up can be specified to deliver higher distribution or storage temperatures, which can be useful where the system also provides domestic hot water.

Sources of heat need not be limited to other heat generation technologies. Recovered heat, if available, can be particularly valuable. Sources can include heat recovery from commercial or process refrigeration, building cooling, data centres etc.

While a level of redundancy is always advisable many ground source projects have been abandoned due to the unnecessary or overenthusiastic specification of back-up systems.

Experience shows that well designed, installed and operated ground source systems are reliable, with long service lives and low maintenance requirements.

Pitfalls and how to avoid them:

— Don't overcomplicate. A design where multiple technologies are thrown at a project regardless rarely work well. A careful selection of technologies, all of which contribute significantly to the project, is a far better and often less costly approach.

— Lack of control and poor control logic are one of the most common mistakes on more complex projects. A typical example is a top-up gas boiler that is intended to assist the heat pump on the coldest days, but which ends up staying on and providing all the heating when the heat pump should have returned to service.

— Not playing to the strengths of the technologies. For example, an air source heat pump to top-up heat from a ground source heat pump is not ideal as when the peak demands occur the air is at its coldest.

B4.4 Retrofit installations

Retrofit ground source systems have unique challenges and requirements, often centering around the fabric of the building and the operating temperatures required by existing distribution systems. Open-loop systems are uniquely suited to retrofit environments where the size of, and disruption caused by, the installation of large closed loops can be prohibitive. Open-loop wells have even be installed in the pavement outside a building in central London. The resulting installation comprises a typical manhole within the pavement with only periodic maintenance access required, see Figures 32 and 33. Note that ensuring adequate separation between abstraction and injection boreholes is very important, see Figure 21.

Heat pumps that can deliver higher than normal temperatures can be invaluable in retrofit projects. However, they are normally less efficient, so lower-temperature equipment should be used where possible. Therefore, a careful assessment of the existing insulation and distribution systems, along with potential upgrade strategies, should be undertaken in preference to simply increasing the load-side distribution temperature.

Figure 32 Well head chamber in the Wandsworth Riverside Quarter Project (courtesy of IFTech Ltd.)

Figure 33 Wandsworth Riverside Quarter showing a finished well head (courtesy of IFTech Ltd.)

B4.5 Free cooling and heating

It is often possible to use borehole water to cool directly, without running the heat pump. Free cooling is delivered without having to pay for the low temperature resource, i.e. no chiller is required. The source of the low temperature can be outdoor air, surface water, groundwater or even cooling that is a by-product of other processes (including heat pumps when heating). Although the term 'free cooling' has been used, there will still be a cost associated with pumping.

Busby (2015) established that mean annual temperatures at 1 m depth when reduced to sea level, range from 12.7 °C in southern England to 8.8 °C in northern Scotland. So, even though the groundwater temperature itself may depart from this calculation due to depth or other local conditions, it is clear that in many locations using it directly with high temperature cooling equipment provides an excellent opportunity to deploy free cooling.

Portcullis House, London

Portcullis House, the parliamentary building located opposite the Palace of Westminster, London, was opened in 2001. It provides offices, committee rooms and other facilities for approximately 200 MPs and 400 administrative staff and uses free cooling.

Groundwater from two water wells sunk 120 m into the chalk aquifer below the building can each deliver 20 l/s. They supply water at 13.5 °C, which is initially stored in two 165 000 litre buffer tanks in the basement before it travels through plate heat exchangers connected to cooling coils inside air handling units. After use, the water is discharged into the River Thames. There are no heat pumps in the system.

Figure 34 Portcullis House (© S.Borisov/Shutterstock)

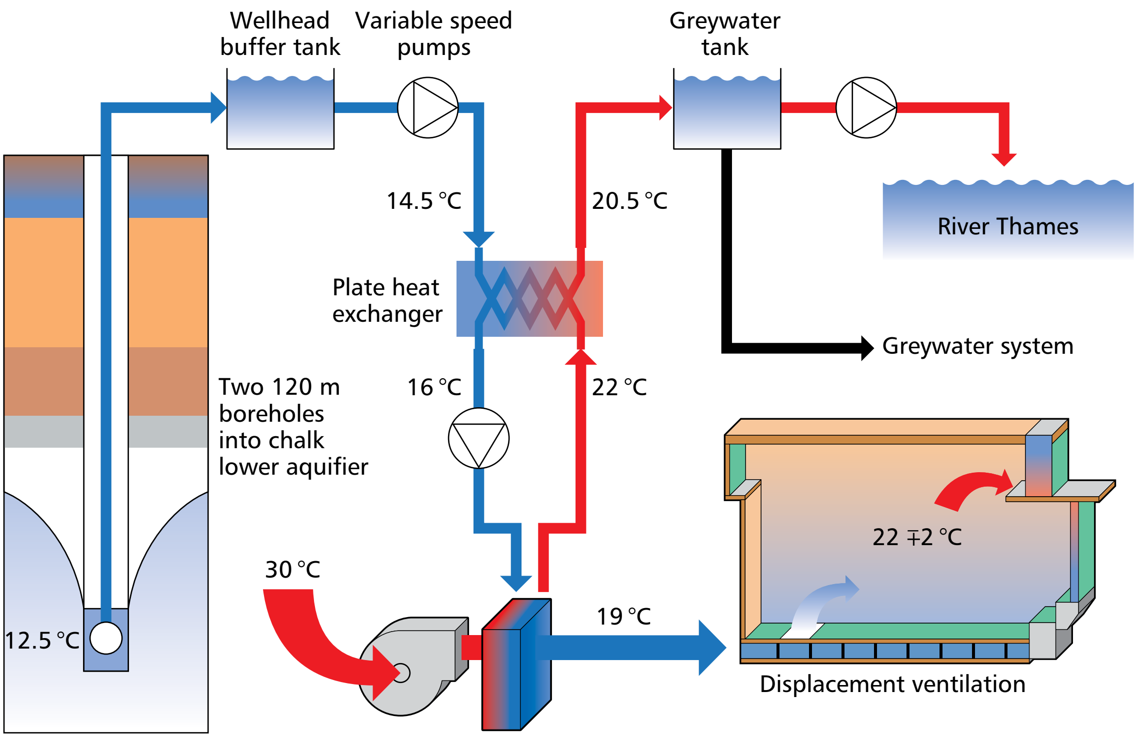


Figure 35 Schematic of the Portcullis House cooling system

Stockholm Arlanda Airport

Since 2009 a novel free heating and cooling system integrated with aquifer thermal energy storage (ATES) has been operational at Arlanda, Stockholm's main airport. This system combines free thermal energy stored in an ATES with high temperature cooling and low temperature heating methodology.

In winter, the warm side of the ATES is used to preheat the incoming fresh air to the terminal buildings (Figure 36). It is also used as necessary to melt ice and snow on the aircraft ramps.

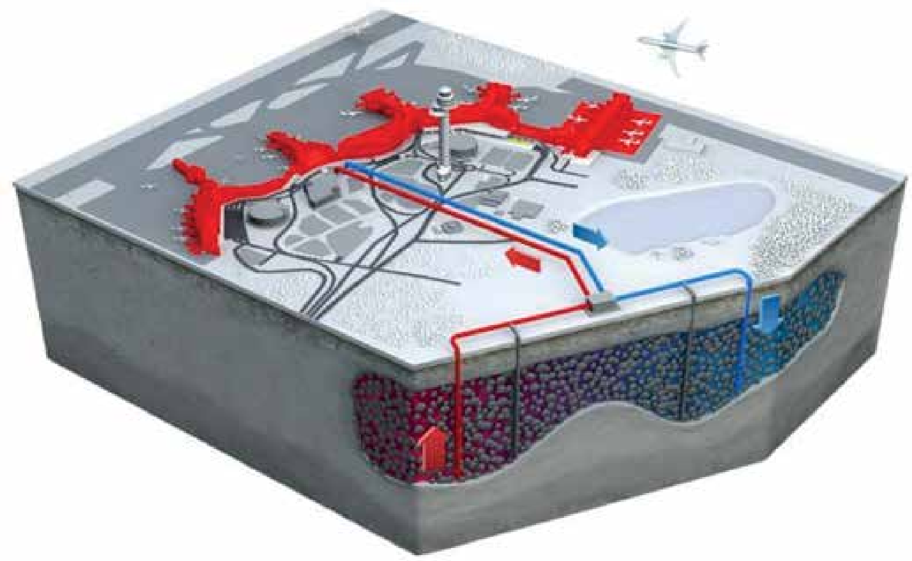


Figure 36 Stockholm Arlanda Airport in winter (courtesy of Swedavia AB)

In summer, the ATES is used to pre-cool the incoming fresh air to the terminal buildings thus reducing the energy required to achieve the setpoint (Figure 37). When the ambient temperature exceeds the free cooing capacity the system is augmented with conventional refrigeration.

Figure 37 Arlanda in summer (courtesy of Swedavia AB)

Figure 38 shows the 11 high capacity wells, five cold (KB1–KB5) and six warm (VB1–VB6) providing a total flow capacity of 720 $m^3 \cdot h^{-1}$ delivering between 6 and 10 MW; a total of around 20 GW·h is delivered annually.

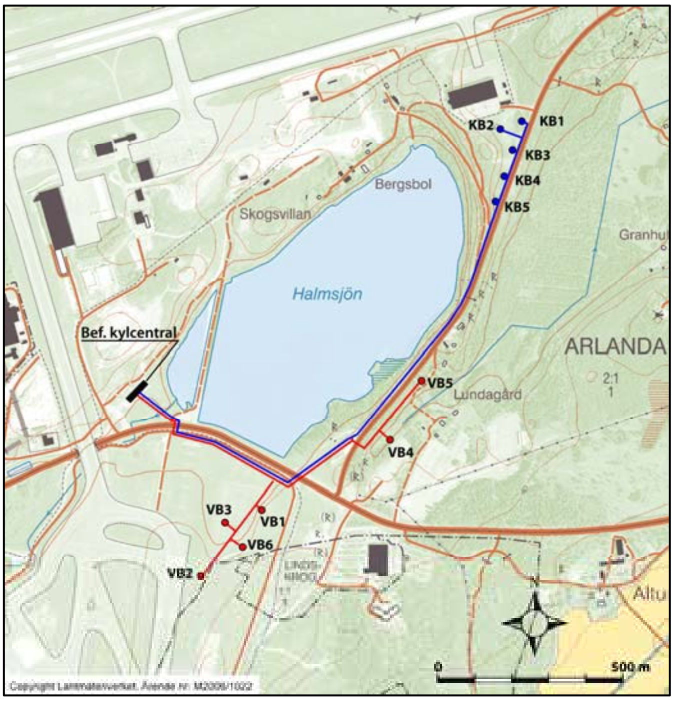


Figure 38 Map of the Arlanda Esker and the 11 abstraction and injection wells (courtesy of Lantmäteriet/Geodata)

There are no heat pumps but the heat exchangers are substantial, see Figure 39. The cold side of the system operates at between +3 and 5 °C and the hot side at +15 °C, although the return temperature can rise to +25 °C in summer.

Figure 39 One of the pair of heat exchangers at Stockholm Arlanda Airport (courtesy of Nic Wincott)

B4.6 Aquifer thermal energy storage (ATES)

Aquifer thermal energy storage (ATES) systems use the aquifer to store thermal energy, whether hot or cold. Groundwater is pumped from one or more 'warm wells' during winter, the higher approach temperature from the stored heat improves the efficiency of the heat pumps. The cooled groundwater emerging from the heat pump is returned to the 'cold wells'. In the summer the process is reversed, see Figure 40.

Open-loop systems lend themselves to ATES when the ground itself is used to store heat rather than calorifiers or other water based thermal energy storage systems. The first pilot demonstration ATES projects were installed in the early 1980s in the US, China, Switzerland and Denmark.

The subsoil, particularly groundwater saturated subsoil, has a high heat capacity. This offers the possibility of storing large amounts of heat and/or cold over a long period, e.g. inter-seasonally. This creates a wide range of opportunities to save energy when it is cheap or freely available and apply other renewable sources, such as the storage of solar heat in the summer, for use in the winter. Another example is the storage of 'cold' collected from ambient air during winter for cooling purposes in the following summer.

ATES systems are attractive because they permit a considerable reduction in the consumption of primary fossil fuels for heating and cooling. An ATES system for high temperature cooling and low temperature heating for an office building may save 70 to 80% of the electricity consumption for cold production and 20 to 40% of the consumption of gas or oil for heat generation.

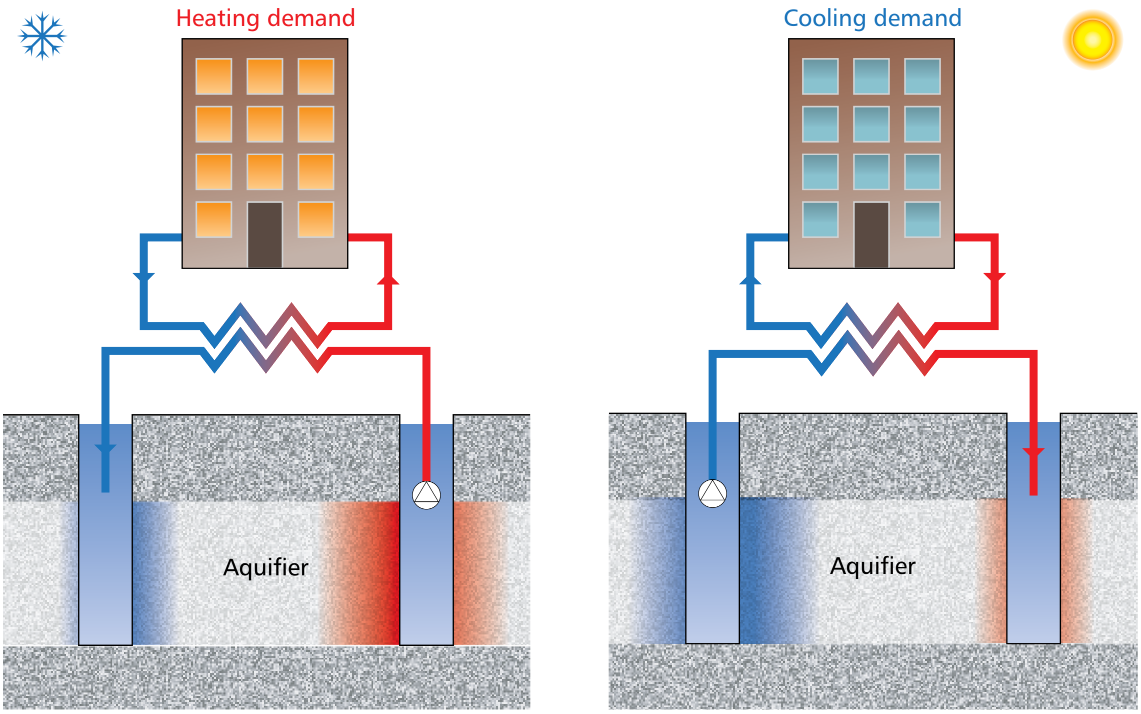


Figure 40 Schematic of an aquifer thermal energy storage (ATES) open-loop GWSHP installation

There are now hundreds of ATES systems in operation. They are found in office buildings, hospitals, shopping malls and district networks in residential areas; more have been implemented in industrial, horticultural and agricultural applications, including plastics processing companies, printing works and glasshouses. The Dutch Railway Company NS is installing ATES heat pump systems in most of its 410 stations.

Many ATES projects are large with a storage capacity in excess of 500 kWt·h. A major benefit of ATES systems is that they can provide free cooling (from the groundwater circuit only — no heat pump required) leading to very high CoPs, often in excess of 50.

Wandsworth Riverside Quarter

Wandsworth Riverside Quarter is a development of apartments on the banks of the River Thames in south-west London. The open-loop GWSHP scheme consists of three heat pumps coupled to an aquifer below the site via an open-loop system of eight 120 m deep boreholes, see Figures 41 and 42 below). The heat pumps supply a peak cooling capacity of 2.25 MW and a peak heating output of 1.2 MW. The aquifer warms over the summer due to the injection of the heat recovered from the cooling loads, leading to improved heat pump performance in winter. As heat for the space heating is drawn out in the winter the aquifer is cooled, leading to higher cooling efficiencies during summertime operation. Under ideal design conditions, the aquifer is cold enough to directly cool the building.

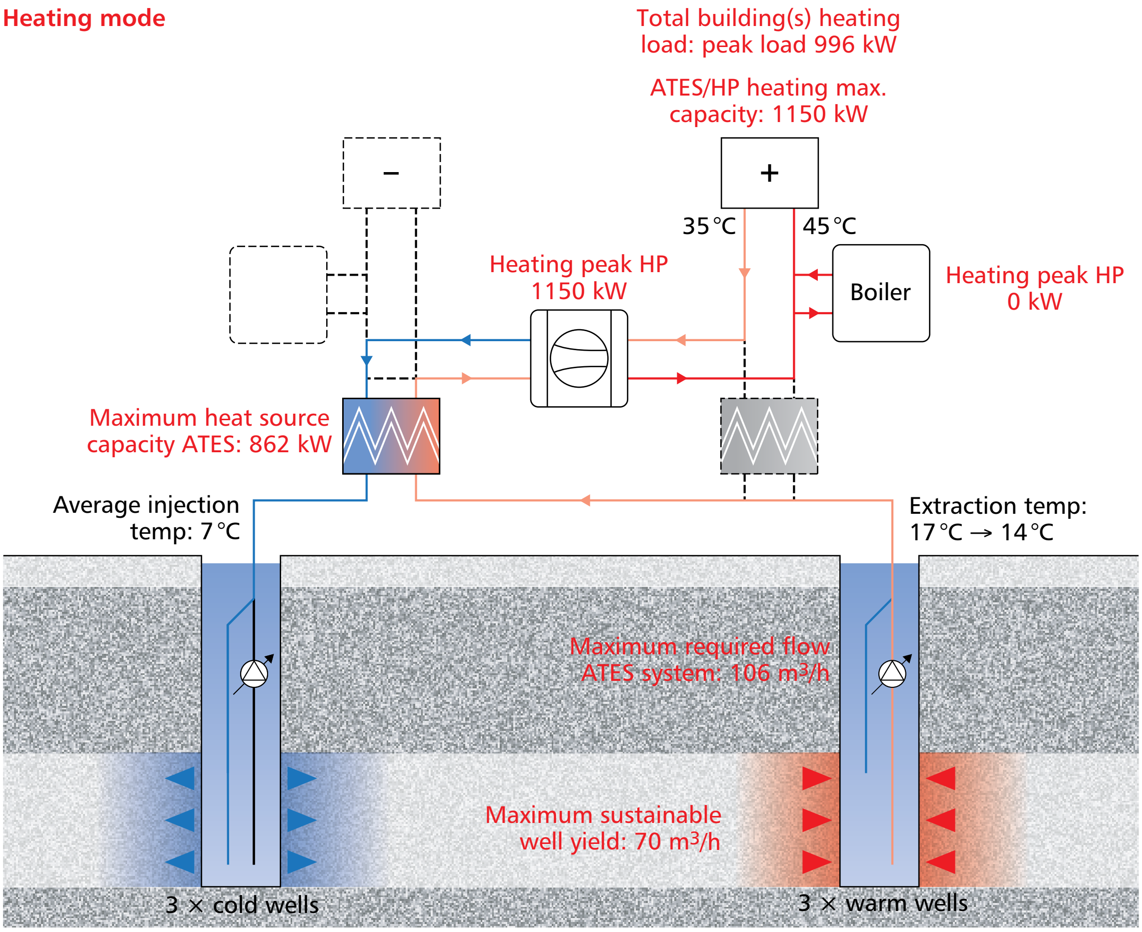


Figure 41 Schematic of Wandsworth Riverside Quarter system in heating mode (courtesy of IFTech Ltd.)

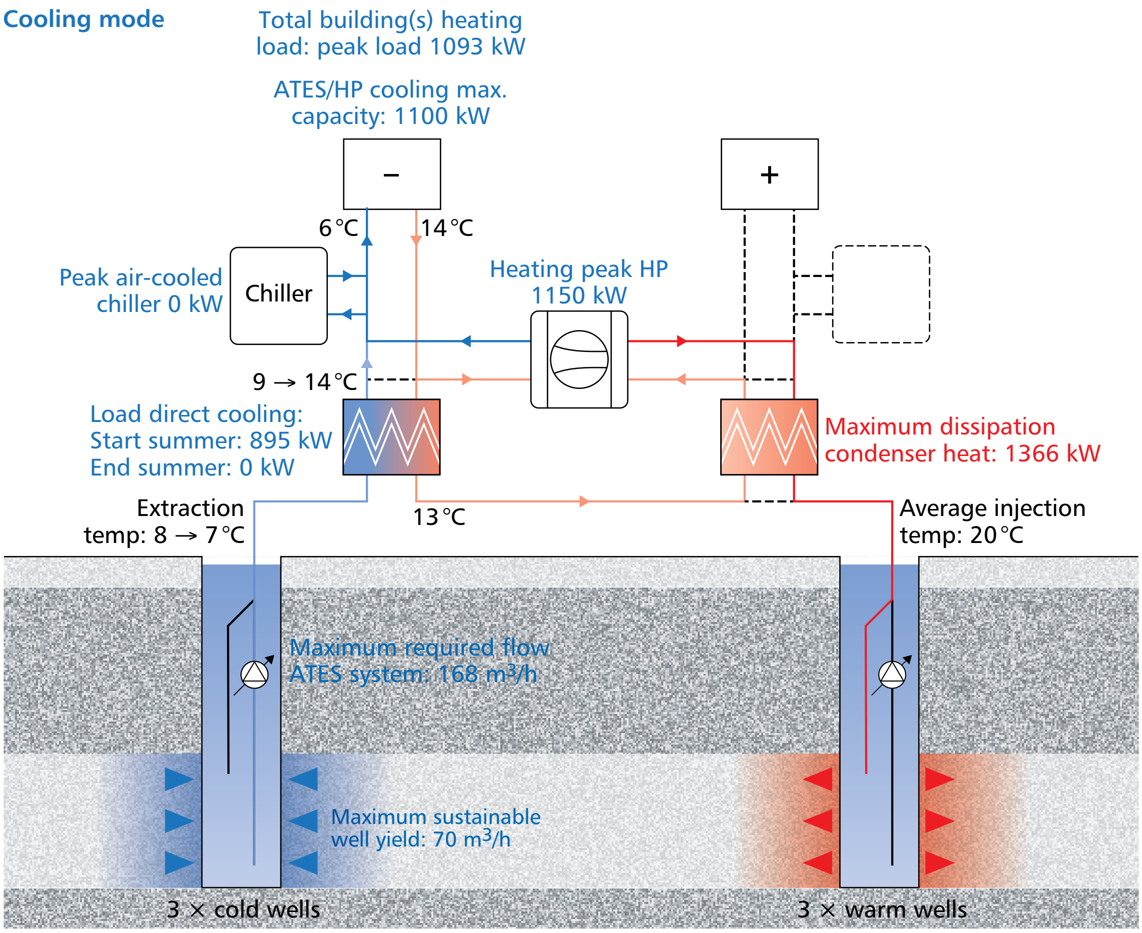


Figure 42 Schematic of Wandsworth Riverside Quarter system in cooling mode (courtesy of IFTech Ltd.)

Trafford Town Hall

Trafford Town Hall in Manchester is another example of an ATES system of two wells of 90 m depth in a sandstone aquifer. It provides 600 kW of cooling and heating capacity and was installed and commissioned in 2013.

