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IEA ECES ANNEX 27

Quality Management in Design, Construction and Operation of Borehole Systems

Final Report

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ECES Annex 27
BoreSysQM

About this Report

To **International Energy Agency**

Executive Committee of the Energy Conservation through Energy Storage (ECES) Technology Collaboration Programme.

Presented by **Bavarian Center for Applied Energy Research**
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ABOUT ECES ANNEX 27

ECES Annex 27 is a concluded project of the International Energy Agency's Technology Collaboration Programme "Energy Conservation through Energy Storage (ECES)". The Annex started in October 2015 with a task definition workshop and lasted until December 2019. Annex 27 saw the participation of 11 countries, of which 81 experts participated in total in the eight workshops.

Annex 27 - Quality Management in Design, Construction and Operation of Borehole Systems should summarize the current situation and best technical practice in major countries using this shallow geothermal technique today.

ECES facilitates integral research, development, implementation and integration of energy storage technologies such as: electrical energy storage, thermal energy storage, distributed energy storage & borehole thermal energy storage.

More information can be found at the following links:
Annex 27 https://www.eces-boresysqm.org
IEA ECES TCP https://www.iea-eces.org
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Preface

Annex 27 - Quality Management in Design, Construction and Operation of Borehole Systems summarizes the current situation and best technical practices in major countries using shallow geothermal technology today. In the majority of situations, employing the earth's sub -surface for thermal energy storage is efficient, safe and reliable with a minimum of challenges encountered. However, in unique geological formations a lack of skill and experience by drilling equipment operators can result in problems that can range from simple and straight forward remedies to extreme damages with significant environmental impact. It is therefore essential that quality technical and management practices are utilized in all project phases to provide safe and reliable solutions that will meet the goals of system owners and end-users.

In many technical areas, guidelines, codes and standards are available to provide important rules and recommendations of best technical practices to prevent problems during construction and operation. However, only in few countries are such guidelines, codes and standards on shallow geothermal techniques available to achieve high quality design, construction and operation that result in safe and reliable systems.

Technical guidelines, codes or standards are available or planned in several countries that can significantly enhance the quality of Borehole Heat Exchangers (BHEs). Within the technical collaboration program, ECES (Energy Conservation through Energy Storage) of the International Energy Agency (IEA) an international working group of experts (IEA ECES Annex 27) was convened to compile and develop measures for quality management on an international basis.

Throughout the work of Annex 27, the French standardization organization AFNOR, proposed the development of a new European Standard (CEN-Standard). A Technical Committee CEN/TC 451 "Water wells and borehole heat exchangers" was established to further detail such a standard. This committee was split in two working groups,

- CEN/TC 451 WG 1 on "water wells"
- CEN/TC 451 WG 2 on "borehole heat exchangers"

Through a series of dialogs between managing directors and technical participants it became readily apparent that there was significant commonality between CEN/TC 451 WG 2 and Annex 27 work resulting in the decision that a collaborative effort between both groups was the most efficient avenue to pursue for a complete and comprehensive end product.

Policy Statement

The continued and expanded use of the earth as a reliable heat source / heat sink employing borehole heat exchangers (BHEs) combined with ultra-efficient heat pumps to heat and /or cool buildings will take on significant importance in the move to beneficial electrification and the replacement of fossil fuels. Additionally, large BHE fields will be utilized for daily, seasonal and annual thermal energy storage further reducing harmful CO_2 emissions on a global scale.

The overall quality of the Borehole System is of significant importance for owners and users as well as the authority having jurisdiction who enforce legal regulations to avoid impact on neighbors and on the environment.

Superior Borehole Systems with high efficiency, economic viability and low environmental impact are achieved through three distinct disciplines:

1. High quality design and engineering;
2. High quality construction methods using industry “best practices”; and
3. High quality and knowledgeable Operation and Maintenance.

- **Currently the vast majority of systems have not encountered problems.**
- In a **very few instances damage have occurred**, which have ranged from small localized impacts to very severe damages when the required extra attention to the local geological and hydrogeological situations were not fully understood and mitigating measures were not employed.
    - A major issue in most countries is the protection of groundwater for human consumption.
    - Also, avoid any connection of aquifers of different pressure or water quality to exclude damage by settlement or changes of water quality due to mixing of different water qualities.
    - Consider swelling of the underground in situations with anhydrite layers in the underground when they get into contact with water.

High quality design and construction requires

- well educated and experienced designers and constructors
- detailed knowledge of the local geological and hydrogeological situation
- high quality materials and components and
- appropriate construction tools

Subtasks 1 and 2 analyze the situation in the different countries and give important and detailed recommendations for the design and construction process.

Guidelines and standards are important to achieve high quality in design and construction.

- Several countries currently have standards with varying levels of detail. It is recommended to review these standards regularly and to revise those documents **in accordance with IEA ECES Annex 27**
- **The new European CEN Standard developed by CEN TC451 WG2 “Borehole Heat Exchangers”, in close collaboration with IEA ECES Annex 27,** is a significant step forward, especially for those countries, which do not yet have any regulation or guidance standards.

Additional measures like supervision of operation in combination with some monitoring can help to improve and keep the quality of a running system and can avoid problems and failures. Thus monitoring requires some sensors and data acquisition to detect any deviation from regular system operation in advance. Subtask 3 gives more details and requirements.

At least some minimal monitoring is required even for small systems to allow for qualified supervision.

Potential problems and solutions in the design, construction and operation phase are discussed in subtask 4. In general, the focus has to be put on preventing problems. However, if any problem occurs solutions are required to remediate.

Summary of Main Results

Legislation

The level of legislation on the construction of borehole heat exchangers varies a considerably between countries and sometimes even within a specific country depending on the region (e.g. Germany and Belgium). Furthermore, there may be variations in the legislation depending on the size of the borehole heat exchanger system. The various laws, acts, codes, standards, norms, guidelines, protocols, rules and regulations primarily focus on avoiding negative environmental effects from the construction and operation of the borehole system. Detailed information on best practices and how to construct and operate these systems is almost non - existent.

The legal framework and enforcement is generally through local bylaws and permits that are issued by the authority having jurisdiction (AHJ) or environmental agency. The permits can be unlimited or in some cases limited in time to complete the borehole system drilling activities. As ground source heating and cooling is a relatively “new” technology compared to water wells for drinking water and mining operations, it is common to see borehole heat exchangers (BHEs) as an adjunct to or as an implicit inclusion to existing rules and regulations. The various legal acts emphasis real concerns respecting the protection groundwater from negative impacts. In countries where groundwater supplies a large part of, or the primary source of drinking water, the rules and regulations concerning the sealing of boreholes are generally stricter and more comprehensive.

Environmental protection is an important issue that most countries focus upon. The BHE must not cause negative effects in terms of temperature variance or the introduction of contaminants. The majority of countries have rules and regulations that prohibit surface water intrusion into a borehole and the cross – contamination of aquifers that can result from the interconnection of aquifers via the vertical drilling process. Additionally, the AHJ generally has strict guidelines to avoid damaging adjacent buildings during the installation and ongoing operation of BHE systems. These damages can be caused by swelling materials (such as anhydrite) or by subsidence amongst other factors.