Figure 43 Trafford Town Hall, Manchester: Council Headquarters (© Mark Waugh / Manchester Press Photography)

Part C: The requirements

1: Preparation and briefing

Objectives:

1.1 To commission the project in accordance with the Code of Practice

1.2 To develop the specification/project brief

Key support tasks:

- Review feedback from previous projects
- Set performance targets
- Pre-application discussions with statutory and regulatory bodies
- Research opportunities for collaboration
- Agree schedule of services, design responsibility matrix and information exchanges
- Prepare implementation plan including technology and communication strategies and consideration of common standards to be used

Information exchange to next stage (feasibility consultant):

- Strategic brief
- Project specification
- Initial project brief

Objective 1.1: To commission the project in accordance with the Code of Practice

Why is this objective important?

The client (sometimes referred to as owner/developer), whether an individual or organisation, will ultimately be responsible for the installation and should therefore take the lead in executing this Code of Practice. When the owner and developer are different entities, responsibility must be determined at the commencement of the project. The aim is to ensure the open-loop groundwater source heat pump (GWSHP) system works effectively is reliable, cost effective, and does not harm the environment. The client will need to ensure compliance with all relevant legislation and any conditions imposed by other stakeholder organisations, for example the local planning authority and the relevant environmental agency.

Minimum requirements

1.1.1 The client shall ensure that this Code of Practice is included as a key requirement in briefs and specifications for the delivery of:

- feasibility studies
- design services
- construction contracts
- commissioning contracts
- operation and maintenance contracts.

1.1.2 The client or their identified representative shall:

- monitor implementation of the Code of Practice on a regular basis and at the end of each stage of the project
- monitor the compliance of the project against the minimum requirements
- obtain evidence that the minimum requirements have been met
- carefully consider upgrading requirements to comply with best practice.

1.1.3 The client shall draw up a clear implementation plan with milestones, reporting, responsibilities and handover points.

1.1.4 The client shall ensure all those working on the project conduct and record a formal and effective handover process between each stage.

1.1.5 The client shall check that suitably qualified and experienced people are employed on the project, appropriate to each stage.

Objective 1.2: To develop the specification/project brief

Why is this objective important?

A project brief shall be prepared by or on behalf of the client. The priority will be to determine the steps needed to assess the viability of the proposed open-loop GWSHP system. The brief shall be used to focus project planning activity, assess the marketplace and identify suitable specialists required to deliver the project.

Minimum requirements

1.2.1 A suitable groundwater source shall be identified. It should be as shallow as possible and within reasonable distance of the heat pump(s) to minimise energy consumed by pumping.

1.2.2 British Geological Survey (BGS) or Geological Survey of Northern Ireland (GSNI) resources shall be used to establish the characteristics of the surrounding geology and hydrogeology, presence or otherwise of existing boreholes and other geological factors to investigate the practicality of installing an open-loop GWSHP system. BGS/GSNI is an important resource of detailed UK geological information, much of which is available free of charge under OpenGeoscience (see https://www.bgs.ac.uk/opengeoscience).

1.2.3 The sustainability aspirations for the building shall be identified, confirmed and used to inform the brief, in particular carbon emissions targets.

1.2.4 The possibility of collaboration to create a heating/cooling energy loop, thermal energy storage and/or a heat network shall be explored.

1.2.5 The projected heating and/or cooling load of the proposed development, including operating temperatures, peak load and seasonal demand, shall be accurately estimated. The calculation shall be in sufficient detail (peak load, hourly annual heat load etc.) to assess the best heat source(s). The loads should, if possible, take into account both predicted and change-of-use demands. It is common for buildings to change operational load cycles after commissioning.

1.2.6 Performance targets, such as operating temperatures, coefficient of performance (CoP) and seasonal performance factors (SPFs), shall be considered and agreed; see B1.3 for more information.

1.2.7 The sources of data to be used to calculate the life cycle (capex and opex) costs (p/kW·h) and carbon (kgCO_2/kW·h) savings of different heating options shall be identified, see *Valuation of energy use and greenhouse gas emissions for appraisal* (BEIS, 2018). This establishes a set of diminishing carbon factors to reflect future decarbonisation of the electricity grid.

Setting the performance targets

It is essential for the client/developer to specify in detail in the contract what they expect from an open-loop GWSHP installation. Without clear performance targets from the outset the overall performance cannot be measured.

Performance targets shall include:

— seasonal performance factors (SPFs) and coefficient of performance (CoP)

— carbon reduction

— groundwater consumption

— maintenance requirements and costs

— running costs

— whole life costs.

1.2.8 The eligibility for government grants and incentives shall be determined and the party to receive the income to be agreed.

1.2.9 The requirement for permissions and certification shall be investigated.

1.2.10 The likelihood of further phases or other development nearby that could utilise the same resources shall be considered.

1.2.11 Any other expectations or aspirations the client may have for the project should be discussed and noted if relevant. These could include visual impact, remote operation and monitoring, long term reliability operational uptime, annual maintenance requirements.

2: Feasibility

Objectives:

2.1 To identify and quantify the groundwater source

2.2 To determine what permissions are necessary to access the groundwater

2.3 To determine heat pump location and groundwater abstraction and discharge details, including costs estimates

2.4 To accurately estimate peak and seasonal heating and cooling demands

2.5 To agree suitable load-side operating flow rates and control strategies

2.6 To select the most appropriate heat pumps system

2.7 To assess operation and maintenance needs and costs

2.8 To conduct a financial analysis to comprehensively evaluate the installation options

2.9 To assess environmental impacts and benefits

2.10 To analyse risks and carry out a sensitivity analysis

Key support tasks:

- Review client brief
- Further pre-application discussions with statutory and regulatory bodies
- Prepare risk assessments
- Undertake third party consultations as required and any research and development aspects
- Review and update implementation plan
- Develop:
  - sustainability strategy
  - maintenance and operational strategy
  - construction strategy
  - health and safety strategy

Information exchange to next stage (design team):

- Feasibility study
- Concept design including outline structural and building services design associated project strategies

When to drill the test well

The feasibility stage describes a comprehensive desk study. This process is intended to deliver a tool to enable an informed decision to proceed with the project to be made with a high level of confidence.

Any desk study inevitably involves some uncertainty, but this must be minimised by using the best information available and by employing experts with appropriate expertise. The highest level of uncertainty is in relation to groundwater quality, quantity and temperature.

Due to the nature of the UK's subsurface geology, ground conditions, quality and yield are hard to predict with accuracy before the water well is drilled and tested so drilling a water well inevitably requires a level of speculative investment. There are strategies that can be employed if the initial yield is disappointing. However, it must be noted that on some occasions despite implementing these strategies the yield will not be sufficient.

Experienced engineers will be able to modify their design around the groundwater flows found and, in addition, there are tried and tested techniques that may be used to improve the performance of the well, most notably acidisation. Alternatively, it is frequently possible to increase capacity simply by drilling another well nearby.

A key decision will be at what point in the design and construction process the test water well is to be constructed. This will vary from project to project; however, the earlier in the program the better, so any uncertainties can be resolved, and the final design confirmed or modified if necessary.

Objective 2.1: To identify and quantify the groundwater source

Why is this objective important?

In the planning and briefing stage, the potential for a groundwater source heat pump system will have been identified. The characteristics of the building's heating and cooling demand, proposed aquifer, site layout, and potential groundwater quality will inform the practicality of using an open-loop GWSHP.

All projects must combine good engineering practice with a detailed evaluation of the local conditions (e.g. the presence of a suitable aquifer, ease or otherwise for drilling, abstraction and injection of water and whether any national or local regulatory issues might impact on project feasibility etc).

The starting point of every new project is to investigate the resources available, in particular the underlying geology and hydrogeology. In the UK, relevant information can be obtained from the British Geological Survey (BGS) or Geological Survey of Northern Ireland (GSNI), including site-specific hydrogeological reports or an initial assessment of subsurface suitability for large-scale open-loop installations, see 'Additional references'. These provide an excellent starting point but do not remove the requirement to employ a qualified hydrogeological expert competent in thermal modelling, preferably dynamic thermal modelling.

Minimum requirements

2.1.1 The groundwater source shall be fully investigated and reported in the feasibility study.

Important considerations are as follows:

- The presence, depth and nature of the target aquifer, and the outline design of borehole(s) required to access groundwater.
- Available geological maps, plans, satellite imagery, previous nearby studies and geographic information system (GIS) data shall also be used to evaluate the site.
- Other water supply or open-loop boreholes records located nearby. The information taken from these records shall be used, such as borehole depth, design and available groundwater yield and water quality.
- The risk of encountering artesian conditions must be fully assessed and evaluated.
- Site layout, specifically the degree of separation possible between abstraction and injection boreholes at the site when required.
- Groundwater level (depth below ground level): groundwater very close to the surface can in some circumstances render injection impractical if not impossible.
- The chemical quality of the groundwater: some aspects of water chemistry, for example the nature and concentration of iron and/or manganese can have a major impact on viability.

2.1.2 An assessment of the risk of corrosion and incrustation within an open-loop ground source heat exchanger system shall be carried out at an early stage of the feasibility study. If a significant risk is found to be present, it shall be assessed further, based on a consideration of analysed water samples.

2.1.3 Assessments shall be undertaken to investigate the presence of particulate matter, dissolved gasses and contaminants in the groundwater source.

2.1.4 The energy potential of the groundwater flow estimated to be available shall be calculated to establish if it can be utilised for the heating/cooling requirement. Rules of thumb shall only be used with great care in the feasibility study and all the calculations must be shown.

2.1.5 Accurate building heating and, if relevant, cooling demand information shall be used to calculate the peak pumping rate, daily and annual groundwater volume required by an open-loop heat pump system to satisfy the load.

2.1.6 The costs of metering and data collection shall be included.

Best practice

Best practice would be to:

BP2.1a prepare a detailed plan and cross section of the location to ensure all and any design constraints are identified; this can also be used to identify the location and potential relevance of adjacent schemes

BP2.1b model in detail the energy potential of the groundwater in the target aquifer to assess the long-term impact of the scheme, the potential for thermal short circuiting and other key variables; this model may be used to provide a clear performance comparison between open and closed loop at this location

BP2.1c offer two options from the outset — one for the ideal yield and another to establish the lowest viable yield; low yield designs may increase capacity with bi- or multivalent systems incorporating CHP, heat recovery, thermal energy storage, dry air coolers, solar thermal panels etc.

BP2.1d compare open-loop and closed-loop based on operational efficiency, contributions to CO_2 reductions and whole life costs taking account of future trends in energy prices and electricity decarbonisation.

Objective 2.2: To determine what permissions are necessary to access the groundwater

Why is this objective important?

When an open-loop GWSHP system is proposed as a heat source a range of permissions may be required. These will vary from site to site and need to be carefully investigated and noted as any oversight can cause costly delays. Pre-application discussion should be sought from the relevant environmental agency, see Appendix C for contact details.

The *Good practice guide for ground source heating and cooling* (GSHPA, 2017) sets out a summary of what should be done to comply with environmental legislation and manage environmental risks. It is based on regulations set out by the Environment Agency for England and, whilst the Guide is relevant across the whole of the UK, it is recommended to consult the equivalent regulatory bodies in Wales (NRW), Scotland (SEPA) and Northern Ireland (NIEA), where necessary.

Details of the requirements in each devolved area can be found in Appendix B. However, note that regulations can change and therefore consultation with the relevant regulatory bodies must be sought to confirm the situation every time.

Minimum requirements

2.2.1 For most open-loop installations, permission is required from the relevant environmental agency, see Tables 6 to 9 in Appendix B. Pre-application advice shall be sought as early as possible to identify site specific requirements and constraints. There may be a charge for this advice.

2.2.2 Consultation shall take place with Natural England or equivalent for any system in or potentially affecting Sites of Special Scientific Interest (SSSIs), Special Conservation Areas (SACs) and Special Protection Areas (SPAs).

2.2.3 When the open-loop GWSHP installation plans to use abandoned coal mine workings for the purpose of extracting heat from mine water, permission shall be sought to enter, disturb or change coal mines managed or owned by the Coal Authority. This includes:

- coal seams
- coal workings, such as existing mine tunnels
- mine entrances

2.2.4 Where required, an application for a Minewater Heat Recovery Access Agreement shall be sought from the Coal Authority (see https://www.gov.uk/government/publications/minewater-heat-recovery-access-agreements).

2.2.5 Early consultation shall be undertaken with the local planning authority to establish if planning permission is required, including the requirement of permissions for temporary works for storage of materials and other construction purposes where necessary.

2.2.6 The Town and Country Planning (Environmental Impact Assessment) Regulations 2011 can apply even when the project is considered as permitted development. Early consultation with the local planning authority shall be undertaken to establish requirements.

2.2.7 Consultation with Distribution Network Operators shall be conducted to establish the availability of power to the building, in particular to the heat pump.

2.2.8 Where planned pipework routes for groundwater abstraction will cross public access paths, the need to apply for temporary suspension of rights of way shall be assessed.

2.2.9 The costs of permissions shall be determined. There will be application charges for any licences and environmental permits required. There will also be annual charges for the time the licence and permit are live. There may also be charges for pre-application advice. The details of these fees can be obtained from the relevant environmental agency.

Typical abstraction/discharge ΔT

A key element of heat pump system operation is the difference in temperature between water entering and leaving the heat exchanger (ΔT). In groundwater systems, whether heating/cooling or both (balanced) this becomes critical to the design as it directly affects the abstraction and discharge temperatures.

Therefore, the operating temperatures and ΔT permissible in any specific location must be considered in detail with the relevant environmental agency and reflect local conditions, protection of sites and species and pressures from other developments. Some smaller schemes may be exempt from the regulations but early discussion with the relevant environmental agency is always advised.

For example, for England, the Environment Agency's *Guidance notes on registration of your ground source heating and cooling system as exempt from the need for an environmental permit* (EA, 2014) state that the temperature of water discharged from the system will not exceed 25 °C and will not vary by more than 10 °C compared to the abstracted water. The ratio between the abstraction and discharge temperatures is also considered:

$$\text{Temperature ratio} = \frac{\text{Discharge temperature}}{\text{Abstraction temperature}}$$

Given the above, for the purpose of feasibility studies it is recommended that a ΔT of ±10 °C is a reasonable starting point until further information becomes available following site-specific investigation and discussions.

Objective 2.3: To determine heat pump location and groundwater abstraction and discharge details, including cost estimates

Why is this objective important?

The location of the heat pump in relation to the load, water and electricity supply, and the spacing, positioning and design of abstraction and injection wells are critical decisions. It is recommended to always start from a good engineering perspective taking into account other determining factors or limiting conditions, for example existing building systems/services, flood risk, access, cost, noise or security considerations.

Minimum requirements

2.3.1 The feasibility of an open-loop system shall be established taking into account all engineering, practical, environmental, space, access and ownership issues. This will include heating or cooling only, heating and cooling and in particular whether aquifer thermal energy storage (ATES) is viable.

2.3.2 The proposed location and space requirement of the plantroom(s) shall be identified and reported in the feasibility study.

2.3.3 The most suitable method of abstracting and discharging groundwater shall be identified and the spacing and location of the abstraction and injection wells established.

2.3.4 The route and distance of any pipelines between the heat pump, the heat load and the groundwater resource shall be measured. The costs shall be estimated and feasibility of transporting the heat shall be established taking into account losses as well as any parasitic energy consumption, for example pumping.

2.3.5 Any filtration and water treatment requirements shall be considered and reported in the feasibility study.

2.3.6 The access conditions to the site for drilling shall be assessed. A significant area is required for the contractor's plant, storage and operations. These must be planned, and risks identified, alongside the client's requirements for continued operations or other construction activities.

2.3.7 The capacity and voltage of the electrical supply required, and the location/route shall be determined.

Minimum separation between abstraction and injection wells

Typical minimum separation required between abstraction and injection wells is around 100 m. If there are multiple abstraction wells, typical separation between each well is around 25 m, see Figure 21 above. These are only indicative and a suitably qualified professional must be engaged to assess the groundwater gradient and appropriate separation requirement.

Objective 2.4: To accurately estimate peak and seasonal heating and cooling demands

Why is this objective important?

An accurate estimate of both the peak output requirement and total annual heating and cooling demand, together with the consumption profile and diversity of the demand are also important considerations to ensure feasibility studies are truly useful decision-making tools.

For an existing building, the estimates will rely mainly on heat loss calculations based on the fabric and ventilation; consider thermal mass, internal and solar heat gains as appropriate. These can be further informed by actual fuel use, meters, local meteorological data and any other relevant site-specific information.

It is worth noting that historical energy consumption is not necessarily an accurate reflection of a well-run and well-controlled building, nor is it an indication of whether the building will be efficiently or inefficiently operated in the future.

Any historical data must be reviewed to take account of all practical energy efficiency measures and any heat recovery opportunities considered to develop a strategy that avoids unnecessary investment while still delivering a safe, comfortable indoor environment.

For new buildings, a modelling approach should be considered. It is important that this reflects the expected operation of the building as it will be used, in the location where it is to be built. This may differ significantly from modelling needed to show compliance with local Building Regulations. CIBSE TM54: *Evaluating operational energy performance of buildings at the design stage* (CIBSE, 2013a) provides a framework for making accurate energy assessments.

In either case, where there are multiple loads in one building or for multiple buildings on the same system or network it is critical to consider the impact of diversity. This is covered in detail in *Heat networks: Code of Practice for the UK* (CIBSE, 2019).

Minimum requirements

2.4.1 For existing buildings, heating and cooling demands shall be estimated on a monthly basis using actual fuel used from meter readings wherever available and an assessment of existing equipment efficiencies, taking account of any potential for cost-effective investments in energy efficiency, or by use of benchmark buildings. Peak loads can be established using a heat loss calculation method based on BS EN 12831 (BSI, 2017b/c) (for heating only) or a dynamic simulation model, and these peak loads can be used to confirm equipment size requirements. It is recommended to ask the client for energy consumption and heat loss calculations and to agree power and energy figures with the client as part of any contracts.

2.4.2 The data shall be analysed to separately estimate the heat demand for space heating, domestic hot water, any other heating and cooling demands such as industrial processes and any system losses within the building.

2.4.3 The space heating element shall be adjusted by means of degree days (see CIBSE TM41: *Degree days: theory and application* (2006)) or other method, for example computer modelling, to provide a detailed heating and cooling demand profile for an average year using an appropriate baseline temperature.

2.4.4 Where possible, an understanding of the daily, weekly and annual occupancy pattern of each building shall be established.

2.4.5 For existing buildings the peak power shall be estimated from a combination of a knowledge of the installed heat source capacity and how these heat sources are operated in practice; benchmarks using floor areas and age of the building; or from half-hourly gas meter readings if available and supplemented by modelling using CIBSE TM54 (2013a). Benchmarks for peak and annual heating and cooling demand estimates based on floor areas that can be used in feasibility studies are given in the following references:

- CIBSE TM46: *Energy benchmarks* (CIBSE, 2009) (for existing buildings)
- CIBSE Guide F: *Energy efficiency in buildings* (CIBSE, 2012) (for existing buildings)
- BSRIA BG9/2011: *Rules of Thumb — Guidelines for building services* (BSRIA, 2011a) (for new buildings).

2.4.6 Future heating and cooling demands for building or system extensions shall be estimated as accurately as possible and where appropriate a sensitivity analysis carried out to show the impact on the design.

2.4.7 For large commercial facilities, peak power and annual heating and cooling demand shall be modelled by development of a dynamic simulation model (DSM) or other approved software intended for use within the GWSHP system design. A sensitivity analysis shall be carried out to show the impact on the design.

2.4.8 In new developments, the Standard Assessment Procedure for the Energy Rating of Dwellings (SAP) and Simplified Building Energy Model (SBEM) are commonly used energy assessment tools. However, they are compliance tools and do not provide sufficient information (e.g. peak load data) for equipment and heat pump sizing. If SAP or SBEM are used, then a further calculation (based on BS EN 12831 (BSI, 2017b/c) or a dynamic simulation model) shall be used to meet this Objective.

Best practice

Best practice would be to:

BP2.4a obtain hourly or half-hourly fuel use data for existing buildings from meters throughout the year where this is available or install monitoring equipment to establish the demands more accurately

BP2.4b include the use of operational data from other similar sites to generate a heating and cooling demand profile; from these data an annual heat load duration curve can be produced

BP2.4c take account of local climates such as the heat island effect in large cities when assessing space heating demands and the lower demand for hot water that may be seen in summer (due to higher cold-water feed temperatures and reduced hot water demand)

BP2.4d dynamically model the building's heating and cooling load using hourly bin data rather than a monthly based static degree day data model

BP2.4e model potential future building occupancy profiles.

Objective 2.5: To agree suitable load side operating flow rates, temperatures and control strategies

Why is this objective important?

Operating flow rates and flow and return temperatures are an important aspect of the feasibility study and will influence both the capital and operating costs as well as the system heat losses. They are key determinants of the impact of the installation on the water source, the efficiency of the GWSHP and the volume of any thermal storage. While there will be opportunities to refine and optimise the design later, the feasibility study must be based on clearly stated assumptions that comply with any legal or other requirements and are practical and achievable.

Minimum requirements

2.5.1 The most suitable operating temperatures for the GWSHP shall be identified, taking account of how efficiencies will vary with operating temperatures across all loads and seasonal profiles, and any limits imposed by the owners or other relevant statutory body.

2.5.2 For a retrofit project, the temperatures used by the existing heating system shall be obtained and any potential for reducing the load side operating temperature identified. (At the feasibility stage, it can be assumed that where improvements have been made to an existing building after the original installation, the heat emitter circuits can be rebalanced to achieve lower operating temperatures.)

2.5.3 The potential to reduce the operating temperature as demand falls (weather compensation) shall be analysed to reduce heat losses under part load conditions. It will take account of pumping energy, especially of variable speed pumps, and the impact on return temperatures.

2.5.4 The temperature difference that occurs at any hydraulic separation (i.e. at a heat exchanger) shall be taken into account in defining operating temperatures.

2.5.5 Careful consideration shall be given to minimising any health risks from scalding and *Legionella* growth, which could occur in the secondary domestic hot water system. Alternative methods of *Legionella* control may be used to permit the use of lower temperatures, see 'Further reading' for standards and guidance, particularly CIBSE TM13: *Minimising the risk of Legionnaires' disease* (CIBSE, 2013b).

Best practice

Best practice approach would be to:

BP2.5a carry out a specific temperature optimisation study taking account all impacts to derive lifecycle costs and environmental performance for a range of temperatures

BP2.5b seek to achieve the lowest feasible operating temperatures, e.g. through use of low input temperature heating devices such as underfloor heating (UFH).

High temperature cooling and low temperature heating

Heat pumps operate at higher efficiency with lower flow temperatures, consequently using a high water temperature when cooling and a low water temperature when heating decreases energy consumption. A saving of about 3% of input energy per 1 °C temperature reduction is to be expected.

- What constitutes high temperature cooling will vary depending upon the cooling distribution devices but flow temperatures between 14 °C and 17 °C with a ΔT of 2–4 K are recommended.
- Heating flow temperatures of 35 °C are increasingly common with surface heating or fan coil units.

Note: Low-temperature heating requires a system design that ensures the heat emitters (radiators, fan-assisted radiators or convectors, or underfloor heating pipes) can deliver the same amount of heat at the lower temperature as old-style radiator systems would have done at traditional temperatures (over 55 °C). This may preclude their use in some retrofit situations although not always, especially if combined with better insulation and other energy efficiency measures.

Objective 2.6: To select the most appropriate heat pump system

Why is this objective important?

In order to select the most appropriate heat pump system, the design concept for the open-loop GWSHP installation must be developed including the type and number of heat pumps in the system, how they are connected together (i.e. in parallel or in series) and other elements such as thermal energy storage, isolating heat exchangers, dry air coolers etc.

There are times when it may be appropriate to use more than one heat generator in an installation. This could be for a variety of reasons, e.g. thermal capacity of the heat source, plant room space, limits to electricity supply, capital costs and operational efficiency objectives. While generally it is important to keep an installation simple, the financial and operational advantages of a multivalent system can be considerable and need to be comprehensively assessed.

Minimum requirements

2.6.1 Working temperature range and operating regime for the heat pump system shall be identified.

2.6.2 The most appropriate generic type of heat pump system able to deliver the working temperatures shall be identified, considering the refrigerant and the associated risks.

2.6.3 The likely long-term maintenance requirements of the heat pump system and any implications for the installation, such as access, top-up of fluids and other limiting factors shall be assessed.

2.6.4 The part load characteristics of the heat pump system shall be appropriate to the system's source and load side conditions, such as energy demands and other limiting factors.

2.6.5 The type of installation and operational strategy shall be determined. (The most straightforward technical solution will be a monovalent heat pump installation capable of meeting the peak heating and/or cooling loads at the required emitter temperatures.)

2.6.6 For bivalent systems that are capable of meeting the heating/cooling loads using parallel operation, the annual load profiles of the building shall be established, and a decision made as to the split of size between the heat pump and the supplementary source(s). The basis for a decision shall take into account any or all of capital costs, running costs, plant physical sizes, and carbon emissions.

2.6.7 For bivalent systems that are run in alternate mode, the heat pump shall be sized to meet the maximum loads that can be achieved at optimum heat pump output temperatures. The alternative source(s) shall be deployed above this valency point and sized to meet the worst-day design loads.

2.6.8 The physical limitations referred to above shall be taken into account in determining the size of the heat pump(s) versus supplementary heating/ cooling sources.

2.6.9 The selected heat pump system shall be compliant with all relevant certification bodies and other legislative requirements.

Best practice

Best practice would be to:

BP2.6a use of building/plant simulation systems coupled to appropriate local climate data; these models, e.g. EnergyPro, allow investigation of the optimal split of the bivalent plant based around considerations of capital expenditure, running costs and carbon emissions

BP2.6b model several options to accurately determine the most energy efficient operational arrangement to further inform the decision; even if the knowledge of daily demand profiles is limited, this type of modelling will be more accurate and is often required to establish how a system will operate in practice, particularly where there are a range of heat sources and thermal storage

BP2.6c use a building energy management system (BEMS) to accurately control the operation of the system; however, BEMS may not be sufficiently technically robust to monitor and control a complex system, particularly a large system with mission critical or multiple end users — in such cases industrial grade supervisory control and data acquisition (SCADA) control systems should be considered.

Assessing the need for a multivalent system

With a monovalent system, the GWSHP should be specified to cover 100% of the thermal energy demand at all times.

With a bivalent/multivalent system, two or more heat generators are used, e.g. a gas CHP, heat pump and electric resistance heater combination. For larger non-domestic systems, it is not uncommon to find a heat pump installation supplemented by a fossil fuel boiler to provide additional peak capacity.

When the controls detect that the heat pump is no longer able to maintain the output temperature or a valency point is exceeded, it triggers one of the following:

— parallel operation (Figure 46): when both heat generators operate at the same time

— alternate operation (Figure 47): when the heat pump is replaced entirely by a second heat/cooling generator capable of delivering 100% of the peak load

— zonal operation: when the area of the building serviced by the heat pump is restricted leaving the remainder unheated or to be heated with a supplementary plant, e.g. direct electric.

Parallel operation is possible where there is only a requirement for additional heating or cooling capacity at load side temperatures that the heat pump is capable of delivering. In this case the heat pump remains in circuit at all times, with the secondary generator brought into operation when the demand side load exceeds the capacity of the heat pump.

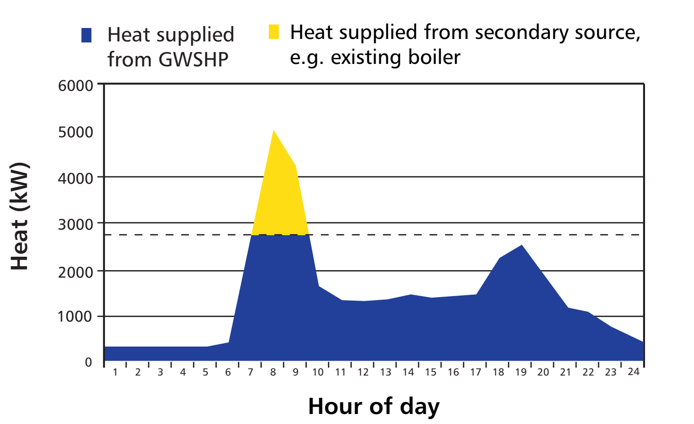


Figure 46 A bivalent system in parallel operation

The sizes of the heat pump and secondary generator can be varied at will, as long as the total capacity of the two systems meets the worst day loads. Careful design, usually employing low loss headers or buffer stores, is required to blend the different flow and return temperatures from the different heat sources to ensure this does not compromise the heat pump operation.

Alternate operation is used in situations where, as the ambient temperature moves towards extremes or the groundwater temperature drops significantly, the heat pump is no longer capable of delivering load side temperatures that will satisfy the required comfort levels in the building. The heat pump is then dropped out of circuit, and the alternate source is brought into operation to cover the total heating or cooling demand, at the required load side temperatures.

This method of operation is typically employed in retrofit situations where, under some ambient conditions, the building thermal envelope and/or the heating/cooling emitters require the use of load side temperatures that are outside the range of the heat pump. Alternate operation is also sometimes referred to as series operation.

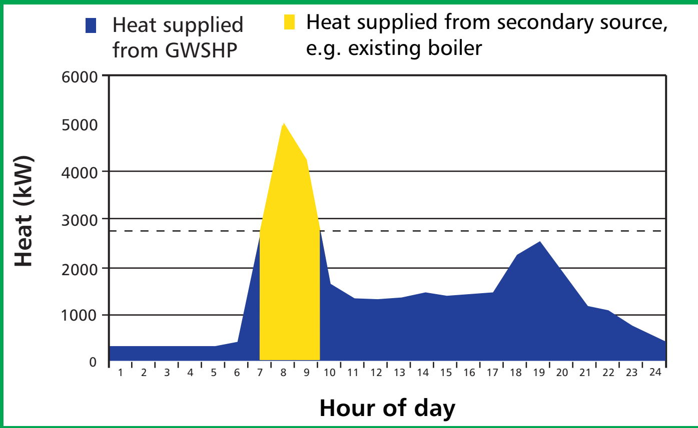


Figure 47 A bivalent system in alternate operation

The decision to employ a bivalent solution shall be assessed in line with a number of factors:

— Physical limitations:
- physical size of heat pump(s) relative to desired plant room size
- size of electrical supply
- thermal capacity of the available groundwater source
- ability of the selected heat pumps to meet the worst day load side emitter temperatures.

— Other design/cost considerations:
- If the heating/cooling load profiles are ‘peaky’, it may be considered economically attractive to provide supplementary sources to meet the peaking loads. This supplementary source might be an air source heat pump or some form of combustion technology.
- If the heat pump system is delivering heating and cooling, then it may be economically attractive to meet the lower of the heating/cooling peak loads with a heat pump, and to supplement the other peak load with an alternative source
- Requirements around plant redundancy, standby/back-up requirements for mission critical applications.

‘Monoenergetic’ is the description given to multivalent installations where only one energy source is used for two or more heat generators. For example, a heat pump supplemented by a direct electric resistance heater is a monoenergetic (electric) system (this is commonly found in domestic heat pumps).

‘Alternate Zonal’ is a system of control when the area heated or cooled is adjusted in real time as the ambient temperature varies to match the maximum output of the heat pump. The remainder of the building may be left unserviced or cooled/heated using another method.

Objective 2.7: To assess operation and maintenance needs and costs

Why is this objective important?

At the feasibility stage, operation and maintenance needs and costs should be assessed and included in the financial model. It is useful to split these into capital, fixed and variable. The main variable operating cost will be for electricity; however, estimates need to be made for non-energy operating costs, for example pump maintenance and inspection. Plant replacement cycles should also be considered and costed. The income from grants and incentives and any heat sold need to be included.

Minimum requirements

2.7.1 An operational model shall be set-up for use in the financial analysis from which operating costs and revenues (if any) can be determined.

2.7.2 A long-term repair/replacement strategy shall be developed to ensure that the true whole life costs are assessed. See CIBSE Guide M: *Maintenance engineering and management* (CIBSE, 2014a) for lifecycle analysis of components.

2.7.3 The cost of parasitic electricity consumption shall be included as well as any estimated overhead and maintenance costs for the GWSHP installation and directly related plant.

2.7.4 *New Rules of Measurement* (NRM) (RICS, 2013/2015) shall be used. NRM provides a standard set of measurement rules and essential guidance for the cost management of construction projects and maintenance works.

2.7.5 The operation and maintenance needs shall be assessed for the abstraction and discharge system particularly the down-hole plant and structures, such as submersible pump, heat exchanger, injection valves and pipework. Occasional CCTV inspection of the borehole will need to be carried out and the water quality monitored regularly with a comprehensive water quality assessment conducted at least annually.

2.7.6 The operation and maintenance cost shall include for all consumables, including top-up refrigerant.

2.7.7 The operation strategy shall consider the impact of global warming potential (GWP) the F-gas Regulations (EU, 2014), the phasing out of HFC refrigerant systems and how system design and plant rooms can be undertaken that protect the future integration of heat pumps using different refrigerants.

2.7.8 For operation, maintenance, durability and security, the location of instrumentation and valves, secondary filtration, heat exchangers and secondary circuit pump location shall be assessed with a secured plant room, ideally in the vicinity of the abstraction well or wells.

2.7.9 A control strategy shall be developed that addresses operational scenarios in different circumstances, for example, part load or different source temperature.

Best practice

Best practice would be to:

BP2.7a base costs on data obtained from actual operating systems where full details of the system are available to ensure it is of a similar type

BP2.7b include instrumentation to allow for condition-based maintenance programmes.

Objective 2.8: To conduct a financial analysis to comprehensively evaluate the installation options

Why is this objective important?

At the feasibility stage, financial analysis is required to investigate the costs and benefits of the various options. Capital cost, operating cost, whole-life cost including disposal costs and internal rate of return on the investment need to be determined. Other key metrics that may be important to the decision are £/kW·h, £/tCO_2. Care must be taken to ensure that the same parameters are used to ensure that the alternatives developed are directly comparable.

BSRIA BG67/2016: *Life Cycle Costing* (BSRIA, 2016a) provides a process for the practical calculation of whole-life costs for the construction and operation of buildings.

Minimum requirements

2.8.1 The factors to be included in the feasibility study shall be agreed in advance with the client. The parameters and variables chosen shall be sufficiently comprehensive to deliver useful results but be proportionate to the project scale.

2.8.2 All analysis shall be conducted in accordance with accepted accountancy principals and cover an agreed period, typically 15–25 years, but 100 years is not uncommon for heat pump projects, unless the projected life of the building is considerably less. Capital equipment replacement costs estimates and timescales shall be included in any calculation.

2.8.3 The cashflow model shall use a discount rate related to the client's cost of capital. Energy prices shall be obtained either from the existing customer's contract prices, BRE's *GreenBookLive* (BRE, online) and market indices such as the *Digest of UK Energy Statistics* (DUKES) (BEIS, online).

2.8.4 The Internal Rate of Return (IRR) and Net Present Value (NPV) shall be calculated, initially for a base case assuming current energy prices remain constant for the analysis period in real terms and a sensitivity analysis used to determine a range of outcomes depending on future carbon content and energy price trajectories.

2.8.5 Where there are viable retrofit energy efficiency measures, the cost savings shall be noted and the expected performance improvement included in the analysis.

2.8.6 The costing in the feasibility study shall be based on realistic estimates to ensure sufficient funding is allocated. An appropriate contingency fund shall be allocated and clearly identified to cover unforeseen costs.

2.8.7 To assess the economic benefit of the system for retrofit installations, the comparative costs will be determined against the total heating costs (fuel, maintenance and capital replacement) the customer would have incurred over the same period if they had retained the existing equipment. In the case of new developments, the comparison will be between the predominant form of conventional heating used for similar developments at the time of the study (e.g. gas boilers).

2.8.8 Full consideration shall be given to the financial implications of any indirect advantages, e.g. use of heat pump avoids the need for a gas supply, flues or fossil fuel storage.

Best practice

Best practice would include:

BP2.8a the creation of a detailed profit and loss account (P&L) and balance sheet and a simplified indexed P&L and balance sheet for the whole life of the system

BP2.8b employing a Royal Institute of Chartered Surveyors (RICS) certified quantity surveyor to estimate build quantities, profits, overheads etc. at feasibility stage.

Objective 2.9: To assess environmental impacts and benefits

Why is this objective important?

The environmental impacts on both local and global levels need to be assessed for all projects. The objective of installing an open-loop GWSHP system is to benefit the environment by reducing fossil fuel energy consumption and progressively decarbonising the heating and cooling of buildings. In achieving this macro objective, the local environment must be protected.

BSRIA BG52: *Life Cycle Assessment — an introduction* (BSRIA, 2013a) provides a methodology for compiling and evaluating the environmental impacts and the primary energy demand of a product system throughout its life cycle.

It should be noted that electricity grid carbon intensity is reducing rapidly and this must be considered when making long-term decisions. Refer to the BEIS website for current and predicted carbon factors (https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal) and the Ground Source Heat Pump Association's (GSHPA) Carbon Calculator (see https://www.gshp.org.uk/Gridwatch.html).

Minimum requirements

2.9.1 An assessment of the environmental impact of your scheme shall be carried out and the results documented.

2.9.2 The British Geological Survey (BGS) or Geological Survey of Northern Ireland (GSNI) resources shall be used to establish the characteristics of the surrounding geology and hydrogeology and help identify any relevant issues that may need additional consideration or otherwise influence the development.

2.9.3 For new-build systems, emission factors used in Building Regulations Approved Document L: *Conservation of fuel and power* (NBS, 2016, 2018) or equivalent shall be used for consistency with compliance calculations.

2.9.4 Heat losses and the carbon intensity of the electricity used to run the heat pump and parasitic pumps shall be taken into account in the CO_2 emissions calculations.

2.9.5 The GHG emissions calculations shall include the impact of refrigerant selected and likely leakage from the system, see 'Further reading'.

Best practice

Best practice would be to:

2.9a use BSRIA BG 10/2011: *Embodied Carbon — the Inventory of Carbon and Energy (ICE)* (BSRIA, 2011b), CEN TC350 Standards or other relevant tools to calculate the embodied and operational environmental impacts of construction materials across the entire life cycle

2.9b climate-proof the open-loop GWSHP in planning, installing and operating schemes that take climate change and increased frequency and severity of extreme weather events into account, see CIBSE Weather Data Sets (http://www.cibse.org/weatherdata); this can include flooding but also prolonged drought, heatwaves etc.

2.9c where appropriate, a Life Cycle Assessment (LCA) shall be carried out in line with BS EN ISO 14044 (BSI, 2006/2018) to measure and evaluate the environmental impacts associated with a product, system or activity, by assessing the energy and materials used and released to the environment over the product's life cycle.

Objective 2.10: To analyse risks and carry out a sensitivity analysis

Why is this objective important?

At the feasibility stage it is important to comprehensively assess the risks of the project. A risk register should be developed and then reviewed and updated throughout the project. A sensitivity analysis should also be carried out to quantify the impact of the identified risks. The risk register and sensitivity analysis will be used to aid the decision to take the project to the next stage. The PRINCE2 manual (see https://www.prince2.com/uk/what-is-prince2) contains some specific advice on producing risk registers and the appropriate terms used, and are particularly relevant for government/public sector projects.

Minimum requirements

2.10.1 A risk register shall be developed using the following categories:

- health and safety
- environment
- construction costs
- construction delays (including unexpected geological and hydrogeological conditions)
- performance of plant and equipment
- changes to the performance of the abstraction and injection wells
- broader economic risks, including future energy prices, regulation
- planning and other permissions.
- reputational risk.

2.10.2 The risk analysis shall examine the likelihood and severity of each risk, who the risk will impact and what mitigating actions are required. The likelihood and severity of each risk shall be re-scored assuming the proposed mitigation measures are in place.

2.10.3 The mitigation measures shall be assigned to the relevant party to take forward.

2.10.4 A sensitivity analysis shall be carried out to show the impact of each major financial risk (both capital and operational) and test the mitigation approach. This should include future cost of energy, carbon and maintenance plus any likely changes in yield and/or demand.

Best practice

Best practice would be:

BP2.10a to carry out a risk analysis workshop to identify and analyse the potential risks to the project

BP2.10b carry out more detailed studies of particular risk mitigation measures to ensure the project moves into the next stage with a lower risk profile

BP2.10c allocate a specific line cost to each risk mitigation measure so these are financially secure.

3: Design

Objectives:

3.1 To design for safety in construction, operation and maintenance

3.2 To accurately determine peak heating and cooling demands and seasonal energy consumption profiles

3.3 To accurately test and quantify the groundwater supply

3.4 To design the groundwater abstraction and discharge details

3.5 To apply for the permissions necessary to access the groundwater

3.6 To specify the most appropriate heat pump system

3.7 To design an efficient load-side hydraulic system interface

3.8 To evaluate environmental impacts and benefits

3.9 To design a data collection system to accurately record performance

3.10 To update and refine risk register and sensitivity analysis

3.11 To prepare a costs statement for the main system elements of the project

Key support tasks:

- Update risk assessments
- Undertake third party consultations as required and any research and development aspects
- Develop commissioning plan
- Review and update:
  - CAPEX and business case
  - sustainability strategy
  - maintenance and operational strategy
  - construction strategy
  - health and safety strategy
  - review and update implementation plan, including change control procedures
  - prepare and submit Building Regulations applications, if applicable
  - prepare and submit applications to the relevant environmental agency (once final design has been adopted)

Information exchange to next stage (construction team):

- Business case including whole-life cost (WLC), CAPEX, OPEX etc.
- Developed design, including borehole design, building services design and updated cost information
- Build plan and comprehensive set of constructions drawings

The importance of accurate design data

Progressing any project from feasibility study to final design must be underpinned with accurate input data. This is important with heat pump projects generally, because a greater than expected heating and cooling demand can overtax the heat supply. This is particularly true of air source heat pumps, where the power (and efficiency) reduces as the external air temperature falls — something which simultaneously increases the heat load. While the relatively stable supply temperature of groundwater avoids this challenge, and the ability to vary the rate and duration of pumping allows some design flexibility, it remains vital to know the capacity limits of the well in question. This information is also essential as part of the application process for any permissions or licenses that may be required.

Critical information required to ensure a robust final design:

(A) *Heating and/or cooling load*: it is essential to have the best possible heat load calculations, including cooling if appropriate. To be of any real value these figures must consider diversity, see Objective 2.4, and ideally the possibility of future changes in the use of the building.

(B) *Groundwater quality, quantity and temperature*: collecting accurate data for an open-loop groundwater project can be particularly challenging due to the difficulty in predicting with any accuracy the quality and quantity of the groundwater before the water well is drilled and tested. This requires a level of speculative investment. However, experienced designers can often design around the yield. There are tried and tested techniques that may be used to improve the performance of the well, most notably acidisation.

Mitigating a lack of yield

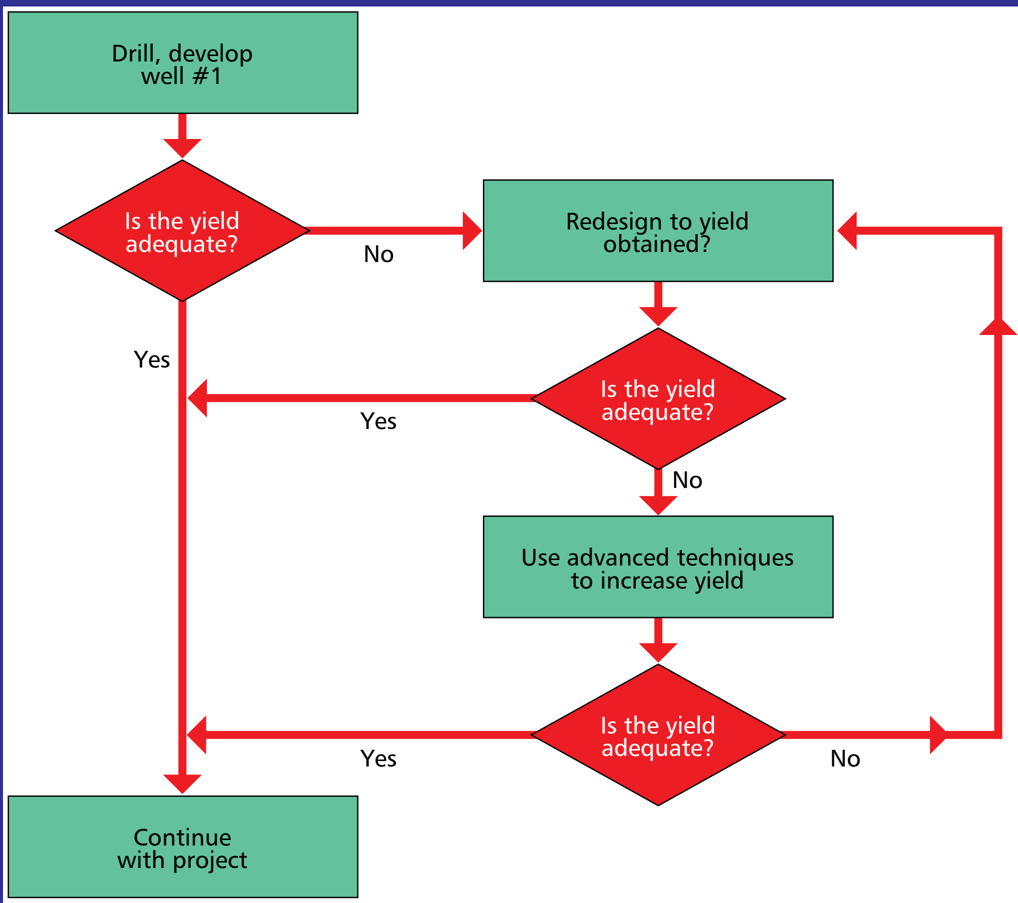


Figure 48 Steps to achieve yield (courtesy of Phil Jones)

Mitigating a lack of yield *(continued)*

A borehole prognosis report provided by an expert will minimise the risks, but it is impossible to predict with certainty the final yield of a water well before it is drilled, developed and tested. Consequently, it is important to decide in advance what action to take if the new well produces less water than expected.

However, a yield below expectation can frequently be overcome using a range of well-established techniques that exist to increase output (or injection capacity). It is also often possible to revise the overall system design to work with the water quantities available.

It is therefore important to employ an expert with appropriate knowledge to advise and oversee system design, well testing and development. Which output enhancement technique(s) to use, and in what order, will differ with geology and from site to site.

Common well development measures may take less than an hour or several days.

Procedures available include:

— acidisation (in chalk aquifers)

— airlift pumping and surging while monitoring suspended solids content and yield

— pumping and surging with a submersible pump while monitoring suspended solids content and yield.

Depending on the details of underlying geology, drilling the well deeper or installing additional wells are also options.

The decisions made will usually be cost-driven although in some cases the critical parameters may be time, reliability or longevity.

Please note that in some cases mitigation measures can fail to work and a new water well will be required or the project abandoned.

Best practice would be to offer two designs from the outset — one for the ideal yield and another to establish the lowest viable yield. Low-yield designs may increase capacity with bi- or multi-valent systems incorporating CHP, heat recovery, thermal energy storage, dry air coolers, solar thermal panels etc.

Objective 3.1: To design for safety in construction, operation and maintenance

Why is this objective important?

Reducing health and safety risks is of primary importance to any project. The designer must first carry out a risk assessment and then mitigate these risks by making appropriate design decisions and assess how the proposed design will be constructed, operated and maintained.