The legislation surrounding construction of BHE systems focuses primarily on avoiding adverse effects on groundwater and environment in general. However, adverse effects are generally only loosely defined and mitigation procedures are virtually non-existent.

Subtask 1 Design Phase

The different systems under consideration in IEA ECES Annex 27 are:

- GSHP (Ground Source Heat Pump) systems that are designed to extract or inject thermal energy (heating or cooling application) from or to the underground that recovers in a passive way.
- BTES (Borehole Thermal Energy Storage) systems that are designed with the purpose of actively storing thermal energy (heat and/or cold) in the underground, most commonly seasonally.
- HT-BTES (High Temperature Borehole Thermal Energy Storage) systems that are designed with the purpose to actively store heat at high temperatures in the underground, most commonly seasonally.

A typical design phase covers the following stages:

- Pre-feasibility study
- Feasibility phase
- Detailed design
- Approval procedure

- Call for tenders

Depending on the size and scope of the project, the different stages cited above will have varying degrees of detail. For small projects such as single-family homes, pre-feasibility and feasibility are often a combined stage with the other major components and integrated in the detailed design.

General Remarks on the Design Approach

Designs vary with respect to borehole depth, borehole spacing, system operating pressures, working temperatures of the heat transfer fluid and equipment operation duration dependent on the intended type of system and the building loads that are to be supported.

There are a number of design software tools available with varying levels of sophistication. Software tools such as EED, GLHEPRO, GLD and GEO-HAND^{light} are sufficient for smaller systems. These tools are applied in the feasibility stage for initial estimates. Some of these software tools can also be employed with larger and more complex systems – systems that encompass hundreds of boreholes, district systems and hybrid systems. It is strongly recommended that designers use detailed energy modelling software tools such as TRNSYS or Trace700 to fully understand the energy loads that a complex system is engineered to support. Additionally, it is vital that designer / engineers take into consideration existing or planned ATES, GSHP and BTES systems in the immediate vicinity to minimize or eliminate thermal interference.

The heat source for a pure extraction system is solar heat and geothermal heat from the date of origin of the earth and the radioactive decay in the upper crust that is stored naturally in the ground. Additionally, heat from solar collectors and waste heat from industrial processes (cogeneration included) are regarded as sources. Sector coupling by power to heat (surplus of renewable electricity is converted into heat and the heat is stored for later use) with BTES for storage is economically viable and may play an important role in future. There are a number of other heat sources used in BTES systems, mainly for seasonal storage. BTES can also serve as cold storage.

It is paramount to differentiate between GSHPs and BTES with respect to borehole spacing. The distance depends on the intended application (GSHPs or BTES), the geological conditions (i.e. the ground thermal properties), intended final drilling depth (increased distance between deeper boreholes to prevent cross drilling damage) and load characteristics. The optimal borehole distance for multi – borehole BTES systems is between 3 - 10 m with closer spacing for high temperature storage (HT-BTES). For independent borehole systems employed in GSHP applications (extraction of heat and cold), which should not significantly thermally interact with one another, a “safe” distance of 6 - 25 m appears to be applied in most countries. This borehole spacing is largely dependent on the ground thermal properties and building energy load profiles while also considering the thermal impact on neighboring properties.

The undisturbed ground temperature is an essential parameter that strongly affects the design and performance of GSHP systems with a lesser impact for BTES systems. This parameter mostly affects heat movement to the surrounding ground. Design ground temperature denotes the average undisturbed ground temperature calculated over the total borehole depth.

Prefeasibility Study

Pre-feasibility studies are typically carried out for large GSHP systems and BTES. The results will normally serve as a point of decision for clients to continue or stop further development. BTES or GSHP options are compared to other forms of heating and cooling, for example district heating/cooling or fuel fired boilers and electrically driven chillers. If the result from this initial study is favorable, the project can continue to the next phase of development.

Depending on the project scope and complexity, the content of a pre-feasibility report will vary. However, site plans, topographic maps, geological maps, hydrogeological maps, databases on wells and boreholes, energy load and temperature demands, predesign and economic calculations to compare with other energy systems are important issues to cover. Data from existing wells and boreholes are very important for understanding the geology at any given site. Since groundwater always plays an important role for any project, it is recommended to search for information on aquifers and groundwater levels at this stage. It is recommended to research as much information as possible, especially on known geological conditions in locally available databases and to understand preliminary energy load profiles of the proposed building(s).

Underground obstacles and limitations can affect the construction of a system significantly. Checking with the AHJ is a vital first step in determining if the project site is subject to drilling restrictions and if there are any pre-existing subsurface infrastructure installations – i.e. natural gas lines, electrical lines, water or wastewater piping, communication lines etc. Further, geotechnical properties need to be considered via a risk analysis that consider the possibility of tectonic activity with possible seismic shifting.

Legal aspects should be addressed at an early stage in any project. In most countries, the user of the system must own the property on which the plant will be installed. By easement use of another property it has to be considered that often after completed installation, the system becomes a part of the property and may change ownership. A local environmental risk analysis is recommended with respect to affecting the soil and the groundwater and global environmental benefits such as reduction of greenhouse gases should be valued.

A rough estimate of the investment cost, energy savings and profitability be recommended at an early stage of the project to facilitate the decision of the client.

Feasibility Phase

In the feasibility phase, the project is further developed to gain more detailed information for deeper planning. Typically, one or several exploratory boreholes are drilled, tested and documented. Furthermore, detailed data (occasionally specially logged) on heat and/or cooling load characteristics as well as temperature profiles are obtained and used as a basis for design. Environmental and legal aspects are also more thoroughly considered.

Test-borehole drillings should be placed close to, or preferably inside the final borefield to be incorporated in the completed system. Exact borefield location is defined by geological conditions and land availability and a survey of underground obstacles. In many countries, a permit is required for exploratory test-drilling. The layout, and especially the depth of the test-borehole should correspond to the final system to allow inclusion in the completed system. To avoid damage to underground infrastructure such as pipes and cables, or hazards due to unexploded ordnances, a thorough investigation of the subsurface, to the extent possible, must be undertaken prior to drilling test boreholes. Local governmental administrative offices and utility providers should be consulted to determine the location of known underground obstacles.

Documentation during test drilling is essential. Geological profiling by visual classification of cuttings by the driller and/or sampling for laboratory analyses is prevalent in most countries. In general, detailed determination of stratigraphy is not required. However, during the test drilling procedure, the drill operator should be able to identify the main geological layers encountered with an emphasis on identifying sealing layers (aquitards). In addition to the driller's log it is recommended to document geological layers by taking physical samples, especially in unconsolidated sediments and sedimentary bedrock rock. All aquitard layers encountered are vitally important to document. The identification of one or multiple aquifers or permeable fracture zones is important information for the design of a borehole system. It is essential to know the groundwater level or hydrostatic pressure, however, the ability to measure these data are dependent on the drilling method is applied. Drilling with mud rotary equipment will block permeability, making measurements in the borehole impossible. In such cases, the groundwater level may be obtained from measurements in adjacent boreholes. Fracture zones, unstable borehole annulus, swelling clay, large water yield, loss of drilling fluid, etc. may all cause drilling issues. These conditions should be noted down in the driller's log. Documentation of drilling the parameters and conditions encountered will greatly assist in understanding the site-specific geological conditions. In small commercial applications this kind of documentation is sometimes neglected.

A Thermal Response Test (TRT) is of great importance when it comes to reliability and quality of a borehole system design. Large systems in an area with diverse site may require multiple test-holes and TRTs to gain sufficient reliable data for the final design. This topic has been examined in IEA ECES Annex 13 and 21. It is recommended to perform one TRT test for every 10-30 boreholes. Not all test boreholes are necessarily used for TRT, but it is important to keep detailed documentation during the drilling procedure, as this provides useful information of the homogeneity of the borehole field and thus indicates the need for multiple test boreholes and TRTs. There is further information available on TRT equipment and methods within the IEA ECES Annex 21.

The duration of TRT must be long enough to ensure a proper evaluation of thermal properties. It is recommended to check automatically for convergence during the ongoing measurement, to find out the required test duration. For evaluation of data obtained from TRTs, the line source method is commonly used. This approximation is only valid when all measured parameters are precise and the heating/cooling load is secured to be very stable. Groundwater flow and load variations make this method unsuitable. When the prerequisites for the line source approximation are not fulfilled, more advanced evaluation methods are required. If measured data show stable conditions the line source approximation can be used. As this is typically not the case, it is recommended to use more advanced evaluation methods and check for convergence.

The report of TRT measurements should include information about the test equipment, test duration and conditions, results and analysis as well as an error analysis of the measurement and evaluation. In Germany the Verein Deutscher Ingenieure (VDI) stipulates how the TRT report should be completed and presented, and in Sweden there is a TRT-guideline issued by the Swedish Geoenergy Center, giving advice on reporting. IEA ECES Annex 21 also gives detailed guidance on TRT.

A main environmental concern in all countries is related to protection of groundwater and thus regulated, but in different ways, and practice may also vary by provinces or regions. In fact, protection of groundwater is the main reason for sealing the boreholes with grout, which is mandatory in most countries. There is a high diversity of regulations and other groundwater related concerns. It is a mandatory requirement to comply with laws on groundwater protection in all borehole applications and to follow any country specific or local regulation related to this issue. There are a number of possible impacts from construction and operation of borehole systems that should be addressed.

In the feasibility stage of a given project, the information gained during test drilling, TRT evaluation and energy load profiles allows a pre-design of the borehole system with tools. Based on this pre-design, first - cost considerations are possible, which is one of the major concerns of the project owner.

A rough investment cost calculation can be carried out for the pre-designed system based on experience from other similar projects. The operational cost is roughly estimated by using the expected amount of used energy and seasonal performance factors using the current price for electricity. The maintenance cost of a borehole system should, if correctly designed and constructed, be very low or practically zero. Some maintenance is associated with the heat pump equipment side of the system, and a degree of control for system pressure and flow rates as well as heat carrier fluid quality is needed. The expected seasonal performance factor (SPF) with a system boundary including at least boreholes, circulation pumps and compressors is used to estimate the energy savings from the system. A rough estimate of profitability may be obtained by the use of straight payback time and/or return of the investment.

Detailed Design

In principle there are two contractual options:

- "Turn Key Contract": The contractor will both design and construct the entire system. This option is mostly applicable for small and relatively simple installations.
- "Performance Contract": The design is performed by the project owner with the assistance of consultants. This option is for larger and more complex applications.

Most important is the load profile regarding heating and cooling energy for the building, so that the modeled design is accurate. Ensuring close cooperation and interaction between the building designer and the designer of the BTES/GSHP system is essential. For modeling of smaller and less complex projects monthly load values are sufficient. For larger and more complex load characteristics, hourly values should be considered. Both energy demand and capacity must be accounted for. Supply and return temperatures in heating and cooling systems are controlled by the site-specific outdoor temperature variation over the year. In general, most countries relate to the outdoor temperature, but in climates with moderate variations (maritime climate), a fixed temperature may be used. It is vital to understand that the ground temperature and system's heat carrier fluid temperature are not the same. These temperatures impact on another but are separate values that must be well understood to execute a quality design.

For studies and analysis of different borefield layout options, software simulation tools are typically used. The number of boreholes, their depths and configuration are determined by such design tools using the given load and the thermal parameters of the subsurface. The groundwater level is important for defining the thermally active length of the boreholes in non-backfilled (grouted) applications as the piping above the groundwater level is surrounded by air and has no thermal contact with the borehole wall. In such cases, the groundwater level should be measured to define the thermally active borehole depth, it should be taken into consideration that the groundwater table may vary during the course of the year.

Natural groundwater flow will have an impact of the thermal behavior of the borehole systems. For GSHP systems, this may be a benefit, while BTES systems may be negatively affected. Most countries are aware of the impact that groundwater flow may have on the system performance. However, due to the complex nature of modelling groundwater flow, this type of analysis is not integrated into most commercially available design tools. The effect of groundwater flow is complex as the effects depend on the relative length of the borehole affected by the groundwater flow, the groundwater velocity and, also the energy balance achieved by the system. In general, low groundwater flow velocities and systems with a high energy balance are not greatly affected by groundwater flow, while systems with high groundwater flow velocity and poor energy balance are affected much more significantly.

The main assumption in all common software tools used in the design process is that heat conduction is the only modelled transport mechanism and groundwater flow is not considered. If groundwater flow does affect the heat transport around the borehole heat exchanger, different effects may arise depending on the situation:

- In applications dominated by either heating or cooling, groundwater flow will have a positive effect on the temperature response and standard design methods will result in an over-design of the system – i.e. too many boreholes.
- In applications that intend to store heat (or cold) in the ground, the thermal losses increase and may make the intended storage underperform or ineffective.
- In large borehole heat exchanger fields, boreholes downstream of the groundwater flow may experience adverse conditions as the flowing groundwater has been thermally interacted with (i.e. become cooler or warmer than the expected static background temperature).

In most countries the market is dominated by single U-pipe BHEs, followed by double U-pipes and occasionally (especially in Germany) various types of coaxial pipes. The selection of the BHE must meet the design criteria. If the BHE type is changed, the borehole field design must be recalculated.

Polyethylene pipes (PE 100), are most commonly used in low temperature or moderate temperature applications. The U-bend at the bottom of the borehole is fusion welded by the manufacturer by the butt-welding method. For connection of the vertical pipes of the BHE to the horizontal collection, various welding methods are available - i.e. socket, butt and electrofusion, with electrofusion being preferable.

PE pipes for pressure applications (such as GSHP systems) are classified by minimum required strength (MRS) based on the international standard ISO 9080.

High temperature BTES (HT-BTES) applications will demand other types of polymer material for both BHE and horizontal piping. For HT-BTES systems, special types of polymers that can withstand higher temperatures are chosen, such as PE RT type II, PP, PEX and some other thermoset materials.