Minimum requirements

3.1.1 The client shall recognise their role and obligations under the current CDM Regulations and register the project prior to the start of the design process.

3.1.2 The Principal Designer shall carry out the requirements of the CDM Regulations and develop a designer's risk assessment at an early stage.

3.1.3 The requirements of the Control of Substances Hazardous to Health Regulations 2002 (COSHH) and the Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR) and other regulatory requirements shall be taken into account in developing the design. Certain refrigerants, in particular ammonia, require a specific risk assessment which shall inform refrigerant choice, plant room location and requirements.

3.1.4 The design company shall be certified under BS EN ISO 9001: *Quality management. Requirements* (BSI, 2015a) or operate in accordance with an equivalent quality assurance scheme and shall mitigate risks in construction, operation, maintenance and decommissioning as far as possible and provide a risk register for use during construction.

3.1.5 The Well Drillers Association (WDA) and British Drilling Association (BDA) procedures, guidance and recommendations shall be considered in the design to ensure all drilling activity is planned and risks identified.

3.1.6 The design shall provide sufficient access around plant and equipment in the plant room to enable safe maintenance to be carried out including access/egress and handling of equipment/parts associated with any repair/replacement works, see BSRIA BG9/2011: *Rules of Thumb — Guidelines for building services* (BSRIA, 2011a).

3.1.7 The design shall locate valve chambers and other facilities requiring access (including surveillance system monitoring terminals) in a suitable location so that safe operation and maintenance can be carried out avoiding any harm to the public.

3.1.8 The design shall mitigate the risks of *Legionella* and follow HSE Code of Practice L8: *Legionnaires' disease. The control of legionella bacteria in water systems* (HSE, 2013).

3.1.9 Adequate access and other provisions shall be made to enable safe replacement of plant in the future. A plant replacement strategy report shall be produced during the design stage.

Best practice

Best practice would be to:

BP3.1a develop the design so the operator can achieve BS EN ISO 14001 (BSI, 2015b) and BS ISO 45001 (BSI, 2018a) certification

BP3.1b have the system built so the client can achieve the BS EN ISO 50001 (BSI, 2018e) energy management standard

BP3.1c have design documentation undergo a due diligence review by a suitably qualified independent third party.

Objective 3.2: To accurately determine peak heating and cooling demands and seasonal energy consumption profiles

Why is this objective important?

At the design stage the values used for peak heat demand will determine the capacity of the GWSHP and any multivalent heating and cooling sources, the capacity of the heat emitters and ancillaries. This will therefore determine much of the capital cost. The annual heat consumption and daily demand profiles will determine the energy consumption of the GWSHP and important elements of the operational cost.

Therefore, the estimates made at the feasibility stage (see Objective 2.4) must now be updated and calculated as accurately as possible.

For new buildings the heat demand estimates should be produced by the appointed building services designer, although the GWSHP designer may have valuable advice based on previous experience. It is vital that a consensus is reached at this stage to avoid the potential for significantly over- or under-sizing of the GWSHP unit, see 'Further reading' for guidance, notably CIBSE TM54 (CIBSE, 2013a).

For existing non-domestic buildings, it will normally be the responsibility of the customer to define the peak heat demand that they wish to contract for and to provide an estimate of their annual heat energy consumption. However, this analysis should be with the close involvement of the GWSHP designer/operator who may be able to draw on experience of supplying similar systems to similar buildings. Conducting an existing-system survey together with accurate heat loss calculations ensures that the HVAC system can meet customer requirements. The Building Regulations *Non-Domestic Building Services Compliance Guide* (NBS, 2013a) for England, and its equivalents for the devolved administrations, confirms the importance of accurate calculations in sizing heat pumps.

The designer has to design for worst case scenarios and judge whether the fabric is constructed as specified in the original design and whether the ventilation rate accurately reflects the building's actual use. This is particularly important when sizing a monovalent heat pump system which should be neither under- or over-sized, but rather sized to the building's requirements. More has been written about this subject by the Zero Carbon Hub (http://www.zerocarbonhub.org).

Minimum requirements

3.2.1 Peak demands for existing buildings shall be assessed as accurately as possible from a combination of data on fuel use (accounting for system efficiency), existing heat source use, and building simulation modelling or other calculation of heat losses as appropriate. Peak demands should account for local climate and building fabric thermal mass; for external temperature selection, see CIBSE Guide A: *Environmental design* (CIBSE, 2015). This assessment should be supported by the heat pump system designer who may be able to use data from monitoring demands at similar buildings to assist.

3.2.2 For existing non-domestic buildings, space heating requirements in each month shall be estimated by the customer, in conjunction with the heat pump designer. This should include fuel or heat meter readings together with a degree day analysis to produce heat consumptions for each month for an average year. It should take account of the location of the building, the required internal space temperature and an appropriate baseline temperature for the building.

3.2.3 For existing buildings, calculations shall be carried using established calculation methodologies and these calculations shall be agreed with the heat pump system designer.

3.2.4 For new non-domestic buildings heat demands shall be estimated using modelling software and by using the guidance in CIBSE Guide F (CIBSE, 2012), CIBSE AM14 (CIBSE, 2010) and CIBSE TM46 (CIBSE, 2008) or other sources of benchmark data, or data obtained from similar operational systems.

3.2.5 For new buildings, heat demands shall be estimated using standard design calculation methodologies based on the proposed fabric and ventilation standards. DHW can be sized using BS EN 806 (BSI, 2000–2012), BS 8558 (BSI, 2015c) and BS 15316-4-2 (BSI, 2017d).

3.2.6 The space heating and cooling consumption shall be profiled using degree days or annual weather files to obtain monthly consumptions and a 24-hour variation in demand created for heating, cooling and hot water demand.

Best practice

Best practice would be to:

BP3.2a use a full year's data and include monitoring of external air temperature so the data can be normalised. The installation of new meters or setting up logging of data using a BMS or BEMS should be considered.

Objective 3.3: To accurately test and quantify the groundwater supply

Why is this objective important?

In the feasibility stage, the potential for a groundwater source heat pump will have been investigated and estimated. To prepare a reliable final design, the quantity and temperature of the groundwater available must be known. Water quality should also be tested and considered during the final design process. If an injection well is to be used, its capacity must also be measured.

Minimum requirements

3.3.1 The groundwater source shall be fully investigated and accurately tested. This will require a water well, or water wells, to be constructed, tested and the data obtained, e.g. the driller's log used to inform the final design.

Important considerations are:

- the presence, depth and nature of the target aquifer
- other users of groundwater from the aquifer
- existing geological maps, plans, satellite imagery, previous nearby studies and Geographic Information System (GIS) data
- other water supply or open-loop boreholes records located nearby
- potential risk and implications of artesian conditions
- site layout, specifically the distance between abstraction and injection boreholes where appropriate
- groundwater level (depth below ground level): groundwater very close to the surface can in some circumstances render injection wells impractical
- the chemical quality of the groundwater: some aspects of water chemistry, for example the nature and concentration of iron and/or manganese can have a major impact on the design.

3.3.2 The British Geological Survey (BGS) or Geological Survey of Northern Ireland (GSNI) shall be provided with the drilling and pumping records. It is a requirement that the BGS is notified of any water well or borehole over 15 m deep.

3.3.3 A detailed assessment of the risk of corrosion and incrustation together with the presence of particulate matter, dissolved gasses and contaminants in the groundwater source shall be carried out and mitigations measures incorporated into the final design and maintenance provision. See Appendix E.

3.3.4 The energy potential of the measured groundwater flow shall be calculated. These calculations must be included with the final design.

3.3.5 Accurate building heat demand information shall be used to calculate the peak pumping rate, daily and annual groundwater volume required by an open-loop heat pump system to satisfy the load. These calculations shall be included with the final design.

Best practice

Best practice would be to:

BP3.3a refine the detailed plan and cross section of the location to ensure all and any design constraints are identified. This can also be used to identify the location and potential relevance of adjacent schemes.

Objective 3.4: To design the groundwater abstraction and discharge details

Why is this objective important?

In the feasibility stage, the location of the heat pump installation and preferred method of abstraction will have been identified. Open-loop groundwater systems all require regular maintenance to ensure the installation is reliable and provides optimum performance, so the design must take into account water quality and any other factors that could degrade performance. Open-loop systems are susceptible to chemical attack and fouling of the heat exchanger, so maintenance frequency depends on the gas content, chemical composition and pH of the water, turbidity, sediment in suspension or other pollutants.

Minimum requirements

3.4.1 The location of the installation and method of abstraction shall be determined using the most up to date and accurate information.

3.4.2 The abstraction and injection wells and related equipment shall be designed taking into account requirements from the relevant environmental agency and other regulatory bodies, and ensuring provision for measurement, regular maintenance and problem-free performance.

3.4.3 The installation shall be designed to the permitted temperature range and ΔT agreed with the relevant environmental agency with regard to local geological and hydrogeological conditions and other consumers.

3.4.4 The abstraction and injection wells shall be designed to take into account all and any conditions specific to the site in particular water quality and chemistry.

3.4.5 Well-heads shall be designed to be sealed and ideally be completed above ground (or, failing that, in a well-drained subsurface chamber). Run-in of potentially contaminated surface water is thus prevented.

3.4.6 The abstraction pump(s) capacity, pipework configuration and location shall be designed taking into account turn-down range, redundancy and planned preventive maintenance access.

3.4.7 Rapid pressure changes as a result of steeply inclined abstraction/heat exchange/injection pipework shall be avoided. For example, avoid plant rooms at high elevations. Injection to aquifers with very deep or very shallow static groundwater levels require careful engineering and hydrogeological design consideration.

3.4.8 Where groundwater is injected back into the ground, the discharge pipework shall be designed as a sealed, pressure managed line. The operating pressure must be appropriate for the particular installation.

3.4.9 The instrumentation, secondary filtration and heat exchanger interface, including capacity, configuration and location shall be designed, taking into account turn-down range, redundancy and planned preventive maintenance access.

3.4.10 The installation shall be designed to ensure optimum performance throughout the range of specified heating and/or cooling loads. Modelling techniques shall be used to verify the design and to ensure transparency the results shall be published as part of the design documentation.

3.4.11 The controls system shall be designed, and an operational strategy shall be developed.

3.4.12 The location of the heat pump shall take into account security to avoid potential human interference.

3.4.13 The installation shall be designed using the best materials, equipment and guidance available within financial parameters to ensure long-life and reliability. Chapter 13 of CIBSE Guide M (CIBSE, 2014a) provides tabulated economic lifetimes for plant, equipment and material selection, including pipe materials, and can greatly assist in correct selection of this when considering a lifetime assessment of a system. BESA TR11: *Guide to the Use of Plastic Pipework* (BESA, 2006) provides useful guidance in this area.

3.4.14 All pipework shall be sized to minimise pressure drops, parasitic energy consumption and to maximise performance.

Best practice

Best practice would be:

BP3.4a for the client to procure an independent verification and commissioning engineer from a specialist company to review and comment on the draft design and prepare a commissioning plan for the construction. The commissioning plan and procedures should be compliant with all the relevant CIBSE Commissioning Codes and BSRIA commissioning guidance, in particular CIBSE Commissioning Code M (2003).

BP3.4b in cases where a risk of incrustation, bio-film formation or corrosion is identified, best practice would be to pass the groundwater through a secondary heat exchanger, rather than through the evaporator (or condenser) of the heat pump itself. This is particularly the case for medium to large schemes.

Objective 3.5: To apply for the permissions necessary to access the groundwater

Why is this objective important?

In the Feasibility Stage the permissions necessary to access the water should have been determined and pre-application discussions held with the appropriate environmental agency and other relevant statutory bodies (see Objective 2.2). At the Design Stage, applications need to be submitted and permissions granted before any abstraction and discharge can take place other than for testing purposes.

The *Good Practice Guide for Heating and Cooling* (GSHPA, 2017) sets out a summary of what should be done to comply with environmental legislation and manage environmental risks. It is based on regulations set out by the Environment Agency for England and whilst the Guide is relevant across the whole of the UK, it is recommended to consult with the equivalent regulatory bodies in Wales (NRW), Scotland (SEPA) and Northern Ireland (NIEA) where necessary.

Details of the requirements in each devolved area can be found in Appendix B; however, note that regulations can change, therefore consultation with the relevant regulatory bodies must be sought to confirm the situation every time.

Minimum requirements

3.5.1 Pre-application discussions will have taken place in the Feasibility Stage with the relevant environmental agency for all abstraction and discharge activity, see Objective 2.2. At the Design Stage, discussions shall continue and full applications submitted.

3.5.2 If required a water features survey shall be carried out, generally covering a 500 m to 1 km radius around the site.

3.5.3 When the open-loop GWSHP installation plans to use abandoned coal mine workings for the purpose of extracting heat from mine water application for a Minewater Heat Recovery Access Agreement shall be granted from the Coal Authority (see http://www.gov.uk/government/publications/minewater-heat-recovery-access-agreements).

3.5.4 All reports shall be completed and submitted with the driller's log and the results of the test pumping and interpretation of the data as required by the relevant environmental agency.

3.5.5 The installation of a GWSHP may be considered permitted development and may not need an application for planning permission. If planning permission is required, applications shall be made to the local planning authority including permission for temporary works for storage of materials and other construction purposes where necessary.

3.5.6 The Town and Country Planning (Environmental Impact Assessment) Regulations 2011 can apply, even when the project is considered permitted development. If required, an Environmental Statement shall be prepared.

3.5.7 The installation of a GWSHP within or affecting Sites of Special Scientific Interest (SSSIs), Special Conservation Areas (SACs) and Special Protection Areas (SPAs) shall require consultation with Natural England (NRW in Wales). Where planning consent or abstraction/discharge consent is required, this consultation shall be carried out by the local planning authority or other regulator. For works where those consents are not required, consult Natural England or relevant regulatory body and obtain their permission before starting work.

3.5.8 Where planned pipework routes for water abstraction or discharge will cross public access paths, the relevant application for temporary suspension of rights of way shall be carried out.

Best practice

Best practice would be to:

3.5a assign an individual as the point of contact for the relevant environmental agency and/or other relevant statutory bodies for all stages of the project.

Typical abstraction/discharge ΔT

A key element of heat pump system operation is the difference in temperature between water entering and leaving the heat pump's heat exchanger (ΔT). In groundwater systems, whether heating, cooling or both (balanced) this becomes critical to the design as it directly affects the abstraction and discharge temperatures.

Therefore, the operating temperatures and ΔT permissible in any specific location must be considered in detail with the relevant environmental agency and consider local conditions, protection of sites and species and pressures from other developments. Some smaller schemes may be exempt from the regulations but early discussion with the relevant environmental agency is always advised.

For example, for England, the Environment Agency's *Guidance notes on registration of ground source heating and cooling system as exempt from the need for an environmental permit* (EA, 2014) state that the temperature of water discharged from the system will not exceed 25 °C and will not vary by more than 10 °C compared to the abstracted water. The ratio between the abstraction and discharge temperatures is also considered:

$$\text{Temperature ratio} = \frac{\text{Discharge temperature}}{\text{Abstraction temperature}}$$

Given the above it is recommended that a ΔT of ± 10 °C is a reasonable starting point until further information becomes available following any site specific investigation and discussions with the relevant environmental agencies.

Objective 3.6: To specify the most appropriate heat pump system

Why is this objective important?

At the design stage, the design concept for the GWSHP installation must be finalised including the type and number of heat pumps in the system and how they are to be integrated. Other elements, such as thermal energy storage, buffer tanks, isolating heat exchangers, dry air coolers etc. will also need to be specified.

Minimum requirements

3.6.1 The working temperatures for the heat pump system shall be specified.

3.6.2 A performance specification for the heat pump system shall be set out including the part load characteristics appropriate to the system's source and load side conditions, such as energy demands and other limiting factors. This shall include full and part load efficiencies, minimum turn-down and maximum start/stops per hour.

3.6.3 An efficient heat pump system able to deliver the specifications above shall be identified. This will include type of heat pump, refrigerant, associated controls etc. Due to the nature of the heat pump marketplace it may be necessary to identify the heat pump manufacturer at this stage and design around their particular offering.

3.6.4 Any thermal energy storage process and associated ancillary equipment required shall be specified.

3.6.5 The likely long-term maintenance requirements of the heat pump type and any implications for the installation shall be assessed.

3.6.6 The capacity and voltage of the electrical supply required and the location route for the cabling shall be specified and for larger schemes the need for additional transformers shall be identified.

3.6.7 The heat pump and its controls shall meet local Building Regulations and shall be compliant with all relevant certification bodies and other legislative requirements.

Best practice

Best practice would be to:

BP3.6a work with three or more heat pump manufacturers or their local distributors. It is likely that each will offer not only different heat pumps but also different ways that they may be integrated into an efficient configuration.

Objective 3.7: To design an efficient load-side hydraulic system interface

Why is this objective important?

To ensure an installation is as efficient as possible, an important design choice is whether the building's heating and/or cooling load are directly or indirectly connected to the heat pump (i.e. is a heat exchanger, buffer tank or similar device used at the interface?).

Indirect connection has the following benefit:

— There is less scope for contractual disputes if the systems are owned, operated or maintained by different organisations.

— It simplifies the integration and operation of multivalent or multivector systems.

— The heat pump and building distribution fluids can be kept separate, if required.

— The metering and accurate measurement of heat delivered and/or consumed is simplified.

Direct connection has the following benefits:

— It is less complex, having fewer components, so less maintenance is required and there are fewer potential points of failure.

— There is no loss of temperature and efficiency between primary and secondary circuits across a heat exchanger.

— Less plant room space is needed.

— There is a potential reduction in capital expenditure (CAPEX).

Minimum requirements

3.7.1 The hydraulic interface shall be appropriately designed, i.e. direct or indirect connection. If a buffer vessel or thermal energy store is to be used the size and location shall be determined.

3.7.2 Where top-up boilers are being specified for use at times of high (peak) demand the connection design shall ensure boilers are used only when required. Care shall be taken not to accidentally exceed any low distribution temperature design parameters especially within the heat pump's condenser.

3.7.3 The heating and cooling loads of the building shall be assessed to a level of accuracy agreed with the client and to comply with all relevant standards (see 'Further reading').

3.7.4 Appropriate de-aerators and particulate filters shall be specified to reduce the risk of contamination effecting operation.

3.7.5 For indirect systems a variable volume control principle shall be employed. If two-port valves are used care shall be taken not to increase net energy consumption.

3.7.6 The design of plant rooms shall provide sufficient space for maintenance access and for future replacement of equipment including suitable power supplies for carrying out maintenance, lighting, ventilation, water supply and drainage facilities.

3.7.7 Any other boundary conditions or influencing factors (e.g. plant room size) shall be noted, action taken and the result reported to all relevant stakeholders.

3.7.8 Thermal energy storage shall be considered to improve the efficiency of heat pump operation.

Best practice

Best practice would be to:

BP3.7a use computer simulation techniques to model the hydraulic arrangements and advanced flow analysis and system modelling capabilities to simulate the system in detail and use this model to further optimise heat pump performance and thermal storage size.

Objective 3.8: To evaluate environmental impacts and benefits

Why is this objective important?

At the design stage the local environmental impacts must be evaluated, in addition the global or macro impacts should be calculated for larger projects or if required by clients or others. The objective of installing GWSHP systems is to benefit the environment by reducing fossil fuel energy consumption and carbon emissions, in achieving this objective the local environment must also be protected.

Minimum requirements

3.8.1 The assessment of the environmental impact of your scheme shall be verified and the results documented. This will form the basis of the Environmental Impact Assessment, if one is required.

3.8.2 The temperature of the groundwater abstraction shall be monitored in order to identify any longer-term warming/cooling of the aquifer

3.8.3 Electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen and, where practicable, pH shall be continuously recorded and regularly monitored to identify any longer-term changes to the aquifer and to protect the heat pump heat exchangers

3.8.4 The anticipated CO_2 savings and carbon intensity of the heat supplied shall be calculated for the project (see https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal). This establishes a set of diminishing carbon factors to reflect future decarbonisation of the electricity grid.

3.8.5 Refrigerants shall be selected taking into account global warming potential and the implications of F-gas Regulations on future equipment replacement and selection, see Appendix B.

3.8.6 Materials shall be responsibly sourced considering the social, ethical and environmental aspects of a construction product from extraction and use to recycling/reuse and disposal. BRE standard BES 6001: *Framework Standard for Responsible Sourcing* (BRE, 2016) is a framework that assesses the responsible sourcing practices throughout the supply chain of construction products and allows manufacturers to prove their products have been responsibly sourced.

Best practice

Best practice would be to:

BP3.8a use BSRIA BG10/2011: *Embodied Carbon — the Inventory of Carbon and Energy (ICE)* (BSRIA, 2011b), CEN TC350 Standards or other relevant tools to calculate the embodied and operational environmental impacts of construction materials across the entire lifecycle.

BP3.8b carry out a Life Cycle Assessment (LCA) in line with BS EN ISO 14044 (BSI, 2006/2018) to measure and evaluate the environmental impacts associated with a product, system or activity, by assessing the energy and materials used and released to the environment over the product's life cycle.

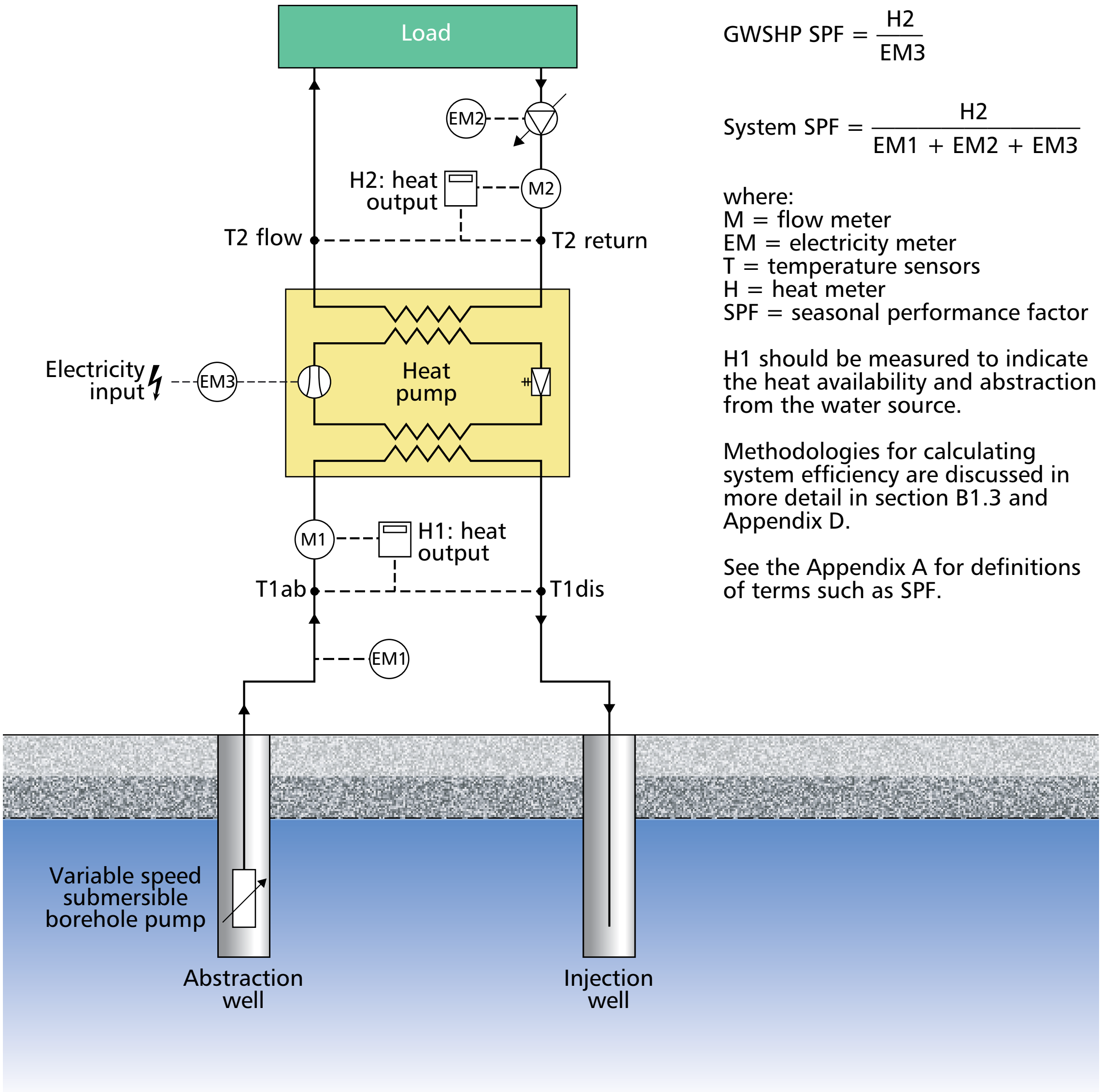
3.8c select and use natural refrigerants, or refrigerants with an ozone depletion potential (ODP) of 0 and a global warming potential (GWP) of 1 or less.