The strength properties of the BHE will be different depending on whether grouted or non-grouted boreholes are used. In either situation, the properties of the BHE material is of utmost importance. There appears to be country to country agreement on pipe bursting pressure, collapsing pressure, extension coefficient and change of strength with increased temperature. For grouted boreholes, also the full contact between the grout and the borehole piping is of great importance.

To ensure high quality, BHE assemblies are mainly manufactured in each country in a controlled factory environment. Manufacturing and testing are performed according to individual country accepted standards. While U-pipe BHEs are delivered as coils, coaxial BHEs with large diameter cannot be practically handled that way. They are instead typically delivered to the construction site as prefabricated pipe tube sections and are welded together on site at insertion in the borehole.

The BHEs are connected to the collection pipe system by electrofusion joints (or socket / butt welded) according to specifications from the joint manufacturer and/or standards.

In groundwater-filled boreholes, piping spacers make no significant difference on the borehole resistance and are therefore rarely used. In grouted boreholes, spacers are recommended in guidelines, but seldom used in practice.

A variety of prefabricated exterior field manifolds have been developed and are commonly used. Less common are designs built on site. In some projects the manifolds are located indoors. Except for very shallow systems, the boreholes and field manifolds are connected in parallel in order to minimize the flow resistance in the system. It is common practice to use high efficiency heat carrier fluid with control valves on manifolds to balance the fluid flow in the underground piping network.

Backfilling or grouting, is mandatory in most countries, but not in the Nordic countries, and with different types of mixtures commercially available. In countries without mandatory backfilling, grouting may still be needed in some cases. Many countries lack manuals or guidelines for backfilling. In Germany “on-site backfilling” with “self-made” grouts has recently been banned and replaced by proven grouts. Materials and procedures, as well as control systems, are currently the subject of various research initiatives.

For the horizontal pipe systems (collection systems) the same piping material should be used as for the BHEs. Common practice is to use PE100 or similar for low temperature applications, and thermal resistant polymers for HT-BTES. The horizontal pipe systems must sufficiently resist above ground weight - e.g. heavy vehicles - and the collapse strength and burial depth should be seriously considered. Horizontal piping should be placed below the frost-free depth in order to avoid elevation heaving of the soil. This elevation heaving occurs if the layer of ice around the horizontal pipes (due to sub-zero operating temperatures) and the frozen soil layer above the horizontal pipes freeze together. Depending on the bed depth of the horizontal pipes, the ground temperature can be significantly higher or lower than at the surface. Therefore, the horizontal pipes of systems with operating temperatures below the minimal ground level temperature can contribute to peak load shaving. The overall impact mainly depends on the length of the pipes and the borehole discharge temperature. It is recommended to consider the hydraulics of the system, the depth and length of the pipe system as well as the impact from the surface to choose a suitable and safe dimension and strength.

In low temperature applications, generally the horizontal pipe system can be placed without insulation. However, parts that are exposed to air, or placed at or above the frost-free depth, and parts close to building foundations must be insulated. Insulation is also needed if the pipes cross or run parallel to water pipes or sewage pipes, and if the system is a HT-BTES system.

It seems to be common practice to embed the horizontal pipes in sand without stones or sharp-edged rocks and to cover that layer with a geotextile material. Native soil material from trench excavation is used to complete the backfilling operation.

Commonly ethanol, ethylene and propylene glycol mixed with water are used as heat carrier fluids. Ethanol is commonly used in water-filled boreholes at a concentration of maximum 28% (non-flammable), and glycol in grouted boreholes at a concentration up to 30 %. Propylene glycol has a comparably high viscosity which makes it less favorable as heat carrier fluid. The ethanol mixtures may be mixed with additives that make it undrinkable. Pure water is used in systems that work well above the freezing point and in systems used for storage of heat only. Corrosion inhibitors and other additives should be avoided if possible. It is recommended to use environmentally safe heat carrier fluids at the lowest acceptable concentration that still provides adequate freeze protection for efficient system operation.

Environmental risk assessments are normally a part of the permit procedure in countries where permits are required. In other countries, there is a lack of standard procedures on how to perform this kind of analysis. Nevertheless, it is strongly recommended to always make an environmental risk analysis showing that such risks have been considered during the project development phase. Technical and economic risks are mainly considered in the feasibility stage. Further in-depth analyses may be stipulated in contracting documents.

Approval Procedures

Approval of installations is handled very differently in different countries. Furthermore, there may be specific city, municipal or provincial requirements within a country. In a few countries there is no permit requirement at all, or only for larger systems. In most countries there are standard procedures and/or norms for system design, but not for the approval of the system. A common procedure is that a borehole system is assessed by local environmental authorities and a permit is given if there is no risk for, by example, groundwater contamination. Approval may be contingent on certain terms and conditions being met by the project owners and their consultants.

Call for Tenders

It is recommended to be aware of the form of contract when preparing the tender documents and specifications.

The quality and skill requirements of contractors that bid on any project should be specified in the tender documents as well as reference projects, certifications of drillers and installers, CVs etc. The majority of countries requires certification of drillers and installers and companies must often have Quality and Environmental Control systems in place. A high-quality installation can be achieved by requiring safety, quality and environmental control certifications as well as references in the tender documents. Drillers are certified according to national, provincial, state and/or local legislation.

Unforeseen damages caused by the borehole installation are of significant importance to identify in the contract documents that should also include a guaranty / warranty period e.g. - warranty period 3-10 years. In some countries, this is dealt with by general contract clauses, in other countries they will be addressed by a court of law. Responsibility for unforeseen damages should be written in the tender contract and it should be a prerequisite that companies responding to the tender are qualified / certified and have specified levels of valid insurances in force.

Subtask 2 Construction Phase

This scope is for the construction of the borehole(s), the installation and control of the BHE, the grout and the grouting process and the documentation of the borehole and BHE.

Site Preparation

The site facilities are those that need to be present before and during the drilling process in order to avoid accidents and to support all the drilling procedures. Apart from physical installations such as fencing, this may include paperwork such as drilling certificates and permits that need to be present.

In order to prevent accidents, some countries require a health and safety plan for the site and work processes to undertaken by the drilling contractor and will be impacted dependent the construction site constraints. In many instances, these safety and work process plans must be approved by consultant and/or authorities before the construction is started.

Generally, there is a requirement for temporary construction fencing around the work entire site. It is common practice that the site owner provides electricity and water to aid the drilling, however, this is not mandatory and drilling contractors may need these services themselves. A plan for safely handling drilling mud and cuttings in an environmentally responsible manner is also required in most countries.

Mapping or detection of underground installations will typically be the driller's responsibility. Checking for soil contamination will also be a part of the investigation prior to drilling. Generally, it will not be allowed to install BHEs in contaminated areas. If the driller unexpectedly encounters contaminated soil, it is the driller's responsibility to inform the planner/engineer and/or the authorities for direction on how to dispose of the contaminated soil/cuttings from the project site. This procedure also applies to spent drilling mud / cuttings and excess water. In most countries, the use of watertight containers for drilling mud and the settling of cuttings appears to be either mandatory or the norm. The deposition of these materials will normally have to be approved by the AHJ.

Drilling

In most countries, it is a requirement that the drillers hold a government recognized certificate that ensures their understanding of drill rig operation, the various geological formations that could be encountered, sound environmental practices as well as a minimum understanding of the basic working principles of a closed loop system. The applied drilling method should be appropriate in the geology in question.

The chosen drilling method is closely related to the geology on the drilling site. In unconsolidated sediments, rotary mud drilling is the method of choice. This method will typically be direct flush cuttings / debris but may also be reverse flushed. The expected drilling depth may also influence the choice of method. There seems to be a tendency for the boreholes to become deeper. In Sweden, boreholes of 250 – 300 m are seen more and more often. Thermal short-circuiting is generally small in BHEs shorter than 300 m. In hard rock, the drilling will typically be made by DTH (down the hole) hammer drilling with compressed air used to lift cuttings and clear the borehole. Alternative drilling methods may be appropriate in unconsolidated sediments. The driller must be able to handle situations with excessive flowing groundwater, artesian waterflow or the release of underground hazardous gases and have the necessary equipment on site to control or mitigate these issues should they arise. These mitigation methods are typically packers and diverters.

The borehole diameter generally seems to vary between 120 mm and 178 mm with casing. Smaller diameters may cause problems for the installation of the BHE. Some of the federal states in Germany have recommendations on diameter of the borehole in relation to the diameter of the BHE-pipe. BHEs with diameters of DN 45 and DN 50 seems to be moving into the market, especially for deeper boreholes. These larger diameters may result in a general increase in borehole diameter.

For the rotary mud drilling there is the option of drilling with or without casing. It seems that drilling without casing is most common. If drilling caseless, it is still common to have short (2 – 3 m) casing through the overburden in order to control the flow of drilling mud and avoid collapse of the loose topsoil into the borehole.

Most countries have a general set of health & safety rules that also apply to drilling sites. They distinguish between "small" and "large" construction sites and is typically related to the number of contractors and personnel working on the site at a given time. The staff working on the site must always be aware of this plan.

The minimum content of a drilling log should be information about the level of fluid in the borehole and the geology of the borehole. Identifying information such as site name, date, position and identification of borehole, name of company and drillmaster are also mandatory. The name of sample examiner is also very relevant, but will have to be added later, if it is not done in the field. The frequency of the sampling varies between the countries. The demands regarding the qualifications of sample examiner (driller or geologist) also varies. In some countries mud loss, caverns/fractures, water yield and water salinity also must be reported.

In complicated geology, it may be useful to do geophysical logging. Geophysical methods seem primarily to be applied for research purposes, in special geological situations or in rare cases to measure deviation of boreholes. There are no general requirements or official guidelines for geophysical logging for borehole systems. Temperature profiles are generally measured in conjunction with a thermal response test (TRT). Because of heat generated during the drilling process it is recommendable to wait for about one week until the heat has dissipated before temperature logging. In larger systems temperature profiles should be measured.

Backfilling or "Grouting" Process

In order to protect the subsurface against intrusion of surface contaminants or to avoid the risk of changing the natural groundwater flow, the boreholes will require some form of sealing. The grouting and sealing of the borehole should generally ensure that all aquitards that have been penetrated are resealed so that all groundwater pressure levels are unchanged.

Most countries have a requirement for sealing penetrated aquitards as a minimum. Belgium and Germany are stricter, dictating a complete grouting of BHEs. Conversely, Sweden and Finland only have requirements for sealing the top of the borehole and a complete seal only if the borehole is in a groundwater protection area and / or if a borehole connects two aquifers or penetrates contaminated soil. Therefore, only a small number of boreholes are backfilled in these countries. In addition to the sealing properties, the grout generally should ensure a good heat transfer and protect the pipes against mechanical damage.

As the legislative prerequisites for grout concerns the sealing properties, it is possible to use other types of materials in the borehole that provide the same functionality. This could be a type of packer or cured-in-place liner. These technologies are not widely in use and may be used only if their effectiveness has been proven and accepted by the authority having jurisdiction.

Where grouting is mandatory, there is a consensus that the boreholes must be filled by pumping the grout slurry from the bottom of the borehole to the top. This is accomplished by employing a through a separate pipe (tremie pipe). In case of deep boreholes i.e. high flow resistance resulting in high pumping pressure, separate pipes can be taken to different levels. By utilizing the fact that the grout typically is denser than the drilling mud in the borehole the grout will displace the mud and fill the borehole completely. Typically, the tremie pipe is left in the borehole after finishing the procedure. In some cases, the tremie pipe is retracted during filling. In Belgium, this procedure is mandatory. Vertical and horizontal groundwater flow in the borehole will impede the construction of a tight seal as the water flow may flush the grouting materials away or form channels in them. Experiments have shown that high pumping pressure during the grouting process combined with high density filling material will improve the sealing properties in case of groundwater flow around the borehole. When layered filling (resealing aquitards) is used in the Netherlands it is common to use a larger diameter pipe inserted in the borehole at the relevant depth. Pellets are then poured into the pipe to create a seal and the pipe is retracted as the seal is created. Generally, commercially premixed filling materials are standard in the participating countries. There are examples of on-site mixing but this approach appears to be less prevalent. The industrial products come with specifications of thermal conductivity and mixing ratios that increase the possibility of getting the correct properties from the filling. Special attention needs to be exercised in saline areas. High salinity will inhibit the swelling properties and requires a sulfate resistant filling material.

In some countries, bentonite is used to achieve the sealing properties. Industrial premixed grouting materials have cement and rock powder as main constituents. Quartz, in some form, appears as a typical thermal enhancer. This may be in the form of fine-grained sand or a quartz powder. Other products use graphite to enhance the thermal properties further. Cement contributes to achieving high physical stability. In order to be

able to document the position of a seal, magnetite can be added to a filling material (enhanced grout). It must be pointed out that smaller voids may go undetected.

One of the issues with the pumped grout is the friction in the tremie pipe. This may lead to pipe bursting. Adding a liquefier similar to those used in concrete may reduce this problem. However, the chemical composition of that liquefier must be approved for use in contact with aquifers.

For mixing of filling materials/grout, continuous mixers are frequently used, due to ease of use, however, issues with the mixing ratio of the produced grout have occurred. Batch mixing will have a higher probability for achieving correct mixing ratios. In Germany colloidal mixers are gaining a footing and are seen to replace the two other mentioned technologies. The mixing procedure ensures a homogenous product mixed at the correct ratio. Mixing and pumping are two separate processes.

Regarding chemo-physical properties there seems to be high confidence in the information from the manufacturers' data sheet. This is despite of known differences in datasheet information and laboratory measurements. In the data sheet, there must be references to the standard methods and norms used in testing the material. Sedimentation rate is a useful parameter in describing the physical properties of a material. However, it is normally too time-consuming to carry out at the worksite. Viscosity tested by marsh funnel and density are two parameters that relatively rapid and can easily be tested on-site.

Only Germany appears to have a procedure in case of fluid loss during grouting. If the injected amount is twice or more of the calculated amount, the work must stop, and the authorities must be informed. Gravel, sand or grout of a higher density or a packer may help solve the problem. It is imperative that the drilling contractor be prepared to address situations with loss of fluid and have the appropriate equipment, material and experience to remedy the problem.