3.8d use supporting renewable systems, e.g. solar thermal for DHW generation and on-site generation of renewable electricity for heat pump/plant room operation; alternatively negotiate a long-term supply agreement of low carbon electricity from a specialist supplier.

Objective 3.9: To design a data collection system to accurately record performance

Why is this objective important?

A comprehensive metering and monitoring system is important to ensure ongoing operational performance (see Figure 49 below for typical metering arrangements). The feasibility stage should have established the performance monitoring requirements in line with any permissions necessary, such as abstraction licence and discharge permit (see Objective 2.2). Other requirements, such as metering for relevant grants and incentives, the client's own performance records and other relevant bodies should also be determined (see Appendix C).



$$\text{GWSHP SPF} = \frac{\text{H2}}{\text{EM3}}$$

$$\text{System SPF} = \frac{\text{H2}}{\text{EM1} + \text{EM2} + \text{EM3}}$$

where:
M = flow meter
EM = electricity meter
T = temperature sensors
H = heat meter
SPF = seasonal performance factor

H1 should be measured to indicate the heat availability and abstraction from the water source.

Methodologies for calculating system efficiency are discussed in more detail in section B1.3 and Appendix D.

See the Appendix A for definitions of terms such as SPF.

Figure 49 Typical metering arrangements for an open-loop GWSHP system, allowing calculation of the efficiency of the GWSHP and of the overall system (see also section B1.3); additional meters may be required in order to provide more detailed reporting, e.g. for grants and incentives

Modern BMS, BEMS, AMR or SCADA equipment (see Appendix A for definitions) can be used to monitor the installed meters/temperatures to allow ongoing performance to be determined and displayed continuously (see Figure 50).

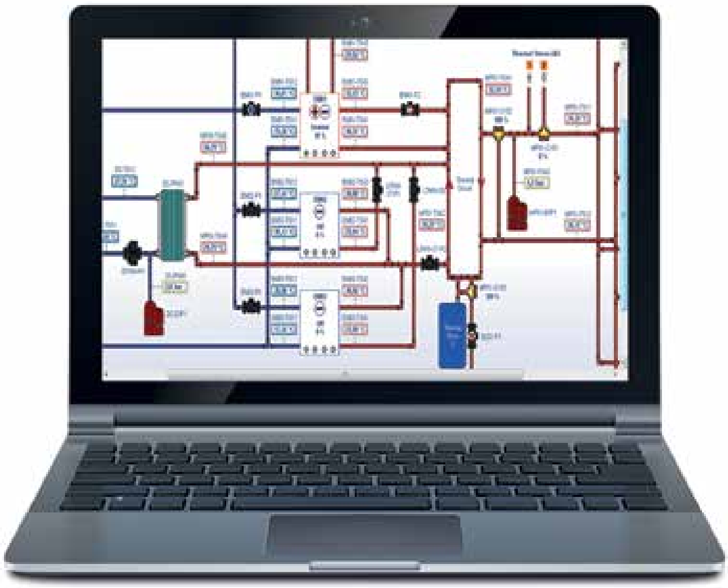


Figure 50 Visual display of SCADA monitoring and control information (courtesy of Energy Machines SA, Luxembourg)

Minimum requirements

3.9.1 The metering and data system shall be designed to ensure that system efficiency can be measured and recorded. This shall also include the necessary data outputs and reports required for maintenance, environmental permissions and incentive schemes, see Figure 49.

3.9.2 Expected system efficiency shall be calculated to enable comparison at commissioning (5.3.4) and operation and maintenance (6.4.7) stages. (See section B1.3 for suggested methodology.)

3.9.2 Meter selection and location shall consider long-term maintenance and periodic calibration issues.

3.9.3 BEMS, SCADA and any other maintenance and performance systems shall be included in the design and set to monitor and manage in real time the heat pump to ensure it is performing optimally, see Figure 50. The monitoring frequencies for reporting purposes shall be at least every 30 minutes.

3.9.4 Sensors shall be designed to ensure flow and return temperatures, yield and flow rates on both the source and load side are accurately recorded. Heat meters shall be used as appropriate and shall comply with BS EN 1434-1 (BSI, 2015/2018) and in line with any guidance for the relevant grants and incentives. Thermal energy meters must be sized with appropriate resolution for the peak and the minimum loads. Monitoring of the source side shall be used to identify any long-term warming/cooling of the aquifer.

3.9.5 The appropriate metering system shall be designed to measure and record all electrical input to the GWSHP including any parasitic load particularly borehole pumps.

3.9.6 Electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen and, where practicable, pH shall be continuously recorded and regularly monitored to identify any longer-term changes to the aquifer and to protect the heat pump heat exchangers

3.9.7 The appropriate metering system shall be designed to comply with the requirements of any licences and grants obtained.

Best practice

Best practice would be to:

BP3.9a monitor the system continuously and design a display with a range of system data; this could be compared against expected energy consumption

BP3.9b use remote data collection to facilitate real time monitoring to detect any performance or maintenance issues

BP3.9c include for monitoring or parameters that would inform a condition-based maintenance regime.

Objective 3.10: To update and refine the risk register and sensitivity analysis

Why is this objective important?

At the feasibility stage, a risk register should have been developed and a sensitivity analysis should have been carried out to quantify the impact of the identified risks.

During the design stage, the financial projections shall be used in conjunction with the risk register to evaluate the effect of uncertainty on objectives and the costs and benefits of mitigating risk. The sensitivity analysis should be carried out using a range of appropriate variables in order to fully stress-test the proposals.

Minimum requirements

3.10.1 The risk register shall be updated and the mitigation measures reviewed and revised as necessary.

3.10.2 A sensitivity analysis shall be conducted to quantify each risk in terms of impact on IRR, NPV and output value. This shall also include assessing the potential benefit from defined risk mitigation measures, for example:

- retaining the risk by informed decision
- avoiding the risk by deciding not to start or continue with the risky activity
- removing the risk source
- changing the likelihood
- changing the consequences.

3.10.3 As a minimum the following sensitivities shall be included:

- geological and hydrogeological variables, including change in yield
- weather impacts, especially drought and flooding
- future energy prices
- construction programme or cost over-run
- plant reliability
- operation, maintenance and management costs.

3.10.4 A separate analysis shall be carried out to assign monetary value to the CO_2 saved (see http://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal).

Best practice

Best practice would be to:

BP3.10a follow the principles of BS ISO 31000 (BSI, 2018b) or equivalent to carry out the risk analysis

BP3.10b adopt a BSRIA soft landings approach (see https://www.bsria.co.uk/services/design/soft-landings) to ensure the operating team/operator is fully engaged in the design process to mitigate risks of inefficient operation.

Objective 3.11: To confirm a cost statement for the main system elements of the project

Why is this objective important?

During the design stage the financial projections shall be updated to reflect the most recent version of the planned installation and the current cost targets for the main elements of the system.

The objectives of this process are to:

— describe, together with the outline proposal drawings, the chosen distribution of the resources within the budget to provide a balanced design to meet the client's needs

— set cost targets for the main elements so that, as the design develops, the targets can be checked and adjustments made so that the overall cost of the project is managed within the budget

— provide the design team with controls that communicate the costs, quantity, quality and time parameters to be followed

— provide the opportunity to consider life cycle costs, see BS ISO 55001 (BSI, 2014b).

This information is used to ensure engineering decisions are financially robust and the financial model can be used in conjunction with the risk register to evaluate the effect of uncertainty on objectives and the costs and benefits of mitigating risk. Project management tools, such as PRINCE2 (see https://www.prince2.com/uk/what-is-prince2), require the business model to be constantly updated throughout the stages of the project. In addition, see CIBSE Guide M (CIBSE, 2014a) for lifecycle analysis of components.

Minimum requirements

3.11.1 The costing team shall be provided with all the information they require to complete the task. This shall include:

- the budget (where alternative budgets have been proposed, the client should state the preferred alternative)
- confirmation of the programme for design and construction times stated in the budget report
- acceptance or variation of any other matters within the budget report
- confirmation of the brief
- outline drawings of the building and site works indicating alternative solutions

- an indication of the preferred specification for the main elements
- outline proposals for installation, indicating any alternative system or structural solutions
- outline proposals for operating duty, capacity and maintenance requirements.

3.11.2 The costs calculations and report shall include:

- a statement of cost
- a broad indication of the specification
- a statement of equipment duties and capacities
- a request for decisions on any alternative proposals and/or procurement routes, with advice thereon
- an updated cash-flow forecast
- allowances for contingencies and design reserve
- an update of inflation projections.

3.11.3 The level of detail of the information provided shall be appropriate to the scale and complexity of the system. Issues to be considered shall include:

- the measurement of approximate quantities and the application of rates to the quantities generated
- comparison of the requirements with analyses of previous projects of a similar character
- use of appropriate cost models, and/or
- a mixture of the above methods.

3.11.4 An evaluation shall be made of key elements of the system which carry major financial implications to assist and inform the decision process.

Best practice

Best practice would be to:

BP3.11a carry out a sensitivity analysis using a range of appropriate variables in order to fully stress-test the proposals

BP3.11b get a Royal Institute of Chartered Surveyors (RICS) certified quantity surveyor to produce an independent full cost breakdown of the project based on estimated quantities, equipment selection and all other relevant overheads, profits, provisional sums and contingencies considering the procurement route selected and particulars of the project

BP3.11c in the feasibility stage, it was identified as best practice to produce a profit and loss (P&L) account and balance sheet. If this process has been followed, the P&L account and balance sheet should be updated.

4: Construction and installation

Objectives:

4.1 To reduce adverse environmental impacts of construction

4.2 To reduce health and safety risks

4.3 To install the groundwater abstraction and discharge system in accordance with the design

4.4 To pressure test, flush clean, purge and fill all pipework and plant

Key support tasks:

- Review and update sustainability strategy and implement handover strategy, including agreement of information required for commissioning, training, handover, asset management, future monitoring and maintenance and ongoing compilation of ‘as-constructed’ information
- Review and update commissioning plan
- Update construction and health and safety strategies

Information exchange to next stage commissioning team):

- ‘As-constructed’ information
- Commissioning schedule/programme

Objective 4.1: To reduce adverse environmental impacts of construction

Why is this objective important?

Although the ultimate aim of an open-loop GWSHP system is to provide an environmental benefit, there may be negative environmental impacts during construction which need to be identified and minimised.

Construction should be as sustainable as possible in line with BS EN 15978 (BSI, 2011) and BS EN 15804 (BSI, 2012/2013) and embodied carbon should be kept to a minimum in line with CIBSE Research Report 9: *Embodied carbon and building services* (CIBSE, 2013c) and BSRIA BG 10/2011: *Embodied Carbon — the Inventory of Carbon and Energy (ICE)* (BSRIA, 2011b).

TM56 (CIBSE, 2014b) deals with resource efficiency in building services, and more information can be found at the website of the Waste and Resources Action Programme (www.wrap.org.uk).

The *Good Practice Guide for Heating and Cooling* (GSHPA, 2017) sets out a summary of what should be done to comply with environmental legislation and manage environmental risks. It is based on regulations set out by the Environment Agency for England and whilst the guide is relevant across the whole of the UK, it is recommended to consult with the equivalent regulatory bodies in Wales (NRW), Scotland (SEPA) and Northern Ireland (NIEA) where necessary.

These minimum requirements below are not intended to be comprehensive but will emphasise particular risks associated with the construction and installation of GWSHP systems.

Minimum requirements

4.1.1 F-gas Regulations shall be followed in the installation of the heat pump system, see 'Further reading'.

4.1.2 In the Feasibility and/or Design Stages, reports will have been completed and submitted to the relevant environmental agency with the results of the drilling and test pumping of the initial test borehole. The findings in these reports shall be used to ensure all risks of contamination and pollution are prevented and controlled.

4.1.3 To ensure every care is taken to avoid risk of contamination, the driller shall ensure all boreholes are drilled in accordance with the design, and any proposed changes shall be discussed with the designer before any drilling takes place or immediately a problem becomes evident. All changes agreed shall be recorded.

4.1.4 To protect groundwater from contamination from surface water ingress, the top 6–20 m of all boreholes shall be lined with compliant, permanent casing. The annulus between borehole and casing should be a minimum of 50 mm to be filled by pressure grouting or tremie pipe, with a low-permeability, frost-resistant, non-shrinking grout. Where there are multiple aquifers, lined compliant permanent casing with pressure grouting shall be used to blank out the non-target aquifers. This will prevent the transfer of water from one aquifer to another and ensure that the target aquifer is not contaminated.

4.1.5 In some strata, artesian water conditions may be encountered, this will require specific management. The potential presence of artesian water should be a specific subject of assessment at the borehole design stage.

4.1.6 Water produced as part of test-pumping should be directed to the location given within the relevant environmental agency drilling and test-pumping consent. If this is the local sewerage undertaker, then permission is required from the sewer owner and a charge might be applied. Permissions for pumping water to any river, lake, canal or estuary must be confirmed prior to pumping. This might be the relevant environmental agency or owner of the waterway.

4.1.7 Cuttings shall be contained and any run-off shall be managed to avoid rain run-off sediment causing an impact to neighbouring property, polluting boreholes, surface water or blocking drains etc. Cuttings may require disposal at the end of the project.

Best practice

Best practice would be to:

BP4.1a conduct a public relations campaign with local residents early in the project, including the provision of large and easily readable posters fixed to the site hoardings to outline the nature of the works and the proposed carbon benefits.

Objective 4.2: To reduce health and safety risks

Why is this objective important?

Reducing health and safety risk is of primary importance in any project. This section is not intended to be comprehensive but will emphasise particular risks associated with the construction of GWSHPs.

Where access cannot be controlled, the health and safety of the general public must be carefully assessed and maximum mitigation measures implemented.

Minimum requirements

4.2.1 A site-specific health and safety risk register shall be developed. This will also include those risks identified in the design stage.

4.2.2 The Health and Safety at Work Act 1974 and the Management of Health and Safety at Work Regulations 1999 shall be followed.

4.2.3 The British Drilling Association (BDA) or equivalent procedures, guidance and recommendations shall be followed. See BDA safety documents, (*Code of Safe Drilling Practice*, Guidance Documents and Safety Alerts), which provide current information from Health and Safety Executive.

4.2.4 Service providers (telecommunications, electricity, gas and water) shall be consulted and their records inspected prior to breaking ground.

4.2.5 On completion of connection, works unauthorised access to the borehole shall be prevented by the installation of a security cover or simply backfilling above the borehole whilst ensuring the position of the borehole is recorded.

4.2.6 Leptospirosis (Weil's disease) is a health risk and anyone with access to groundwater shall be made aware and ensure that any medical practitioner treating them for flu-like symptoms is aware of their particular risk.

4.2.7 The risks of installing large refrigeration systems, including leakage, explosion, asphyxiation, fire and toxicity shall be managed throughout construction.

4.2.8 HSG47: *Avoiding danger from underground services* (HSE, 2014a) must be followed to minimise health and safety risks associated with excavation.

4.2.9 Where pipework routes for groundwater abstraction cross public access paths, trenches and site compounds shall have fences and warning signs.

Objective 4.3: To install the groundwater abstraction and discharge system in accordance with the design

Why is this objective important?

Open-loop GWSHP systems should be designed to have a long life and be exceptionally reliable. This is only achieved if good construction standards are specified and delivered. The open-loop GWSHP system should be installed using the best materials, equipment and guidance available within agreed financial parameters to ensure long life and reliability. If any issues arise during the construction and installation stage where the design cannot be followed, e.g. due to unforeseen site conditions, the contractor must immediately refer back to the designer and any modifications must be carried out and recorded transparently and permanently with the full agreement of all parties.

Minimum requirements

4.3.1 The Contractor shall report any requirements for a variation in the design to the designer and other agreed parties, such as the client, and any modifications must be carried out and recorded transparently and with full agreement of all parties especially the groundwater specialist.

4.3.2 The abstraction system shall be installed according to the design and comply with all Environment Agency, SEPA, NRW or NIEA and other relevant and current environmental and water quality standards and regulations

4.3.3 The discharge system shall be installed according to the design and comply with all Environment Agency, SEPA, NRW or NIEA and other relevant and current environmental and water quality standards and regulations

4.3.4 Contact between water and atmospheric oxygen shall be minimised or prevented, especially if the water is initially reducing and contains elevated concentrations of iron or manganese (e.g. many mine waters).

4.3.5 The introduction of large quantities of biofilm-forming bacteria to wells shall be avoided, by preventing the ingress of surface soils during and after drilling. Also by cleaning/sterilising newly completed wells, rising main and pumps, using a chlorine solution.

4.3.6 Well-heads shall be sealed and ideally be completed above ground (or, failing that, in a well-drained subsurface chamber). Run-in of potentially contaminated surface water is thus prevented.

4.3.7 The pressure within the abstraction/heat exchange/injection system shall be managed and sharp drops in pressure avoided, which might lead to degassing of CO_2 or N_2 and thus to bubble formation.

4.3.8 Pressure changes within the abstraction/heat exchange/recharge pipework shall be evaluated to ensure that areas of under-pressure do not develop.

4.3.9 An excess pressure of 0.5 to 1 bar shall be maintained at the head of any injection well. Groundwater levels may fluctuate, therefore care shall be taken to ensure the bottom of the recharge pipework is never above the water level in the discharge well and it should ideally be some distance below the operational water level to hinder contact with oxygen and to maintain pressure.

4.3.10 In the absence of simpler solutions, consideration may be given to the installation of a throttle or regulating valve at the base of the recharge main, in order to manage excess pressure.

4.3.11 The location of the groundwater abstraction and discharge equipment shall take into account safety and security to avoid accidental damage and potential human interference.

4.3.12 The groundwater abstraction and discharge equipment shall be installed according to the designer's instructions using the best materials, equipment and guidance available within financial parameters to ensure long life and reliability.

4.3.13 All pipework whether steel or polymer, pre- or post-insulated, shall be installed in accordance with all relevant standards and with the manufacturer's instructions and guidance.

4.3.14 Welding of steel or polymer pipework shall only be carried out under suitable conditions observing all manufacturers conditions and recommendations. The welding area must be protected especially during inclement weather and operations suspended if there is any risk installation integrity could be compromised.

4.3.15 All fitters employed to install the pipework shall have completed the appropriate training and hold appropriate certificates demonstrating competence for the type of pipe system being used.

4.3.16 The Contractor shall carry out quality inspections at each stage of the installation process and keep appropriate written records.

Best practice

Best practice would be to:

BP4.3a adopt a system of independent inspection to verify that the above quality checks are being undertaken including written records of sample checks carried out

BP4.3b employ an independent clerk of works in line with the duties, roles and responsibilities described by the Institute of Clerks of Works and Construction Inspectorate of Great Britain (https://www.icwci.org) to check and verify works as they are completed.

Objective 4.4: To pressure test, flush clean, purge and fill all pipework and plant

Why is this objective important?

Pipe testing and hygiene across the system are frequently overlooked or poorly performed, yet these can cause problems that seriously impact the efficient and reliable operation of any system. Fouling can be caused by debris accumulation, oxygen ingress, chemical reactions between materials in the system, dissolved or suspended metals or minerals etc. Rectification after construction can be expensive and time consuming.

Information, such as the use of inhibitors and dealing with water hardness, can be found in BG 50/2013: *Water Treatment for Closed Heating and Cooling Systems* (BSRIA, 2013b).

Minimum requirements

4.4.1 Testing of the load-side pipework shall be carried out in accordance with the relevant regulations and standards, and BSRIA or CIBSE guidance.

4.4.2 The impact of low output temperatures from the heat pump on the hydronic system shall be considered, including the associated health and performance implications, for example microorganism growth and management in hot water distribution circuits.

4.4.3 Pressure testing to identify leaks and initial flushing and cleaning shall be carried out to remove debris.

4.4.4 Discharge consent shall be obtained for the purge/flushing waste discharges, if required. Otherwise proper local disposal procedures must be followed.

4.4.5 The air shall be purged out of the system to avoid microbubbles adhering to the pipe wall.

4.4.6 The system shall be set to work in accordance with the specification.

5: Commissioning

Objectives:

5.1 To follow a structured commissioning management plan

5.2 To commission the source side of the heat pump installation

5.3 To commission the heat pump and immediate supply side equipment

5.4 To commission and calibrate the performance data collection system

5.5 To carry out a formal handover and provide appropriate and comprehensive information to the operations team

Key support tasks:

- Review and update sustainability strategy and implement handover strategy, including agreement of information required for training, handover, asset management, future monitoring and maintenance
- Review and update commissioning plan

Information exchange to next stage (operators):

- Commissioning report

Objective 5.1: To follow a structured commissioning management plan

Why is this objective important?

Commissioning is a complex, often fragmented part of the construction process which demands good organisation. The main objective is to deliver a system that works well, efficiently and safely, and to manage the overall commissioning activities, including programming to achieve the project completion date.

Thorough commissioning procedures should be adopted based on CIBSE Commissioning Codes and BSRIA guidance (see 'Further reading').

Minimum requirements

5.1.1 Pre-commissioning checklists shall be developed to identify all the work activities required have been completed to confirm the system is ready for commissioning.

5.1.2 A clear/structured commissioning management plan shall be compiled according to CIBSE Commissioning Code M (CIBSE, 2003) and shall be co-ordinated with the design and installation programme of the main contractor. The contractor and client shall allow sufficient time for the complete commissioning process and ensure integration into the overall programme.

5.1.3 A commissioning management team shall be appointed with appropriate experience and qualifications. TM1/88.1: *Commissioning HVAC Systems: Guidance on the division of responsibilities* (BSRIA, 2002) suggests appropriate arrangements for projects where a commissioning specialist is to be appointed. Equipment manufacturers' instructions shall be followed. Manufacturers should be involved in the commissioning process wherever possible.

5.1.4 Checklists shall be used to monitor the progress of the entire commissioning process and integrated into the commissioning contractor's quality management system. The requirements for demonstration and witness testing shall be identified from the outset, including the identification of those responsible.

5.1.5 All parties involved in the commissioning process shall be provided with documentation procedures for dealing with contract variations. A change control mechanism shall be set up, which includes documentary records of what has been changed, how it has been changed, and why. A unique numbering system shall be used to identify individual work items.

5.1.6 A commissioning report shall be produced according to CIBSE Commissioning Code M (CIBSE, 2003). This shall include any faults, deficiencies or problems identified in the commissioning process and shall clearly identify the remedial actions taken.

5.1.7 Any required post-occupancy activity shall be identified and carried out at the appropriate time, such as further checks or operator training (see also Objective 5.4).