Geophysical measurements during and after grouting are generally used if there is a suspicion that something is wrong with the grouting/sealing. A short thermal response test (TRT) and temperature logs may give some useful indications about the grout sealing. When using a short TRT to identify grouting problems it is necessary to measure an undisturbed temperature log before the TRT. After the termination of the TRT another temperature log should be measured. Gamma-gamma logs can also be used to give information about the consistency of the grout plug. If the grout in question has been enhanced with magnetite, it is possible to get an indication about loss of suspension. Magnetite enhanced materials allow for an automated controlled backfilling process and subsequent measurement and controlling of the BHE. Such an automatic grouting control is required in some areas of Germany.

There are no general requirements regarding the curing time of grout. However, experimental investigation in Germany indicates that a curing time of one month before the grout is subject to low temperatures greatly reduces the risk of exfoliation of the grout.

Borehole Heat Exchangers

The procedure to install the BHE-pipes is typically to put the single or double U pipe on a reel, either motorized or suspended from the drilling rig, connect weights to the U-bend and fill the pipe with fluid. The necessary counterweight needs to be calculated. The weights and the fluid reduce the buoyancy in the mud- or water-filled boreholes. If the BHE is pre-filled with antifreeze mixture instead of water, this will omit the process of replacing the water with antifreeze but may cause complications if the BHE has leaks causing spillage or contains dirt. Spacers and centralizers are often specified in projects but in practice these devices often cause installation

issues that outweigh any perceived or promised performance advantages. During the installation care must be taken not to damage the pipes in the process.

Pressure tests or leakage tests are always required, but often there is no consistent procedure for the test. The duration of the test, the number of tests and the test pressure varies. The results of the tests are sometimes less reliable. Significant leakage (order of magnitude in liters per hour) can be detected easily while small leaks such as “pinholes” *may* go undetected. Flow testing may indicate installation errors and provide a means to double check head loss calculations for circulation pump sizing. It is recommended to carry out a flow test and compare the results with the expected values.

Generally, there is a requirement for electrofusion welding of the horizontal connection pipes. This must be carried out by certified PE-welders. Threaded joints are generally not allowed to be covered with soil. Metal joints are in some countries not allowed underground and generally should be avoided due to corrosion risk. The pipes must be placed in a bed of sand without stones or sharp particles. A marker tape above the pipes may reduce the risk of damage from future excavation activities.

Test protocols and documentation can provide valuable information if future problems are encountered or when system modifications are planned. Generally, these test procedures apply to larger systems and the terms and conditions will normally be specified in the construction contract. For smaller systems, it is necessary to document/test at least the following:

- Borehole position, dimension and depth
- Planned deviation of the borehole
- BHE length, dimension, type, pressure class
- Filling material and/or sealing material type, amount and position
- Result of pressure / leakage test
- Heat carrier fluid - type and concentration
- Result of flow test
- Flowrate, duration and result of de-aeration process
- Type / method of connection to horizontal pipes
- Position of the horizontal pipes
- Type, dimensions, equipment and position of manifold, if present

In Germany, the test protocol for horizontal pipes and BHE is carried out according to VDI 4640. All other participating countries rely on tender-specific requirements on larger systems. A visual inspection should be carried out and documented with photos before back filling of trenches. A gradient on the horizontal pipes will facilitate air bleed. Flowrates for purging should be noted.

Start-Up

It is recommended to carry out a proper check of function and performance of the system at commissioning. A follow up check on function and performance after 5 years is suggested.

For commissioning, there is a general reference to the normal conditions for deliveries. Check lists are primarily for mechanical components, refrigerants and antifreeze levels.

It is recommended that the building owner receive instructions that provides, at a minimum, a basic procedure of how to operate the system.

Sweden, Germany and The Netherlands have comparable and high levels of documentation and instructions that are handed over to the building owner / operator. The main elements are:

- Documentation for planning approval
- Description of system with as – built drawings
- Sequence of operation for the functioning of the system
- Description, manufacture specifications and datasheets for main system components
- Protocols for self-control
- Instruction for maintenance and operation
- Efficiency calculation and EIA is mandatory in some countries

Supervision of the Construction Process

For larger projects, it is generally the norm to have a consultant that is independent of the drilling company to provide oversight of the construction process. There are no definitive standards concerning oversight protocols, however, Sweden and Germany have somewhat more regulated procedures. Turnkey contracts will typically have different conditions from trade or general contracts - e. g. supervision by the consultant is much reduced or non-existing. Some level of supervision during the construction process is recommended. The extent of supervision is related to the size of the project and the type of contract.

Subtask 3 Operation Phase

Supervision of Operation

Monitoring of GSHP and BTES system performance is important to confirm that the installed GSHP/BTES system meets the intended design criteria, to provide fault-detection possibilities and to support improvement and optimization of design and system control. Feedback provided by the performance monitoring is of use to building owners and management staff as well as to designers and component manufacturers.

The monitoring of BHE and GSHP systems offers the following information:

- Management, reliability, and fault-detection of BHEs and GSHP systems
- Energy performance of the BHEs and the GSHP systems
- Influence on ambient underground environment and groundwater

There are two main procedures for data acquisition: manual meter reading and automatized data acquisition. Monitoring of small size GSHP systems can be carried out easily and economically via manual meter reading on a regular basis, at least monthly. For large sized GSHP systems, an automated data acquisition procedure should be employed.

Suggested parameters for monitoring in the BHE circuit in small systems are fluid temperatures, pressure, and flow rates. Error messages displayed on the heat pump are also important. In large systems, additional parameters for monitoring and evaluation of the system efficiency are recommended and an automated data acquisition system is required. In addition to system management, monitoring capabilities allow for performance analysis including the influence on the underground environment and groundwater and may be required in gaining approval for the project. Underground temperatures and underground system inlet and outlet fluid temperatures can provide valuable information for analysis and adjusting system performance parameters.

The GSHP system with BHEs require very little maintenance. However, in order to maintain operational reliability of the GSHP system the following data should be monitored and checked:

- Minimum and maximum inlet temperatures of the BHE
- Pressure drop over time in the ground loop
- Error messages of the GSHP

The -BHE minimum and maximum temperatures can be assumed to correspond to the discharge temperatures of the brine exiting the heat pump (evaporator or condenser) or exiting the heat exchanger for direct geothermal cooling. These data can be picked up from most heat pumps. Furthermore, it is worthwhile monitoring the current amount of heat extracted/injected from/into the ground, especially if a change in use of the building occurs. If the amount exceeds the design conditions, measures have to be taken to avoid too low or too high subsurface temperatures. For reliability purposes, a supervisory control of the BHE and heat pump system is recommended, with an emphasis on the temperatures and the pressures of the ground loop.

The energy performance of a GSHP system is decisively determined by the efficiency of the heat pump. Therefore, the system boundary for the energy performance calculation must include the geothermal loop and the heat pump including an electrical backup heater and allows a neutral comparison with other heating systems. Detailed analyses of the energy performance during operation crossing this boundary usually requires extra expenses for metrology. Therefore, this is only recommended for large size or costly (in purchase and/or operation) systems.