5.1.8 When the commissioning procedures have been satisfactorily completed, the commissioning specialist shall certify that the system has been commissioned in accordance with the project specification and the relevant commissioning codes. The certificate shall be countersigned by all relevant parties as agreed in 5.1.2.

5.1.9 In the event that commissioning does not reach the standards agreed in 5.1.2, then following remedial works to identify and solve problems, the commissioning process shall begin again based on a new commissioning plan.

Objective 5.2: To commission the source side of the heat pump installation

Why is this objective important?

The apparatus for collecting heat from or rejecting heat into groundwater will have been carefully designed, specified and installed to fulfil specific requirements and to enable the heat pump to perform as intended. This will involve pumping the water out of the ground and returning it back into the ground, body of surface water, storage tank, reservoir or drain. The objective of commissioning the system is to ensure that the source side of the installation supports the planned performance and fulfils all other requirements.

To undertake this commissioning, it will be necessary for the load side of the heat pump(s) to be ready to receive a heating and/or cooling supply as appropriate.

The system will have been 'set to work' at 4.4.6 to allow it to stabilise. Now the source side components, e.g. isolating heat exchangers, must be checked, adjusted and commissioned.

Minimum requirements

5.2.1 All available design calculations and documentation, equipment data and test sheets, flow diagrams, installation and test records shall be collected and collated.

5.2.2 A commissioning schedule and record document shall be prepared detailing all relevant heat pump and ancillary equipment performance parameters, for example evaporator (source side) flow rates, pressure drops, pump heads, ΔT etc.

5.2.3 A commissioning schedule and record document shall be prepared detailing all relevant source water environmental parameters, e.g. temperature constraints, abstraction limits etc.

5.2.4 Before operating any heat pump compressor, adequate flow rates shall be established in the source and load side circuits. Failure to do this can lead to damage caused by freezing in the heat pump heat exchanger.

5.2.5 All hardware functions shall be verified as to the design and all pipework shall be checked to ensure correctly it is installed and protected. The system shall be adjusted as necessary and all results shall be accurately recorded.

5.2.6 All environmental and other parameters relating to the groundwater source shall be measured and the results accurately recorded.

5.2.7 On commissioning an injection or abstraction well, the initial specific capacity characteristics shall be determined via a step-drawdown test (Misstear, Banks and Lewis, 2017). The operational specific capacity (yield and water level) shall be monitored regularly for signs of decreased well performance.

5.2.8 The relevant environmental agency shall be notified of the intention to commence commissioning of the system to ensure compliance with any relevant conditions in the abstraction licence and discharge permit.

5.2.9 All information and data collected shall be recorded correctly into the site's operations and maintenance manual and records.

5.2.10 Following initial commissioning, any filters and/or demountable heat exchangers shall be inspected for debris, cleaned if necessary, and re-sealed prior to further operation.

Best practice

Best practice would be:

BP5.2a off-site monitoring of the source side data to confirm initial and ongoing performance and to immediately warn of any reduction in performance or malfunction: of principal importance will be the source groundwater flow rate, absolute temperature and temperature differential.

Objective 5.3: To commission the heat pump and immediate supply side equipment

Why is this objective important?

A heat pump installation will have been specified and designed to exchange energy with a heating and/or cooling load. Site specific operating strategies will have been developed to satisfy this load, e.g. base load or peak lopping. The flow and temperature parameters will also have been specified.

The heat pump will have been 'set to work' to allow the system to stabilise. Now the heat pump unit and its ancillaries, e.g. isolating heat exchangers must be checked, adjusted and commissioned to ensure they fulfil all these requirements especially at the times of peak demand.

Minimum requirements

5.3.1 Commissioning operatives shall receive appropriate training in commissioning the system to achieve the designed performance.

5.3.2 The heat pump shall be commissioned in accordance with the manufacturer's and designer's settings and procedures at full load and part loads.

5.3.3 Any flushing loops shall be closed off before commissioning commences.

5.3.4 The maximum flow rate to the distribution system shall be adjusted to the design value. Great care must be taken that the flow rate through the heat pump load side is optimised as this is critical to correct operation.

5.3.5 All measured data and set points on valves etc. shall be recorded on the commissioning record sheet and a copy provided to the customer.

5.3.6 The source side flow rate shall be at a rate which satisfies both the flow requirements of the heat pump source side heat exchanger and comply with any defined abstraction or temperature limits.

5.3.7 The maximum abstraction rate is set out in the permissions issued by the relevant environmental agency and shall not be exceeded.

Objective 5.4: To commission and calibrate the performance data collection system

Why is this objective important?

During installation controls, meters, sensors and data recorders will have been installed, see Figure 49 above. The specification needs to take into account the data collection needs of the client and the reporting requirements of third parties, e.g. the Environment Agency, as a condition of granting abstraction permission, or the Office of Gas and Electricity Markets (Ofgem) as the basis for relevant grants and incentives payments. These sensors and data recorders must be meticulously calibrated and commissioned to ensure the reliability and accuracy of the data.

Minimum requirements

5.4.1 Prior to commissioning, an initial check shall be carried out to ensure the installation has been carried out in accordance with both the designer's and meter manufacturer's instructions, particularly in relation to location, access, orientation and sensor installation.

5.4.2 BEMS, SCADA and any other maintenance and performance systems shall be commissioned in accordance with the design.

5.4.3 The data recorder shall be calibrated under load to establish that flow rate and temperatures are being recorded accurately. This should include spot checks with temporary measurement equipment to confirm/correct operation.

5.4.4 The groundwater levels and quality shall be monitored including electrical conductivity (EC), dissolved oxygen, total dissolved solids (TDS) and pH levels, and the results verified against spot checks with hand-held or laboratory tests.

5.4.5 For heat meters, a verification calculation shall be carried out to demonstrate that the conversion to kW·h from the flow rate and temperature measurements is correct.

5.4.6 The system efficiency as predicted in 3.8.2 shall be recalculated, agreed and recorded, to be used as the baseline for long term monitoring (see section B1.3). If this significantly deviates from the design figures then remedial action should be taken, or a reason identified, discussed and recorded.

5.4.7 An information pack shall be provided to the operations and maintenance teams as to the functioning of the data recording system and the reporting requirements.

5.4.8 The sensors and data loggers shall be integrated into the energy management system so they may be used to measure, control and optimise installation performance in real time.

Best practice

Best practice would be to:

BP5.4a enable off-site monitoring and control to facilitate rapid response to any faults in the commissioning process.

Objective 5.5: To carry out a formal handover and provide appropriate and comprehensive information to the operations team

Why is this objective important?

Handover follows on from project completion, which is the point in the construction process when the senior construction team or project manager determines that the installation is complete and ready for the client. Once completion has been certified, the contractor surrenders the site to the client who then assumes full responsibility. The handover process is regulated by Building Regulations.

The main parties involved in the handover process will typically be the senior construction team, mechanical and electrical contractors, any nominated sub-contractors, the designer and the client's maintenance personnel or nominated maintenance contractor. Good communication is especially important during the final stages of construction. Ideally the maintenance team should be involved as early as possible in the project and long before the handover process takes place.

Where a commissioning manager is appointed, they will supervise and confirm satisfactory completion of all the stages of the handover.

Minimum requirements

5.5.1 A formal handover between the construction, maintenance teams and any other identified key party shall be carried out in line with BG1/2007: *Handover, O&M Manuals and Project Feedback. A toolkit for designers and contractors* (BSRIA, 2007). This is vital to ensure that all aspects of the design are explained and the importance of correct operation and maintenance are understood, including requirements for any abstraction licence and discharge permit.

5.5.2 A comprehensive 'snagging' list will be prepared and arrangements made for any remediation required and subsequent re-inspection.

5.5.3 A comprehensive operations and maintenance manual shall be compiled both electronically and in hard copy to include:

- a schedule of planned maintenance
- the use of performance data to identify repair or maintenance requirements
- a list of all components and their suppliers
- a list of specialist training courses (required and desirable)
- an explanation of the design concept
- general and detailed system schematics
- refrigerant type and quantity.

Best practice

Best practice would be to:

BP5.5a contract an independent professional to plan and carry out the stages of the handover.

BP5.5b adopt a BSRIA soft landings approach (see https://www.bsria.co.uk/services/design/soft-landings) with provisional sums for between one and three years ongoing engagement by the contractor, operator and relevant professionals (e.g. design engineers to monitor the operation and performance of the completed plant on an ongoing basis and work together to rectify faults and latent snags, and to tune, tweak and optimise system performance). BSRIA soft landings would also require that the operating team/operator is fully engaged in the design process to guide the team on the best design approach to allow for cost effective efficient operation.

6: Operation and maintenance

Objectives:

6.1 To reduce health and safety risks to staff, customers and the general public

6.2 To minimise environmental impacts of operation and maintenance

6.3 To deliver a maintenance schedule that maximised system efficiency, reliability and asset life

6.4 To provide appropriate monitoring and reporting, including reliability and CO_2 emissions

Key support tasks:

- Conclude activities listed in handover strategy including post-occupancy evaluation, review of project performance, project outcomes and research and development aspects
- Update project information, as required, in response to ongoing client feedback until the end of the building's life

Information exchange (to client):

- Annual reports and regular performance monitoring reports, as agreed
- All data and feedback to client including planned and unplanned maintenance reports and costs

Objective 6.1: To reduce health and safety risks to staff, customers and the general public in operation and maintenance

Why is this objective important?

Reducing health and safety risks for staff, customers and general public is of primary importance in any project. This section is not intended to be comprehensive but will emphasise particular risks associated with the operation and maintenance of open-loop GWSHPs.

Minimum requirements

6.1.1 The Control of Substances Hazardous to Health (COSHH) Regulations 2002 and the Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR) may apply and shall be followed where appropriate.

6.1.2 The heat pump operator shall be certified under BS ISO 45001.

6.1.3 Plant rooms, vaults and manholes containing heat exchangers, pumps and other equipment shall be kept locked and access controlled.

6.1.4 Checks on the water systems shall be carried out and any water treatment recorded in accordance with HSG274: *Legionnaires disease* — Part 2: *The control of legionella bacteria in hot and cold water systems* (HSE, 2014b) to be in compliance with the The Water Supply (Water Fittings) Regulations 1999.

6.1.5 The possibility of groundwater posing a risk to health through disease or other pollution shall be considered and appropriate mitigation measures taken.

6.1.6 Gas detection systems, including refrigerant detection systems and pump-down facilities shall be checked in accordance with regulations.

6.1.7 Method statements and risk assessments shall be kept up to date with current regulations and best practice, e.g. ammonia system risk assessments need revisiting every three years.

6.1.8 Hazardous materials and consumables, for example refrigerants are to be disposed of appropriately considering all waste management legislation.

6.1.9 On-site safety equipment shall be checked and maintained, e.g. chemical showers, eye baths, respirators.

Objective 6.2: To minimise environmental impacts of operation and maintenance

Why is this objective important?

Although the ultimate aim of a GWSHP system is to provide an environmental benefit there may be negative environmental impacts during operation and maintenance that need to be identified and minimised. The permissions issued by the relevant environmental agency or statutory bodies will have specified requirements in monitoring and reporting to ensure the system operates within the agreed parameters. Other regulations, such as F-gas, also need to be complied with.

Minimum requirements

6.2.1 The management and operation of the GWSHP should be considered in any BS EN ISO 14001 (BSI, 2015b) system operated by system operator.

6.2.2 The monitoring requirements of any open-loop system will be set out in the conditions of the relevant environmental agency. The temperature of the water discharged shall be monitored continuously to ensure it is within the differential and absolute limits set by the relevant environmental agencies or other regulators.

6.2.3 The operator shall maintain records of all monitoring required by the relevant environmental agency or other regulators including the pressure and flow rate, temperature, calibrations, examinations, tests and surveys and any assessment or evaluation made on the basis of such data.

6.2.4 The appropriate environmental agency shall be notified without delay following the detection of:

- any malfunction, breakdown or failure of equipment or techniques, accident or emission of a substance not controlled by an emission limit which has caused, is causing, or may cause significant pollution
- the breach of a limit specified in the permission, for example ΔT
- any significant adverse environmental effects.

6.2.5 The operator shall allow access by the relevant environmental agency and other regulators if requested to allow inspection of the system in operation.

6.2.6 If the relevant environmental agency has identified the risk of saline intrusion, additional monitoring shall be required.

6.2.7 The long-term yield/health of the aquifer shall be monitored including groundwater levels, electrical conductivity (EC), dissolved oxygen, total dissolved solids (TDS) and pH levels.

6.2.8 F-gas Regulations shall be followed in operating and maintaining the heat pump, see Appendix B. Only qualified technicians shall carry out any of the following work on a heat pump system:

- maintenance
- leak checking
- recovering refrigerant gases.

Best practice

Best practice would be to:

BP6.2a set up the energy management system, such as SCADA, to continuously electronically monitor the parameters required by the relevant environmental agencies and other regulatory bodies, record these and take appropriate automatic intervention, for example plant turn down or shut down, if breached or in danger of breaching.

Objective 6.3: To deliver a maintenance schedule that maximises system efficiency, reliability and asset life

Why is this objective important?

The quality of materials, design and construction of the borehole itself as well as the GWSHP is important but correct operation and timely, proficient maintenance is also essential to ensure the installation remains reliable and provides optimum performance throughout its lifetime.

Open-loop GWSHP systems are by definition in direct contact with the water. The chemical composition, total dissolved solids (TDS), sediment content or other pollutants present in the water may affect both the borehole structure and the heat pump/heat exchanger assembly. Regular inspection and maintenance of both is essential to ensure a long and trouble-free life.

Minimum requirements

6.3.1 The basis for the planned maintenance regime shall be in accordance with BS ISO 55000 (BSI, 2014a) following the 'Plan-Do-Check-Act' cycle of continual improvement.

6.3.2 Maintenance on central plant shall be according to manufacturer's instructions, BG66/2016: *Maintenance Contracts: A guide to best practice for procurement* (BSRIA, 2016b) and CIBSE Guide M: *Maintenance engineering and management* (CIBSE, 2014a).

6.3.3 To minimise the risk of damage, 'as installed' drawings of the installation shall be maintained and provided to all stakeholders and displayed in the plant room.

6.3.4 All staff shall receive appropriate training before operating or maintaining any equipment.

6.3.5 In addition to regular inspections, a remote monitoring and surveillance system shall be installed and the system continuously monitored to ensure efficient operation. All alarms, for example refrigerant leakage or pump failure alarms, shall be investigated and the location of the fault identified and repairs shall be carried out as required and without delay.

6.3.6 Comprehensive records of test results, groundwater levels, water quality, yield and treatment and any repairs to the system shall be maintained.

6.3.7 Major plant maintenance shall always be scheduled to minimise any interruptions in heat supply and wherever possible there shall be sufficient resilience in the system to prevent supply interruptions.

6.3.8 In wells that are susceptible to clogging, consideration shall be given to regularly repeating the step-drawdown test (Misstear et al., 1990) at intervals of 3 to 5 years to accurately determine specific capacity.

6.3.9 For wells in which the performance has deteriorated due to incrustation or biofilm formation, rehabilitation may be undertaken when the specific capacity has fallen below a certain 'trigger' threshold. The exact form of rehabilitation will depend on the type of clogging but will usually involve a combination of chemical treatments (e.g. acid treatment), physical removal (surging, brushing or jetting) and biocidal treatments (chlorination), see Howsam (1990), Howsam et al. (1995) and Misstear et al. (1990). Rehabilitation seldom returns the well to its original efficiency and some wells may require repeated treatment every few years according to an agreed schedule.

6.3.10 Pressures and temperatures shall be recorded to check that all pipework has been operated within the specified design parameters. This is particularly important when plastic pipe has been used to ensure pipe integrity and longevity.

Best practice

Best practice would be to:

BP6.3a adopt a BSRIA soft landings approach to ensure the operating team/operator is fully engaged in the design process to guide the team on the best design approach to allow for cost effective efficient operation

BP6.3b reassess the GWSHP system annually to ensure it functions within the requirements of the Code of Practice and any future updates.

Objective 6.4: To provide appropriate monitoring and reporting, including reliability and CO_2 emissions

Why is this objective important?

Monitoring and reporting requirements will have been defined by the relevant environmental agency and other regulatory bodies as part of the process of issuing the relevant permissions and licenses and by the Office of Gas and Electricity Markets (Ofgem) or other relevant grant/tariff awarding bodies for any grants and incentives. These reports and notifications will need to be prepared and sent in the agreed format and at the agreed intervals.

It is important to monitor the operation of the installation and to provide regular reports to the client so that a high standard of performance can be maintained. In larger systems, the details of the reporting requirements will typically form part of the contract for the operation of the system.

Minimum requirements

6.4.1 Monitoring Certification Scheme (MCERTS), the framework of standards to monitor the emissions to air, land and water and local Building Regulations, shall be followed (see www.gov.uk/government/collections/monitoring-emissions-to-air-land-and-water-mcerts).

6.4.2 The continuous monitoring of the abstraction and discharge system shall be carried out to alert the operator if specified limits are exceeded.

6.4.3 The operator shall send all reports and notifications in line with the relevant permissions to the relevant environmental agency or other regulatory bodies at the agreed interval and all records shall be kept for at least twelve years.

6.4.4 The operator shall send all reports to Ofgem or other relevant grant/tariff awarding body at an agreed interval.

6.4.5 The electrical input to the heat pump and the electrical inputs to the source side circulation pumps shall be monitored and reported at an agreed interval.

6.4.6 A performance report shall be produced by the operations and maintenance contractor, at an agreed interval (ideally monthly), to be issued to the client, which typically contains the following information:

- health and safety incidents
- operating and performance data including groundwater level, yield and temperature and related design data and anticipated energy consumption and production
- unplanned downtime, system failures and faults that occurred
- planned downtime and maintenance activities carried out
- planned maintenance events due over the next 30 and 90 days
- electricity consumption and running cost
- indirect CO_2 emissions from electricity use and displaced CO_2 emissions compared to alternative fuel(s)
- results of mandatory F-gas inspections.

6.4.7 An annual report shall be prepared by the operations and maintenance contractor and shall include the information in 6.4.6 and also information on:

- long-term yield and condition of aquifer including total dissolved solids (TDS), temperature trends etc.
- calculation of average CO_2 emission factor for heat over the year
- seasonal performance factor (SPF) (see section B1.3 and minimum requirements 3.8.1 and 5.3.4).

6.4.8 The annual report shall be made available electronically and issued as hard copy by request.

Best practice

Best practice would be to:

BP6.4a generate more frequent reports, for example issued on a monthly basis, could constitute best practice; larger systems could consider public, online reporting

BP6.4b set up the energy management system, such as SCADA, to automatically record the items in 6.4.6 and 6.4.7, and in a pre-prepared format, dramatically reducing the manpower required to produce the report and therefore reduce the operating cost.

7: Decommissioning

Objectives:

7.1 To decommission the heat pump

7.2 To decommission the source side

Key support tasks:

- Produce decommissioning plan
- Engage with the relevant environmental agency and other regulatory bodies on processes of decommissioning and the level of requirements for site reinstatement

Information exchange (to decommissioning team and regulatory bodies):

- Decommissioning plan
- Reports in line with F-gas and other regulations
- Reports to the relevant environmental agency and other regulatory bodies as required
- Report to client

Objective 7.1: To decommission the heat pump

Why is this objective important?

Any end-of-life heat pump, whether used for heating, cooling or both, must be correctly decommissioned to avoid any risk of pollution, minimise waste and maximise the recovery for reuse of its constituent parts. The equipment can contain hazardous materials, such as ozone depleting substances (ODS) and fluorinated gases (F-gases) so particular care must be taken to recover for reuse or safe, correct disposal of all refrigerant in accordance with F-gas legislation, see Appendix B.

Owners and operators have legal obligations under UK and EU F-gas Regulations to ensure that any company and/or person they allow to install, service, maintain, repair, carry out leakage checks and/or decommission their refrigeration and/or air conditioning systems holds valid F-gas qualifications.

CIBSE TM56: *Resource efficiency of building services* (2014b) provides general principles and tools relating to the end-of-life and disposal of building services, and more information on this topic can be found at the website of the Waste and Resources Action Programme (WRAP) (www.wrap.org.uk).

Minimum requirements

7.1.1 Under UK and EU F-gas Regulations any person carrying out decommissioning of a heat pump that contains fluorinated greenhouse gases shall hold a valid F-gas qualification.

7.1.2 All documentation shall be kept and correctly completed as required by current UK and EU F-gas Regulations.

7.1.3 All chemicals, including secondary refrigerants such as or ethylene or propylene glycol and ethanol mixtures, shall be stored in an area where spills will be contained and if contaminated, treated as hazardous/special waste.

7.1.4 All chemicals, especially hazardous substances should be disposed of appropriately considering the relevant environmental and waste management legislation and the client's duty of care.

7.1.5 Solutions containing refrigerant of any type shall not enter groundwater, watercourses or surface water drains.

7.1.6 If contaminated water accidentally enters public sewers, the water and/or sewerage company and other relevant authorities shall be notified immediately.

7.1.7 When effluent is discharged to surface or ground water a discharge consent shall be obtained from the relevant environmental agency. Any additive to the abstracted water would result in the discharge water being an effluent.

7.1.8 When effluent is discharged into public sewers a trade effluent consent or a trade effluent agreement shall be obtained from the water and/or sewerage company and all discharges shall comply with the agreed conditions.

7.1.9 The heat pump shall be dismantled and disposed of in accordance with all current legislation.

7.1.10 All compressors or associated components shall be placed on a drip tray to collect any leaking oil. The drip tray shall be emptied regularly and the oil collected appropriately recycled or treated as hazardous/special waste.

7.1.11 All ancillary buildings and equipment shall be dismantled or demolished to an acceptable standard and in accordance with all current legislation and any specific agreements with regulatory and other bodies.

Best practice

Best practice would be:

BP7.1a for all traces of the installation shall be removed and the site reinstated such that no visible evidence remains.

Objective 7.2: To decommission the source side

Why is this objective important?

Although the ultimate aim of a GWSHP system is to provide an environmental benefit there may be negative environmental impacts during decommissioning that need to be identified and minimised.

Reducing health and safety risks is of primary importance. This section is not intended to be comprehensive but will emphasise particular risks associated with the decommissioning of GWSHP systems. It is recommended advice is sought from risk management authorities, such as the environmental agencies and local authorities, before any work is undertaken.

Minimum requirements

7.2.1 As each situation is different in terms of its location, geological setting, borehole construction, dimensions, hazards and intended site after use, guidance shall be obtained from the relevant environmental agency around the specific requirements for the site, for England see *Good practice for decommissioning redundant boreholes and wells* (EA, 2012b) [available on request from the Environment Agency].

7.2.2 Before decommissioning a borehole, consideration shall be given as to whether it can be retained as a monitoring facility. If it is to fulfil part of a planning condition or other legal monitoring requirement, discussions shall take place with the relevant environmental agency. Consideration shall be given to improved headworks to allow access while ensuring no contamination pathway from the surface to the groundwater.

7.2.3 When a borehole or well is to be backfilled, information on the geological strata encountered by the borehole and how it was constructed (including depth, diameter and casing details) shall be obtained from site records or the original driller's log. The British Geological Survey (BGS) or Geological Survey of Northern Ireland (GSNI) national water well archive and other borehole databases shall also be consulted.

7.2.4 When planning the decommissioning works, in addition to any site specific after-use considerations, the method shall address the following objectives:

- remove the hazard of an open hole (safety issues)
- prevent the borehole acting as a conduit for contamination of groundwater
- prevent the mixing of contaminated and uncontaminated groundwater from different aquifers
- prevent the flow of groundwater from one geological horizon to another
- prevent the wastage of groundwater from the overflow of artesian boreholes.