The influence of BHEs on the underground environment and groundwater can be estimated by monitoring the discharge temperatures of the evaporator (in heating mode), the condenser (in mechanical cooling mode) or the heat exchanger for direct geothermal cooling (in direct geothermal cooling mode). If more in – depth analysis is required, further investments may be necessary, e.g. additional monitoring borehole(s) to control groundwater level, regular sampling regime etc. Therefore, it is strongly recommended to monitor temperatures into the BHEs at the initial stages of the project. If the temperatures drop or rise beyond design parameters, additional measures should be implemented. If there are no contractual prerequisites for detailed supervision and monitoring of the underground environment and groundwater, it is recommended, at a minimum, to employ a supervisory control system to monitor the temperatures of the BHEs.

Monitoring

Monitoring in small systems has to be reduced to an absolute minimum for economic reasons. The minimum amount of monitoring points and their management for small size GSHP systems is the fluid inlet and outlet temperatures of the BHE and system flowrate. Simple heat meters provide all three data points in conjunction with manual data reading. In some cases, these data are available from the heat pump control unit and can be recorded manually on a regular basis.

Large systems typically have much more sophisticated control systems or full building automation system (BAS) control system. A BAS is intelligent of both hardware and software, connecting heating, venting and air conditioning (HVAC), lighting, security, and other systems to communicate on a single platform. These system allows for more sensors and data acquisition and storage. In most cases, automatic data acquisition and evaluation, with access to historical data is possible or can be implemented into the software without significant additional costs. In addition to fluid temperatures and flowrates in the BHE circuit, the electricity consumption of the circulation pump(s) should be measured.

Evaluation

Often, simple graphical display of temperatures, flowrate or heat extraction rate over time gives a good indication of the agreement between planning and operation. In addition, unexpected variations can be seen in such graphs and identified for further evaluation and interpretation.

For performance indication, COP and SPF can be used. While COP only relates to the heat pump, SPF-values can be calculated for different system boundaries, which have to be specified. In addition, energy savings and reduction of CO_2 emission in comparison with conventional fossil-fueled boilers are interesting as performance indicator.

New Technologies Related to Monitoring

Recently, the monitoring systems or services with internet for small size systems are gradually becoming available. Some heat pump manufacturers provide such services and the end - user has access to data via internet and can obtain an overview of the present status of their system. Data can sometimes also be exported for further evaluation. Some innovative companies are providing smartphone applications that display system performance parameters and remote heat pump control.

Subtask 4 Problems, Failures, Investigation and Solution

Firstly, it must be emphasized that in the vast majority of cases there are very few problems with BHEs in GSHPs and BTES systems. The fraction of systems with problems compared to the total number of installations is extremely small. Nevertheless, occasional problems have occurred resulting in some serious impacts. Thus, proper quality management of GSHPs and BTES systems must consider such prior failures and provide mitigating measures to avoid repeating mistakes.

In general, the problems with BHEs can result from various activities carried out during project execution. The cause may originate from the local geological and hydrogeological parameters not being understood or considered fully resulting in inappropriate installation methodology. In addition, technical causes and lack of technical skills may cause problems due to mistakes in the design and the construction itself. To avoid such problems, both require well-educated and experienced consultants for design, as well as highly qualified drillers and installers in the construction phase. Also local authorities responsible for the permit, which typically have excellent knowledge of the geology and hydrogeology in their area, must consider the local situation during the approval process.

There are hydrogeological risk potentials including multi - aquifer and layered systems, artesian groundwater flows as well as differences in pressure potential of groundwater layers. There are geological risk potentials such as solution phenomena/pathways through perturbation systems, e.g. in the case of carbonate, sulphate or salt rocks; flow movements e.g. flowing sands; mineral alterations/swelling (anhydrite/gypsum, clay minerals); outgazing. Geotechnical risks, which include cavities, landfills and contaminated sites are other considerations.

Drilling into an artesian aquifer results in a rise of the groundwater level up to the surface. Such uncontrolled flow and pressure loss may result from the use of improper drilling techniques or equipment selection. If, in special cases, the lower aquifer is leaking into a shallower aquifer, this situation may not be immediately recognized and thus is one of the main risks. In general, penetrating sealing layers (aquitards) requires extra care and attention and can result in leakage of one aquifer into another if not sealed properly. Unexpected chemical characteristics and hydraulic conditions can result in changes of water quality and increase or decrease of water level, which may affect foundation conditions such as unforeseen settlement. When drilling into geological layers that are rich in organic matter or in volcanic areas, gas (e.g. CO_2, CH_4, etc.) can occur, which requires appropriate technical measures to avoid problems.

Design Mistakes

In all design and construction, groundwater protection is a high priority and any degradation in quality due to:

- introduction of pollutants from the surface,
- leakages of the heat transfer fluid,
- mixing of water of different quality,

that changes the biological composition of the ground water must be avoided.

Additionally, there are technical and anthropogenic risks due to design and construction phase errors. All of the geological, hydrogeological and anthropogenic risks potentials mentioned above can overlap.

Under-sizing of the BHE field leads not only to insufficient heating power and too high heating costs, but also to failures in the overall system. Unexpected costly repairs/replacements of components may be necessary. In water-filled boreholes, as is common in some Scandinavian countries, this can result in freezing of the borehole and the BHE pipes can be damaged by buckling due to the external pressure. This effect can also occur when boreholes are too closely spaced. There are also examples of frost heaving damage due to freezing around horizontal pipes, and also possibly at borehole connections points and casing.

Potential solutions are additional boreholes, additional heat source for regeneration of the borehole, additional heating system and shut down of the ground source borefield at critical times. The same situation can occur during retrofit projects when an old heat pump equipment is replaced by a newer unit with higher efficiencies.

Conversely, oversizing is typically not problematic for the operation of the system, apart from the capital expenditure being higher than necessary.

Inaccurate load estimations may occur due to changes in user behavior or climate changes compared to the assumptions made in the design process. Building loads may be over-estimated due to a conservative estimate done by the HVAC engineer. As a result, the system is over- or undersized. Solutions mentioned above can then be applied.

Misunderstanding of the geology, underground temperature and ground thermal conductivity may result from mistakes in interpretation of data extracted from a geological database. In large BHE fields, the geology may vary within the BHE field, or incorrect measurements were obtained from a TRT resulting in incorrect determination of the thermal properties. Geological expertise is required in planning of such systems to be able to verify the data. The result is again that of an over- or undersized system. Sufficient test drillings adapted to the size of the BHE field and depth oriented geological TRT measurements and evaluation may help to prevent such problems.