7.2.5 All pipework shall be removed together with any other infrastructure and the condition of any borehole casing and grout shall be examined to ascertain whether its retention in the hole would prejudice any of the objectives of the abandonment. Where the casing has corroded or broken, or the grouting failed it may be necessary to remove materials to prevent any flow of groundwater around the outside of the borehole. If this is required, expert advice shall be sought from a suitable specialist on appropriate techniques and associated risks.

7.2.6 For artesian boreholes, the decommissioning process shall aim to confine the groundwater to the aquifer from which it came. To control the artesian flow, one of the following shall be used:

- pumping the borehole to produce the necessary drawdown
- pumping nearby boreholes
- extending the casing above ground level beyond the elevation to which water will rise in the borehole (the potentiometric or piezometric surface)
- introducing dense, non-polluting fluids into the borehole
- introducing a pre-cast plug at an appropriate level within the hole
- using an inflatable packer and pressure grouting the void space below it.

7.2.7 The backfilled borehole/well shall be completed with an impermeable plug and cap to prevent entry of potentially contaminated surface run-off or other liquids.

7.2.8 Accurate records shall be kept of the abandonment details for future reference, including:

- the reasons for abandonment (for example water quality problems)
- measurement of groundwater level prior to backfilling
- the depth and position of each layer of backfilling and sealing materials
- the type and quantity of backfilling and sealing materials used
- any changes made to the borehole/well during the abandonment (for example casing removal)
- any problems encountered during the abandonment procedure.

7.2.9 The location of disused boreholes and wells shall be clearly marked on site records.

7.2.10 The relevant environmental agency and British Geological Survey or Geological Survey of Northern Ireland (GSNI) shall be notified of the abandoned well location and structure.

7.2.11 Notice shall be given to the relevant environmental agency and the necessary applications forms shall be completed to revoke the abstraction licence and surrender the discharge permit for the system.

Best practice

Best practice would be to:

7.2a mark or deeply inscribe well caps with the word 'WELL'. Even if done crudely it can avoid considerable risk, delay or uncertainty in the event of the structure being discovered during excavation by others in the future, who may not otherwise know what the feature is.

Appendices

Appendix A: Glossary of terms and abbreviations

AHU	Air handling unit.
Air conditioning	All the processes required to closely manage the air within a space, i.e. heating, cooling, humidity control, ventilation and filtration of incoming air. It is frequently misunderstood to mean cooling only.
AMR	Automatic meter reading.
ASHP	Air source heat pump.
BEMS	Building energy management system.
Bleed	In the context of a standing column well heating and/or cooling systems, bleed is where some of the water from the system discharge, usually less than 10%, is diverted to be used for another purpose, e.g. domestic consumption, irrigation or to waste to improve system efficiency. These systems are considered consumptive by the water authorities and environmental agencies.
BMS	Building management system.
Borehole	A long, narrow vertical hole drilled frequently, but not necessarily, to access groundwater.
Capex	Capital expenditure.
CDM	Construction (Design and Management) Regulations 2015.
CEEQUAL	Civil Engineering Environmental Quality Assessment and Award Scheme.
Closed loop	A type of ground heat exchanger that consist of pipework (usually plastic) through which a fluid is circulated to collect heat from or reject heat into the ground or body of water in which it is installed.
Comfort cooling	Sensible cooling only, and may refer to tempering the indoor air temperature by a few degrees rather than chilling it to a predetermined temperature.
CoP	Coefficient of performance: an expression of the output of a machine in heating mode as a proportion of input power (compressor and fans) and hence is the rated capacity divided by the rated power input. In practice this is expressed as a single figure or as a percentage.
CoSP	Coefficient of system performance: a ratio that describes the efficiency of a heat pump taking into account the input power from internal control circuits and compressor, as well as fan and pump power required to overcome any fluid resistances of its own heat exchangers (but not those external to the unit). Therefore it is the rated capacity divided by the rated total power input and is more representative of the unit's efficiency than the simple CoP. In practice, it has become the de facto measure of CoP and is expressed as a single figure or as a percentage. This ratio is now described in BS EN 14511-1 (BSI, 2018).
COSHH	Control of Substances Hazardous to Health Regulations 2002.
cSPF	Calculated seasonal performance factor (see also SPF and SCoP): uses BS EN 15316-4-2 (BSI, 2017d) as the calculation method.
CRC	Carbon Reduction Commitment.
DC	Direct current.
Delta-T or ΔT	The temperature difference between the water abstracted and the water discharged, or any other relevant temperature difference in the HVAC system.
DHW	Domestic hot water.
DX	Direct expansion: used to describe the situation where refrigerant in a heat pump is used to directly heat (or cool) the final medium being heated.
DP	Differential pressure.

Drawdown	In subsurface hydrogeology, drawdown is the change in hydraulic head observed at a well in an aquifer, typically due to pumping a well as part of an aquifer test or well test.
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations 2002.
DSM	Dynamic simulation model.
EC	Energy centre.
ECA	Enhanced Capital Allowance.
ECO	Energy Company Obligation.
EER	Energy efficiency ratio: describes the efficiency of a heat pump machine in cooling mode. The rated capacity is divided by the rated total power input. In practice this is expressed as a single figure or as a percentage.
ETL	Energy Technology List.
EU ETS	EU Emissions Trading System.
Free cooling	Cooling which is delivered without having to pay for the low temperature resource. This can be outdoor air, surface or groundwater. The discharge flow after a heat pump in heating mode can be a useful source of free cooling.
GHG	Greenhouse gas.
GIS	Geographic information system.
GSHP	Ground source heat pump.
GWSHP	Groundwater source heat pump.
Heat exchanger	A device for the transfer of heat energy from one medium to another. It can take a variety of different forms; the commonest in everyday use is a central heating radiator where hot water is circulated through pipes or plates and gives its heat up to the surrounding air.
Heat transfer fluid	Historically a calcium chloride solution was used, which is why it is sometimes erroneously called ‘brine’. Today heat pumps in the UK generally use an aqueous mixture containing biocides and corrosion and scale inhibitors and, if required, an anti-freeze component, often monoethylene glycol (MEG) or polyethylene glycol (PEG). *Note*: sometimes called ‘thermal transfer fluids’.
HN	Heat networks (also commonly referred to as district heating).
Heat pump	A device for transferring energy in the form of useful heat from one place to another. It cannot store, make or destroy heat energy — it simply moves it. There are a number of techniques that exploit heat transfer; the most common in use is the refrigeration cycle. A heat pump is capable of transforming a large quantity of low grade, low temperature heat.
Hybrid	Multivalent systems can also be described as hybrid systems.
Hydraulic	Use of water or another liquid heat transfer medium such as glycol as the heat-transfer medium in heating and cooling systems. Also referred to as hydronic.
IRR	Internal rate of return.
LCA	Life cycle assessment.
Leptospirosis	Weil’s disease.
Load	Building or other use (e.g. a swimming pool) or industrial process that uses the heating or cooling generated.
MCERTS	Monitoring Certification Scheme.
Mono-energetic	An installation where there is one source of heating backed up by some direct electric heating.
Mono-valent	An installation where there is only one source of heating.

Multi-valent	An installation with multiple sources of heat, e.g. where a heat pump is support with both solar and an oil boiler.
NPV	Net present value.
NRM	RICS *New Rules of Measurement*.
Open-loop	A heat collection system whereby water is extracted from either the ground or an open water source (i.e. lake, river or sea) and is passed directly through a water source heat pump. This water may be re-injected or passed to waste; in the latter case water charges may be incurred.
Open water	Open water can also be used to describe surface water.
OPEX	Operational expenditure.
P&L	Profit and loss account.
Reducing agent	An element (such as iron or calcium) that loses ('donates') an electron in a redox (reduction–oxidation) chemical reaction. Since the reducing agent is losing electrons, it is said to have been oxidized.
Reverse cycle heat pump	A reverse cycle system is a refrigeration system that can, by means of a valve that reverses the flow of the refrigerant fluid, change the operation of the system from heating to cooling.
RHI	Renewable Heat Incentive.
SCADA	Supervisory control and data acquisition.
SAP	Standard Assessment Procedure.
SCoP	Seasonal coefficient of performance: an efficiency metric of heat pumps that describes performance of the unit over a typical season where the source temperature varies. Frequently used with heat pumps where the source temperature changes considerably over the year and hence efficiency and/or output varies. It is determined using the calculation method given in BS EN 14825 (BSI, 2018).
SBEM	Simplified Building Energy Model.
SEER	Seasonal energy efficiency ratio: an efficiency metric of reverse cycle heat pumps that describes the performance of the unit over a typical cooling season where the source temperature varies. Used mostly with air source heat pumps where the source temperature varies over the year leading to variations in efficiency and/or output.
SPF	Seasonal performance factor: similar to SCoP in that it is a ratio expressing the efficiency of a heat pump by describing heat output to total energy input taking into account variations in performance over the heating season. Under BS EN 15316-4-2 (BSI, 2017d), input energy includes auxiliary energy that may be all or part of pump/fan power. Care must be exercised as to whether this is intended to include any additional boost heat from other sources (e.g. electric immersion heater) and the full pump/fan power to overcome all resistances of circuits (i.e. not just the heat exchangers of the heat pump). See Appendix D for definitions of system boundaries.
SWSHP	Surface water source heat pump.
TER	Target Emission Rate.
TFEE	Target Fabric Energy Efficiency.
TTF	Thermal transfer fluid, e.g. glycol.
Turbidity	A measure of the degree to which the water loses its transparency due to the presence of suspended particulates.
Water well	A water well is an excavation or structure created in the ground by digging, driving, boring, or drilling to access groundwater.

Appendix B: Key legislation

This appendix outlines the legislation that is likely to impact on an open-loop GWSHP project. It is not intended to be comprehensive nor in sufficient detail to test compliance. It is essential readers consult the latest regulations.

It should be noted that some regulations are devolved to the administrations of Scotland, Wales and Northern Ireland and there are important differences (see Appendix C for contact details of regulatory bodies).

Health and Safety legislation

Although the Health and Safety at Work Act 1974 is fundamental, the Construction Design Management Regulations 2015 (CDM) shall govern all stages from design through to operation. The Control of Substances Hazardous to Health Regulations 2002 (COSHH) and the Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR) may apply. During the operating phase the control of *Legionella* risk is an important consideration and HSE Code of Practice L8 (HSE, 2013) and associated guidance HSG274 (HSE, 2014) shall be followed. The Fluorinated Greenhouse Gases Regulations 2015 (F-gas Regulations), the Pressure Equipment Directive (2014/68/EU) (PED) and BS EN 378-4: *Refrigerating systems and heat pumps. Safety and environmental requirements. Operation, maintenance, repair and recovery* (BSI, 2016) shall be considered.

Planning legislation

The installation of an open-loop GWSHP is usually considered to be permitted development and may not need an application for planning permission. When installing a GWSHP in the grounds of a non-domestic building, planning permission is required if the total surface area covered by the installation (including any pipes) exceeds 0.5 hectares (Town and Country Planning Act 1990, amendment 2012).

The Town and Country Planning (Environmental Impact Assessment) Regulations 2011 can apply even when the project is considered permitted development. These regulations apply the EU directive on the assessment of the effects of certain public and private projects on the environment (usually referred to as the Environmental Impact Assessment Directive) to the planning system in England.

Planning permission may be required for temporary works for storage of materials and other construction purposes. Permissions will be needed from any land owner in addition to planning permission. An easement (a right to cross or otherwise use someone else's land for a specified purpose) may be required.

Planning approval may impose other construction conditions, e.g. dealing with removal of waste, storage of materials, dust and noise nuisance. There may be a requirement to comply with the Considerate Contractors Scheme.

Environmental Regulations

Environmental Permit and Abstraction Licence

See Tables 6 to 9 below, for details of regulatory permissions for delivering abstraction and discharge for the Environment Agency (EA) in England, Natural Resources Wales (NRW) in Wales, Scottish Environment Agency (SEPA) in Scotland and Northern Ireland Environment Agency (NIEA) in Northern Ireland.

Table 6 Regulatory permissions for delivering abstraction and discharge for the Environment Agency (EA), England (source *Groundwater control: design and practice* (Preene et al., 2016); reproduced by permission of CIRIA)

Abstraction permission	Discharge permission
EA regulates abstraction licensing under the Water Resources Act 1991: • Flow rate ≤ 20 m^3/day: no permission required. No requirement to notify EA. • Abstraction for 27 days or less, any flow rate > 20 m^3/day (water not put to use): temporary licence required. • Abstraction for 28 days or more, flow rate > 20 m^3/day (water not put to use): full licence required for portion put to use, transfer licence required for portion not put to use. *Note*: the flow rate quoted for the different levels of licensing is the total dewatering flow rate from the site or project, not the flow rate from individual sumps, pumps, or wells.	Discharge to surface water or groundwater: EA regulates water discharge activities (discharges to surface water) and groundwater activities (discharges to ground) under The Environmental Permitting (England and Wales) Regulations 2016. Where dewatering pumping is for less than three months, the EA has granted an exception that dewatering flows can be discharged to surface waters without the need for an Environment Permit, provided that the water is uncontaminated and will not cause adverse effects on aquatic life. In all other circumstances an Environmental Permit is required for discharge of dewatering flows to surface water or to groundwater. If water treatment technologies are used to remove contaminants or otherwise treat water before discharge, a mobile plant permit and deployment form will also be required from the EA for the groundwater treatment plant.
	Discharge to sewer: Trade Effluent Consent required (from Regional Water Company).

Table 7: Regulatory permissions for delivering abstraction and discharge for Natural Resources Wales (NRW), Wales (source *Groundwater control: design and practice* (CIRIA, 2016); reproduced by permission of CIRIA)

Abstraction permission	Discharge permission
Governing regulations: Water Resource Act 2012 • Flow rate < 20 m^3/day: no permission required; no requirement to notify NRW. • Abstraction for 27 days or less, any flow rate 20 m^3/day (water not put to use): temporary licence required. • Abstraction for 28 days or more, flow rate > 20 m^3/day (water not put to use): full licence required for portion put to use, transfer licence required for portion not put to use. *Note*: the flow rate quoted for the different levels of licensing is the total dewatering flow rate from the site or project, not the flow rate from individual sumps, pumps, or wells.	Discharge to surface water or groundwater: (NRW) regulated under Water Resources Act 2012 Where dewatering pumping is for less than three months, the NRW has granted an exception that dewatering flows can be discharged to surface waters without the need for an Environment Permit, provided that the water is uncontaminated and will not cause adverse effects on aquatic life. In all other circumstances an Environmental Permit is required for discharge of dewatering flows to surface water or to groundwater. If water treatment technologies are used to remove contaminants or otherwise treat water before discharge, a mobile plant permit and deployment form will also be required from the EA for the groundwater treatment plant under the Environmental Permitting (England and Wales) Regulations 2010.
	Discharge to sewer: Trade Effluent Consent required (from Regional Water Company).

Table 8 Regulatory permissions for delivering abstraction and discharge for Scottish Environment Protection Agency (SEPA), Scotland (source *Groundwater control: design and practice* (Preene et al., 2016); reproduced by permission of CIRIA)

Abstraction permission	Discharge permission
Governing regulations: The Water Environment (Controlled Activities) (Scotland) Regulations 2011 (as amended) Dewatering abstractions that comply with General Binding Rule 15 (GBR15) require no notification to SEPA provided that GBR15 is complied with. The requirements of GBR15 can be summarised as: • In geological strata where groundwater flow rates are low (e.g. silts, days, low permeability bedrock), groundwater may only be abstracted for less than 180 consecutive days. • In geological strata where groundwater flow is high (e.g. sands and gravels and sandstones) groundwater may only be abstracted for a total of five separate days, in any 180 consecutive day period. • Groundwater must not be abstracted within 250 m of a wetland or within 250 m of any (non-dewatering) abstraction • All reasonable steps must be taken to ensure that the quantity of sediment in the abstracted water is minimal. • Discharge of the abstracted water must be via a surface water drainage system authorised by SEPA or Scottish Water (as appropriate). Dewatering abstractions that do not comply with GBR15 are subject to the following requirements: • Flow rate < 10 m^3/day: compliance with General Binding Rule 2 (GBR2) is required. No requirement to notify SEPA provided that GBR2 is complied with. • Flow rate 10 m^3/day to 50 m^3/day: registration with SEPA required. • Flow rate 50 m^3/day to 2000 m^3/day: simple licence required. • Flow rate >2000 m^3/day, or boreholes greater than 200 m depth: complex licence required. *Note*: the flow rate quoted for the different levels of licensing is the total dewatering flow rate from the site or project, not the flow rate from individual sumps, pumps, or wells.	Discharge to surface water or groundwater: (SEPA) regulated under The Water Environment (Controlled Activities) (Scotland) Regulations 2011 (as amended). No requirement to notify SEPA for discharge of uncontaminated groundwater abstracted directly from a dewatering system without contact with any other drainage run-off. This only applies to uncontaminated groundwater. For contaminated discharges: • Discharge rate < 10 m^3/day: registration with SEPA required. • Discharge rate 10 m^3/day to 100 m^3/day: simple licence required. • Discharge rate > 100: complex licence required. Discharge to sewer: Trade Effluent Consent required (from Scottish Water).

Table 9 Regulatory permissions for delivering abstraction and discharge for Northern Ireland Environment Agency (NIEA), Northern Ireland (source *Groundwater control: design and practice* (Preene et al., 2016); reproduced by permission of CIRIA)

Abstraction permission	Discharge permission
Governing regulations: Water Abstraction and Impoundment (Licensing) Regulations (Northern Ireland) 2006 • Flow rate < 10 m^3/day: compliance with permitted controlled activities (PCA) is required. No requirement to notify NIEA provided that PCAs are complied with. • Flow rate 10 m^3/day to 20 m^3/day: compliance with PCAs is required. NIEA must be notified. • Flow rate 20 m^3/day to 100 m^3/day: simple licence required. • Flow rate > 100 m^3/day: complex licence required. *Note*: the flow rate quoted for the different levels of licensing is the total dewatering flow rate from the site or project, not the flow rate from individual sumps, pumps, or wells.	Discharge to surface water or groundwater: Trade effluent and site drainage discharge consent required under the Water (Northern Ireland) Order 1999 (NIEA) Discharge to sewer: Trade Effluent Consent required (from Northern Ireland Water).

Coal Authority permissions

Those wishing to gain access to abandoned coal mine workings for the purpose of extracting heat from minewater will require the permission of the owner of the coal mine workings. In virtually all circumstances in England, Scotland and Wales (but not Northern Ireland), the owner will be the Coal Authority and will issue a Minewater Heat Recovery Access Agreement.

Water industry legislation

Devolved water legislation means separate water industry acts, orders and regulations apply across the UK. Early consultation with the local water supplier is recommended to avoid late changes to design, installation and abortive/rectification costs.

Water industry Acts and Orders

These are:

— England and Wales: the Water Industry Act 1991 (as amended)

— Northern Ireland: The Water and Sewerage Services (Northern Ireland) Order 2006 (as amended)

— Scotland: the Water (Scotland) Act 1980 (as amended).

The provisions within these Acts and Orders cover water company infrastructure within the highway and other areas to ensure they are able to maintain a reliable wholesome supply and ensure they have sufficient access to their assets.

Water Supply (Water Fittings) Regulations and Byelaws

These are:

— England and Wales: The Water Supply (Water Fittings) Regulations 1999

— Scotland: The Water Supply (Water Fittings) (Scotland) Byelaws 2014

— Northern Ireland: The Water Supply (Water Fittings) Regulations (Northern Ireland) 2009.

The Water Fittings Regulations and Byelaws play an important role in protecting public health, safeguarding water supplies and promoting the efficient use of water within customers' premises. They apply to water supplied by the water undertaker from the point where water enters the property's underground pipe (usually at the stop tap at the property boundary), to where the water is used in plumbing systems, water fittings and water-using appliances, such as washing, cooking, central heating and sanitary purposes.

There are a number of interface points where the regulations and byelaws need to be followed, the supply of water make-up at the energy centre, the co-ordination of a buried heat network with water infrastructure and the supply of domestic hot water services within buildings. Additionally, advanced notification is a requirement and it is recommended this is done at an early stage.

Building Regulations

For England and Wales, Part L (2013) of the Building Regulations 2010 (as amended) deals with the conservation of fuel and power in domestic and commercial buildings. For Scotland, the equivalent is Part F of the Building (Scotland) Regulations 2004 (as amended). For Northern Ireland, the equivalent is Section 6 of the Building Regulations (Northern Ireland) 2012 (as amended). The legislation covers new-build and refurbishment projects.

Under Part L, compliance for dwellings is calculated using the Standard Assessment Procedure (SAP) taking into account Target Fabric Energy Efficiency (TFEE). The TFEE standards are not applied to non-dwellings but include the Target Emission Rate (TER).

In addition to Part L 2013, section 9 of the *Domestic Building Services Compliance Guide* (NBS, 2013b; Scottish Government, 2015) deals extensively with heat pumps. The guide covers ground source, water source and air source heat pumps.

Energy-related Products Directive

Directive 2009/125/EC Regulation 547/2012/EC, on ecodesign requirements for water pumps, sets minimum efficiency requirements on water pumps set out under the Ecodesign Directive for energy related products. This regulation mainly addresses manufacturers of water pumps placing these products on the European market. However, customers may also be affected and should be aware.

EU and Government schemes and incentives

Renewable Heat Incentive

The Renewable Heat Incentive (RHI) supports the deployment of renewable and low-carbon heating technologies. The scheme helps to bridge the gap between the cost of renewable heating systems and the conventional alternatives. Ofgem is responsible for accrediting applications to the scheme and making payments to participants (see https://www.ofgem.gov.uk/environmental-programmes).

Microgeneration Certification Scheme

Microgeneration Certification Scheme (MCS) is a nationally recognised quality assurance scheme, supported by BEIS. MCS certifies microgeneration technologies used to produce electricity and heat from renewable sources (see https://www.microgenerationcertification.org).

Energy Technology List (ETL)

The Energy Technology List (ETL) is a register of products that may be eligible for 100% tax relief under the Enhanced Capital Allowance (ECA) scheme for energy saving technologies. The Carbon Trust manages the list and promotes the ECA scheme on behalf of government (see https://www.gov.uk/guidance/energy-technology-list). Water source (internal water loop only) split and multi-split systems, including variable refrigerant flow (VRF), are eligible under the scheme.

Climate Change Levy

The Climate Change Levy (CCL) is a tax on energy delivered to non-domestic users in the UK (See https://www.gov.uk/green-taxes-and-reliefs/climate-change-levy). It is designed to incentivise energy efficiency and to reduce carbon emissions. Introduced on 1 April 2001 under the Finance Act 2000, the CCL has formed part of the UK's Climate Change Programme.

The levy applies to most business users across industry, commerce, agriculture, public administration, and other services. Users in the domestic, charitable and transport sectors are typically exempt.

EU Emissions Trading System (EUETS)

If the Energy Centre has more than 20 MW thermal input, then it will need to be included within the EUETS (see https://ec.europa.eu/clima/policies/ets_en). This will require payments based on the fuel used however there are free allocations for heat pump systems. An opt-out provision was set by BEIS's legislation for small emitters and hospitals in the UK for the Phase 3 of the EUETS.

Appendix C: Useful contacts

United Kingdom

Department of Business, Energy & Industrial Strategy
1 Victoria Street
London
SW1H 0ET

Telephone: 020 7215 5000
Email: enquiries@beis.gov.uk
Website: www.gov.uk/beis

Ground Source Heat Pump Association
39 Dryburgh Road
London
SW15 1BN

Telephone: 0330 2234 302
Email: info@gshp.org.uk
Website: www.gshp.org.uk

Heat Pump Association
2 Waltham Court
Milley Lane
Hare Hatch
Reading
RG10 9TH

Telephone: 0118 940 3416
Fax: 0118 940 6258
Email: info@heatpumps.org.uk
Website: www.heatpumps.org.uk

Well Drillers Association

Website: www.welldrillers.org

British Drilling Association

Telephone: 01773 778751
Fax: 01773 782724
Email: office@britishdrillingassociation.co.uk
Website: www.britishdrillingassociation.co.uk

British Geological Survey
Environmental Science Centre
Nicker Hill
Keyworth
Nottingham
NG12 5GG

Telephone: 0115 936 3100
Fax: 0115 936 3200
Email: enquiries@bgs.ac.uk
Website: www.bgs.ac.uk

Coal Authority
200 Lichfield Lane
Mansfield
Nottinghamshire
NG18 4RG

Telephone: 0345 762 6848
Email: thecoalauthority@coal.gov.uk
Website: https://www.gov.uk/government/organisations/the-coal-authority

National Parks UK
Plas y Ffynnon
Cambrian Way
Brecon
LD3 7HP

Email: info@nationalparks.gov.uk
Website: www.nationalparks.gov.uk

Water Regulations Advisory Scheme (WRAS)
Unit 13, Willow Road
Pen-y-Fan Industrial Estate
Crumlin
Newport
Gwent
NP11 4EG

Telephone: 0333 207 9030
Email: info@wras.co.uk
Website: www.wras.co.uk

England

Environment Agency
National Customer Contact Centre
PO Box 544
Rotherham
S60 1BY

Telephone: 03708 506506
Minicom (for the hard of hearing): 03702 422549
Email: enquiries@environment-agency.gov.uk
Website: www.gov.uk/government/organisations/environment-agency

Natural England
(for access, rights of way, protected areas)
4th Floor, Foss House, Kings Pool, 1–2
Peasholme Green
York
YO1 7PX

Telephone: 0300 060 3900
Email: enquiries@naturalengland.org.uk
Website: www.gov.uk/government/organisations/natural-england

Scotland

Scottish Environment Protection Agency (SEPA)

Telephone: 03000 99 66 99
Website: www.sepa.org.uk

Wales

Natural Resources Wales (NRW)
c/o Customer Care Centre
Ty Cambria
29 Newport Rd
Cardiff
CF24 0TP

Telephone: 0300 065 3000
Email: enquiries@naturalresourceswales.gov.uk
Website: www.naturalresourceswales.gov.uk

Northern Ireland

Northern Ireland Environment Agency (NIEA)
Klondyke Building
Cromac Avenue
Gasworks Business Park
Malone Lower
Belfast
BT7 2JA

Telephone: 0300 200 7856
Email: nieainfo@daera-ni.gov.uk
Website: www.daera-ni.gov.uk/northern-ireland-environment-agency

Geological Survey of Northern Ireland
Dundonald House
Upper Newtownards Road
Belfast
BT4 3SB

Telephone: 028 9038 8462
Fax: 028 9038 8461
Email: gsni@detini.gov.uk
Website: https://www.bgs.ac.uk/gsni

Europe

International Energy Agency
31–35 rue de la Fédération
75739 Paris Cedex 15
France

Telephone: +33 1 40 57 65 00
Fax: +33 1 40 57 65 09
Email: info@iea.org
Website: www.iea.org

European Heat Pump Association (AISBL)
Rue d'Arlon 63–67
1040 Brussels
Belgium

Telephone: +32 2 400 10 17
Email: info@ehpa.org

Website: http://www.ehpa.org

Appendix D: Calculating system efficiency

Section B1.3 briefly discusses the methodologies used in this Code of Practice for assessing and comparing the efficiency of heat pump systems, both with each other and with various fossil fuel installations. These draw on definitions laid out by SEPEMO (SEasonal PErformance factor and Monitoring for heat pump systems in the building sector), an EU-project that ran from June 2009 to May 2012 (see http://sepemo.ehpa.org). It developed a universal methodology for the field measurement of heat pump systems and calculation of seasonal performance factor (SPF) to reflect the conditions 'in real installations'.

SPF is a measure of heat pump system efficiency and can be used to accurately compare different heat pumps installations across different climates. The main parameters influencing a heat pump systems performance are:

— the heat pump unit

— the quality of installation (design and execution)

— the type, design and temperature level of the heating system

— the building energy demand (heat load)

— user behaviour

— climatic conditions.

The standardised methodology of measuring the SPF makes it possible to compare the heat pump system with fossil fuel heating systems such as oil or gas. By this comparison it is also possible to calculate the CO_2 emissions and primary energy reduction potential from different heat pump systems compared to other heating systems.

There are various ways that SPF can be established, which use different systems boundaries (see Table 10 and Figure 51 below). Due to the fact that the units can operate in heating and/or cooling mode the system boundaries and the SPF calculation methodology is separated into heating and cooling modes.

For more detail, including example calculations, refer to *D4.2./D 2.4. Concept for evaluation of SPF* (version 2.2) (EHPA, 2012).

Table 10 System boundaries for the calculation or measurement of system efficiency (based on EHPA, 2012)

System boundary	Components covered for stated mode	Notes
SPF_1	Heating: heat pump unit only Cooling: cooling unit only	This is similar to CoP (heating) or EER (cooling) as defined in BS EN 14511, except that CoP is instantaneous and has to be quoted with an associated source and sink temperature while SPF is a seasonal average.
SPF_2	Heating: • heat pump unit • equipment needed to make the source energy available for the heat pump Cooling: • cooling unit • equipment to dissipate the heat energy	This level of system boundary responds to SCOPNET (heating) or SEERON (cooling) in prEN 14825.
SPF_3	Heating: • heat pump unit • equipment needed to make the source energy available • back-up heater Cooling: • cooling unit • equipment needed to dissipate the heat energy • all auxiliary drives of the cooling system	SPF_3 represents the heating/cooling system and thereby it can be used for comparison to conventional heating systems (e.g. oil or gas). For monovalent systems SPF_3 and SPF_2 are identical.
SPF_4	Heating: • heat pump unit • equipment to make the source energy available • back-up heater • all auxiliary drives including the auxiliary of the heat sink system Cooling: • studied cooling system • possible additional cooling systems	This level corresponds to the total heating/cooling system performance for a building.

Note: Some commentators use the term SPF_5 to indicate system efficiency, which is the total efficiency of the whole heat pump circuit including all emitters. To the authors' understanding, this boundary is not defined in SEPEMO and could either stop at heat exchangers or include secondary system circuit losses.

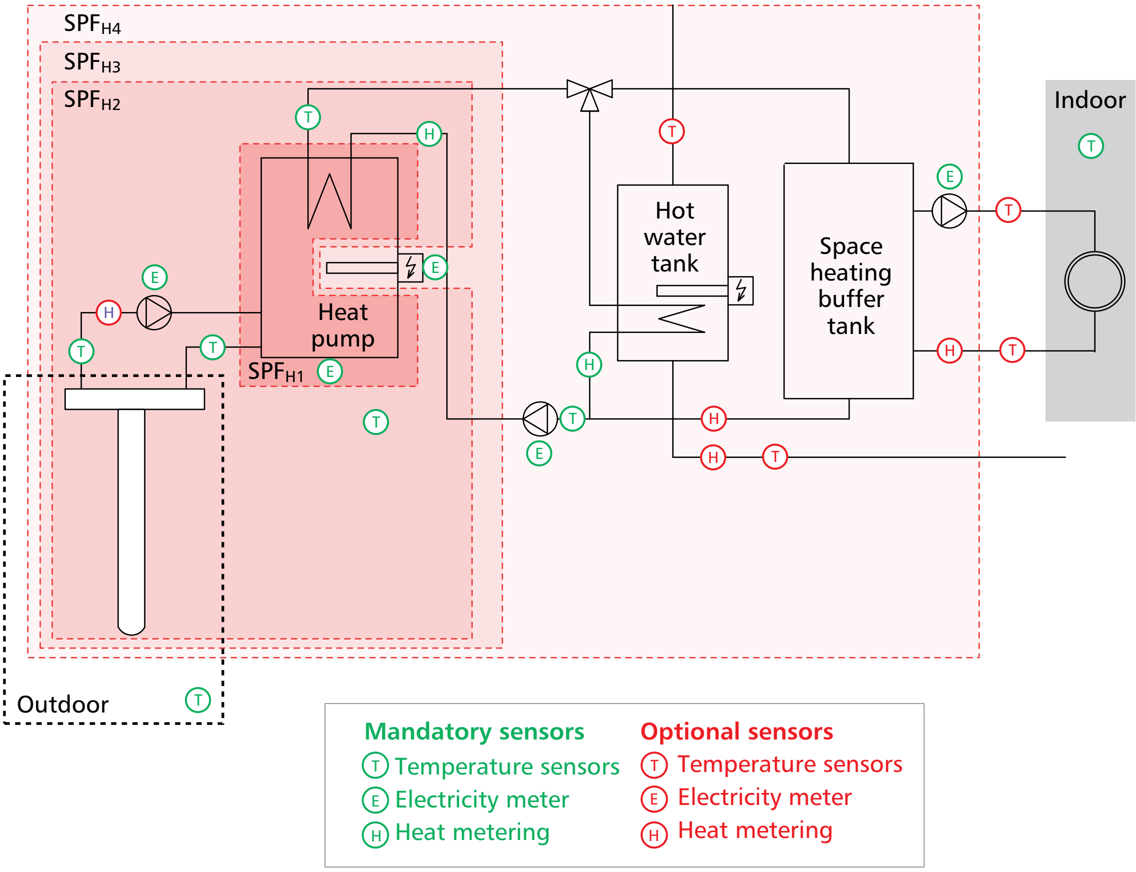


Figure 51 Example schematic of a heating system showing boundaries as described in Table 10 (adapted from EHPA (2012), Figure 1)

Appendix E: Environmental best practice checklist

The following table is taken from GSHPA's *Good Practice Guide for Ground Source Heating and Cooling* (2017) and is reproduced by permission of the GSHPA.

Activity	Closed loop (operational to prevent pollution or reduce risk of liability)*	Open-loop (operational)*	Required by Environment Agency
Siting of scheme (contaminated land, source protection zones, etc.)	✔	✔	✔
Determine environmental impact of scheme	✔	✔	✔
Assessment of geological conditions (multiple layers, artesian conditions)	✔ †	✔	✔
Ensure pipework integrity to prevent leaks	✔		
Pressure testing of scheme	✔		
Type of thermal transfer fluid to be used	✔		
Operational monitoring of pressure in loop	✔		
Development of care and maintenance and emergency plan	✔	✔	
Monitoring volumes abstracted and discharged		✔	✔
Monitoring of temperatures	✔	✔	✔
Testing recharge well		✔	
Test pumping to determine quality and quantity of water available		✔	✔
Determine the potential risk of flooding, impact on third party assets (subsistence/ movement)		✔	
Determine long term sustainability of scheme (will include testing and possibly thermal modelling)	✔	✔	

* To ensure the system is operating efficiently (for owners' and operators' own information)
† If a vertical scheme

Appendix F: References and further reading

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Further reading

Standards

Standard number (listed in order of standard number)	Title	Notes
British (BS), European (EN) and International (ISO) Standards		
BS EN 253:2009 +A1:2015	*District heating pipes. Preinsulated bonded pipe systems for directly buried hot water networks. Pipe assembly of steel service pipe, polyurethane thermal insulation and outer casing of polyethylene*	
BS EN 378-4:2016	*Refrigerating systems and heat pumps. Safety and environmental requirements. Operation, maintenance, repair and recovery*	
BS EN 805:2000	*Water supply. Requirements for systems and components outside buildings*	
BS EN 806-3:2006	*Specifications for installations inside buildings conveying water for human consumption. Pipe sizing. Simplified method*	
BS EN 806-4:2010	*Specifications for installations inside buildings conveying water for human consumption. Installation*	
BS EN 1434-1:2015 +A1:2018	*Thermal energy meters. General requirements*	
BS 5422:2009	*Method for specifying thermal insulating materials for pipes, tanks, vessels, ductwork and equipment operating within the temperature range -40 °C to +700 °C*	
BS 8558:2015	*Guide to the design, installation, testing and maintenance of services supplying water for domestic use within buildings and their curtilages. Complementary guidance to BS EN 806*	
BS EN ISO 9001:2015	*Quality management systems. Requirements*	
BS EN 12828:2012 +A1:2014	*Heating systems in buildings. Design for water-based heating systems*	
BS ISO 13612-2:2014	*Heating and cooling systems in buildings. Method for calculation of the system performance and system design for heat pump systems. Energy calculation*	
BS EN ISO 14001:2015	*Environmental management systems. Requirements with guidance for use*	Certification for environmental management
BS EN ISO 14044:2006 +A1:2018	*Environmental management. Life cycle assessment. Requirements and guidelines*	

Table continues

Standard number (listed in order of standard number)	Title	Notes
BS EN 15316-4-8:2017	*Energy performance of buildings. Method for calculation of system energy requirements and system efficiencies. Space heating generation systems, air heating and overhead radiant heating systems, including stoves (local), Module M3-8-8*	
BS EN 15450:2007	*Heating systems in buildings. Design of heat pump heating systems*	
BS EN 15632-2:2010 +A1:2014	*District heating pipes. Pre-insulated flexible pipe systems. Bonded plastic service pipes. Requirements and test methods*	
BS EN 15632-4:2009	*District heating pipes. Pre-insulated flexible pipe systems. Non bonded system with plastic service pipes; requirements and test methods*	
BS EN 15698-1:2009	*District heating pipes. Preinsulated bonded twin pipe systems for directly buried hot water networks. Twin pipe assembly of steel service pipe, polyurethane thermal insulation and outer casing of polyethylene*	
BS EN 15804:2012 +A1:2013	*Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products*	
BS EN 15978:2011	*Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method*	
BS EN ISO/IEC 17025: 2017	*General requirements for the competence of testing and calibration laboratories*	
BS ISO 31000:2018	*Risk management. Guidelines*	Certification for risk management
BS ISO 45001:2018	Occupational health and safety management systems. Requirements with guidance for use	Certification for occupational safety
BS EN 50598-2:2014 +A1:2016	*Ecodesign for power drive systems, motor starters, power electronics & their driven applications. Energy efficiency indicators for power drive systems and motor starters*	Defines IE (international efficiency) classes for variable speed drives. To be incorporated in the ErP as part of the Extended Product Approach.
BS ISO 55000:2014	*Asset management. Overview, principles and terminology*	
Danish Standard		
DS 439:2009	*Code of Practice for domestic water supply installations*	
Association of German Engineers (VDI) Standard		
VDI 4640 Blatt 2	*Thermal use of the underground — Ground source heat pump systems*	
BRE Standard		
BES 6001	*BRE Environmental & Sustainability Standard — Framework Standard for Responsible Sourcing*	BRE standard for responsible sourcing

Guidance

Organisation	Publications
American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)	*Procedures for Commercial Building Energy Audits* (2nd edition) (2011)
Building Engineering Services Association (BESA)	*Guide to the Use of Plastic Pipework* (TR11) (2006)
Building Research Establishment (BRE)	*Design of low-temperature domestic heating systems: A guide for system designers and installers* (FB59) (2013) *Making the most of renewable energy systems* (DG531) (2014) *Green Guide to Specification* (4th edition) (BR390) (2009)
Building Services Research and Information Association (BSRIA)	*Environmental code of practice for buildings and their services* (2nd edition) (COP6/99) (1999) *Heat Pumps — A guidance document for designers* (BG7/2009) (2009) *Heating controls in large spaces* (TN23/97) (1997) *Illustrated Guide to Renewable Technologies* (BG1/2008) (2008) *Embodied Carbon — the Inventory of Carbon and Energy (ICE)* (BG10/2011) (2011) *Screeds with underfloor heating — Guidance for a defect-free interface* (IEP11/2003) (2003) *Sustainable housing — options for independent energy, water supply and sewerage* (AG26/97) (1997) *Underfloor Heating and Cooling* (BG4/2011) (2011) *Water Treatment for Closed Heating and Cooling Systems* (BG 50/2013) (2013) *Life Cycle Assessment — an introduction* (BG 52/2013) (2013)
Domestic Building Services Panel	*Underfloor Heating: Design and Installation Guide* (2016) *Domestic Heating Design Guide* (2017)
Chartered Institution of Building Services Engineers (CIBSE)	Guide A: *Environmental design* (2007) Guide B: *Heating, ventilating, air conditioning and refrigeration* (4 volumes) (2016) Guide C: *Reference data* (2007) Guide F: *Energy efficiency in buildings* (2012) Guide L: *Sustainability* (in preparation) *Building performance modelling* (2nd edition) (AM11) (2015) *Non-domestic hot water heating systems* (AM14) (2010) *Sustainable low energy cooling: an overview* (KS03) (2005) *How to design a heating system* (KS08) (2006) *Energy efficient heating: an overview* (KS14) (2009)

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Organisation	Publications
Chartered Institution of Building Services Engineers (CIBSE) (*continued*)	*Energy assessment and reporting methodology* (2nd edition) (TM22) (2006) *Resource efficiency of building services* (TM56) (2013) *Building log book toolkit* (2nd edition) (TM31) (2006) Research Report 9: *Embodied carbon and building services* (2013) (https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q20000008I754AAC)
The Coal Authority	*Guidance notes and application form for minewater heat recovery access agreements* (2016) (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/569600/Guidance_Notes_and_Application_Form_for_Minewater_Heat_Recovery_Access_Agreements_2016.pdf)
CIRIA	*Environmental good practice on site guide* (4th edition) (C741D) (2015) *Environmental handbook for building and civil engineering projects.* Part 1: *design and specification* (C512) (2000) *Guide to sustainable procurement in construction* (C695) (2011)
Environment Agency/Department for Environment, Food & Rural Affairs	*Groundwater Protection* [online] (https://www.gov.uk/government/collections/groundwater-protection) *Owning a watercourse* [online] (https://www.gov.uk/guidance/owning-a-watercourse)
European Commission	Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulation (EC 1907/2006) Classification, Labelling and Packaging of substances and mixtures (CLP) Regulation (CE 1272/2008) Directive on establishing a framework for Community action in the field of water policy (2000/60/EC) Measuring instruments directive (MID) (2014/32/EU) Directive on the protection of groundwater against pollution and deterioration (2006/118/EC)
European Heat Pump Association (EHPA)/ Ecofys	*Heat Pump Implementation Scenarios until 2030* (2016) (https://www.ehpa.org/fileadmin/red/03._Media/03.02_Studies_and_reports/Heat_Pump_Implementation_Scenarios.pdf)
Greater London Authority (GLA)	*Sustainable Design and Construction: Supplementary Planning Guidance* (2014) (https://www.london.gov.uk/sites/default/files/osd34_sustainable_design_construction_spg.pdf)
Ground Source Heat Pump Association (GSHPA)	*Good practice guide for ground source heating and cooling* (version 2) (2017)
Health and Safety Executive (HSE)	*Controlling noise at work* (L108) (2012) (http://www.hse.gov.uk/pubns/books/l108.htm) *Control of Substances Hazardous to Health Regulations 2002. Approved Code of Practrice and guidance* (6th edition) (ACOP L5) (2013) (http://www.hse.gov.uk/pubns/books/l5.htm) *Dangerous substances and explosive atmospheres. Dangerous Substances and Explosive Atmospheres Regulations 2002. Approved Code of Practice and guidance* (2nd edition) (ACOP L138) (2013) (http://www.hse.gov.uk/pubns/books/l138.htm)

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Organisation	Publications
Health and Safety Executive (HSE) (*continued*)	*Electricity at work: Safe working practices* (3rd edition) (HSG 85) (2013) (http://www.hse.gov.uk/pubns/books/hsg85.htm) *Reporting accidents and incidents at work. A brief guide to the Reporting of of Injuries Diseases and Dangerous Occurrence Regulations 1995* (RIDDOR) (INDG453) (2013) (http://www.hse.gov.uk/pubns/indg453.htm) *Safe work in confined spaces. Confined Spaces Regulations 1997. Approved Code of Practice, Regulations and guidance* (ACOP L101) (2014) (http://www.hse.gov.uk/pubns/books/l101.htm) *Managing Health and Safety in Construction. Construction (Design and Management) Regulations 2015. Guidance on Regulations (L135)* (2015) (http://www.hse.gov.uk/pubns/books/l153.htm) *Personal protective equipment at work* (3rd edition) (L25) (2015) (http://www.hse.gov.uk/pubns/books/l25.htm) *Manual handling. Manual Handling Operations Regulations 1992. Guidance on Regulations* (ACOP L23) (2016) (http://www.hse.gov.uk/pubns/books/l23.htm) *EH40/2005 Workplace exposure limits. Containing the list of workplace exposure limits for use with the Control of Substances Hazardous to Health Regulations 2002 (as amended)* (EH40/2005) (2018) (http://www.hse.gov.uk/pubns/books/eh40.htm) *Managing for health and safety* (HSG65) (2013) (http://www.hse.gov.uk/pubns/books/hsg65.htm) *Safety of pressure systems. Pressure Systems Safety Regulations 2000. Approved Code of Practice and guidance on Regulations* (ACOP L122) (2014) (http://www.hse.gov.uk/pubns/books/l122.htm) *Safe use of work equipment. Provision and Use of Work Equipment Regulations 1998. Approved Code of Practice and guidance* (ACOP L22) (2014, amended 2018) (http://www.hse.gov.uk/work-equipment-machinery/puwer.htm) *Working at height. A brief guide* (INDG401) (2014) (http://www.hse.gov.uk/pubns/indg401.pdf) *Workplace health, safety and welfare. Workplace (Health, Safety and Welfare) Regulations 1992. Approved Code of Practice and guidance* (ACOP L24) (2014, amended 2018) (http://www.hse.gov.uk/pubns/books/l22.htm) *Legionnaires' disease: Technical guidance* (HSG274) (2014) [3 parts] (http://www.hse.gov.uk/pubns/books/hsg274.htm)
HM Government/NBS	*Domestic Building Services Compliance Guide* (2013 edition incorporating 2018 amendments) (https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l) *Non-Domestic Building Services Compliance Guide* (2013 edition) (https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l)
Institution of Engineering and Technology (IET)	*Code of Practice for Electrical Safety Management* (2013)

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Organisation	Publications
Office of Gas and Electricity Markets (Ofgem)	*Non-Domestic Renewable Heat Incentive. Guidance Volume One: Eligibility and How to Apply* (Version 5) (2015) (https://www.ofgem.gov.uk/sites/default/files/docs/2015/10/guidance_volume_1_v5_publish_0.pdf) *Non-Domestic Renewable Heat Incentive.. Guidance Volume Two: Ongoing Obligations and Payments* (Version 7) (2016) (https://www.ofgem.gov.uk/ofgem-publications/89240/guidancevolume2v7finalmarch2016-pdf) *Non-Domestic Renewable Heat Incentive.* Metering Placement Examples (Version 1) (2014) (https://www.ofgem.gov.uk/publications-and-updates/renewable-heat-incentive-guidance-non-domestic-scheme-metering-placement-examples)
Scottish Government	*Building Standards technical handbook 2017: non-domestic buildings*. Section 3: Environment and Section 6: Energy (2017) (https://www.gov.scot/publications/building-standards-2017-non-domestic) *Building Standards technical handbook 2017: domestic buildings*. Section 3: Environment and Section 6: Energy (2017) (https://www.gov.scot/publications/building-standards-2017-domestic)
Scottish Environmental Protection Agency (SEPA)	Supporting Guidance (WAT-SG-62): *SEPA's requirements for activities related to geothermal energy* (https://www.sepa.org.uk/media/219751/sepa-s-requirements-for-activities-related-to-geothermal-energy.pdf)
Swedish District Heating Association	*District Heating Substations* Technical Regulation F101 (https://www.energiforetagen.se/globalassets/energiforetagen/det-erbjuder-vi/publikationer/f101-district-heating-substations-design-and-installation.pdf)

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