Construction Mistakes

A revision of the design by the construction companies and engineer is important for fast reaction in case of any problems encountered during construction. The drilling method may not work as planned in design phase (depth, diameter, etc.). This can be solved by a re-design according to new information by the driller. Problems during construction may include:

- planned final borehole depth not reached - additional boreholes must then be drilled,
- Installation depth of loop less than borehole depth - consider lower BHE length by re-design,

- Connection of boreholes during drilling - there are ways to avoid this occurring, but that is a planning issue,
- Pipe leakage - this occurs occasionally, mostly due to improperly welded connections between the BHE and the horizontal pipe system and is typically observed during pressure testing prior to refilling of the shaft,
- Pipe clogging - in most cases an additional borehole is required,
- Pipe collapsing - in most cases an additional borehole is required,
- Air purging - this is an essential issue performed after filling the system with brine; ventilation valves are common on high points in the system; to avoid problems with air (oxygen diffusion included), larger systems are often equipped with vacuum air purging,
- Poor documentation while drilling – in many countries it is obligatory to report all boreholes to the geological survey,
- Other geological and hydrogeological conditions than those expected - change drilling and construction method and re-design.

Potential problems while drilling are numerous and cannot be discussed in detail here. In general, a well-educated, experienced and skilled operator of the drilling rig is required who can react to problems with appropriate tools, materials and equipment. Therefore, thorough planning and a good understanding of the geology of the location is essential. Often site-specific solutions are needed. It is necessary to keep good contact with the authorities when it comes to problems regarding drilling and unforeseen geology.

While installing the BHE loop problems may occur such as:

- U-tube did not reach the scheduled depth - take out the U-tube and drill again
- Damage of U-tube due to bending - take out the U-tube, drill again if necessary and insert a new U-tube
- Lack of sufficient weight - take out the U-tube and increase the weight
- Descent of tube after withdrawal of the casing - secure the tube at the top of the borehole or deficient grouting
- Water leakage after inserting U-tube - take out the U-tube, drill again and insert a new U-tube
- Installation without reel should be avoided.

In many countries, proper sealing of boreholes by grouting is an important requirement. Therefore, the grouting process must be carried out thoroughly, especially when an aquitard is penetrated while drilling. Special focus needs to be put on the grouting material and the methods and equipment used for mixing. The mixing equipment used has to be appropriate for the material and the water/grout ratio must be kept exact. Some grout properties like density or marsh time can easily be determined at the site to verify correct mixing. Settlement is a potential risk for improper grouting in areas of high geological risks like connection of aquifers with different pressure or water quality or high differences in water temperature or connection of anhydrite layer to aquifer. Special focus must be put on thorough grouting. Magnetite enhanced grouting material allows for check of grouting quality of the entire borehole.

Issues While Operation

During operation of a plant, typically no major problems occur. In some rare cases, changes in the usage of a building may modify the heating and/or cooling load and thus show the same symptoms as an undersized or oversized system. The solutions are the same as previously described.

In GSHP systems, the replacement of a heat pump with one that has higher efficiency has an impact on the energy balance. The extracted/injected heat from the underground is increased while the borehole field size remains static. For compensation, additional boreholes can be drilled, or the ground load can be decreased by adding supplementary heating or cooling sources.

Prevention of Damage and Failure

The recommendations given for the design and the construction, as well as the operation will help to prevent damage and failure. Nevertheless, well trained and experienced engineers /designers and contractors / drillers are essential to avoid problems. Approval authorities have the responsibility to investigate risks and to approve projects in a well-balanced manner of required restrictions and tolerable impact on the underground. Good standards provide best practices and should be accepted by all players.

Environmental Assessment

In some countries, a more thorough environmental assessment is required which studies the influences of construction work and later system operation on the underground, especially on the groundwater, focusing on temperature changes. In addition, the above-mentioned geological and hydrogeological impacts should be included.

Introduction

On a mid- and long-term perspective, the total energy consumption worldwide will need be satisfied completely by renewable energies. The available renewable forms are solar energy (solar radiation and its secondary forms like wind, biomass etc.), which can be converted into electricity or thermal energy, and geothermal energy extracted from the underground, which can be used directly in the form of low temperature heat. Geothermal energy at high temperature level can be converted to electricity. Additionally, the heat capacity of the underground can be used for thermal storage. Use of tidal power plants are very limited to certain spots around the world.

The thermal use of the underground is an important technology to increase energy efficiency for heating and cooling in domestic and commercial applications. In some countries, the market for underground thermal energy storage (UTES) for heating and cooling, and especially for ground source heat pumps (GSHP) has grown rapidly over the last years. Depending on the local geological situation, different technologies are applied. Besides aquifer-based systems like aquifer thermal energy storage (ATES) or groundwater heat pumps, systems with borehole heat exchangers (BHEs) like borehole thermal energy storage (BTES) or heat pumps with BHEs are the most popular applications. They cover a wide range from family homes to large commercial buildings for heating, cooling, combined heating and cooling, as well as very large BTES for seasonal storage of heat (e.g. in solar district heating systems, cogeneration, etc.). As a consequence, such growing markets require special effort in quality management to achieve well running systems without harmful effect to the underground environment.

Objectives of Annex 27

The overall objectives of Annex 27 are to secure good quality practices and avoid mistakes and failures related to the borehole system in design, construction, and operation. Information and knowledge collected should serve as a basis for national and international standards and guidelines. Additionally, the compiled experiences of the international experts' group will be a valuable contribution for education of consultants, drillers, installers, and operational staff.

These objectives, when fully implemented, will make GSHPs with BHEs and BTES technically safer, more cost efficient and will promote the future wide – spread use of this technology. Consequently, the knowledge and confidence of the regulatory bodies in this technology should be reinforced to avoid ineffective restrictions resulting in increasing costs.

The specific objectives are:

- Collect and compile national standards and guidelines for BTES/BHE for heating and cooling
- Analyze national design procedures and construction methods
- Identify and investigate problems of the design and construction phases
- Work out handbooks and guidelines for design and construction in order to avoid future mistakes
- Investigate operational failures
- Work out preventative guidelines for monitoring, maintenance, and rehabilitation measures
- Identify related problems in order to establish further R&D

Additionally, the intensive collaboration with CEN/TC 451 WG 2 on "borehole heat exchangers" and the contribution of Annex 27 became an important outcome of Annex 27. The new standard will be launched in 2020.

Scope of Annex 27

The scope of this Annex includes quality management issues of borehole heat exchangers for ground source heat pumps and BTES in all project phases ranging from design to construction to operation.

Annex 27 is organized in four subtasks covering the major project phases:

Subtask 1
Design Phase
Leader: Sweden

Subtask 2
Construction Phase
Leader: Denmark

Subtask 3
Operation Phase
Leader: Japan

Subtask 4
Problems, failures, investigation, solution and environmental assessment
Leader: Germany

The major content of the four subtasks is determined by typical activities in the different project phases.

1. Design phase
   - Energy concept
   - Pre-feasibility
   - Feasibility
   - Detailed planning
   - Approval procedure
   - Call for tenders
2. Construction phase
   - Site preparation
   - Drilling methods
   - Borehole heat exchangers
   - Grouting
   - Final test-methods
   - Start-up
3. Operation
   - Supervision and monitoring of operation
   - Maintenance
4. Problems, failures, investigation and solution and environmental assessment
   - Common problems with BHEs and BTES
   - Problems resulting from poor grouting
   - Problems deriving from modification of design parameters
   - Description of methods - how to avoid and how to solve these problems – remediation

Work Approach

To get the most complete overview on the techniques applied to the situation in the participating countries, local experts were enlisted to complete common questionnaires for each subtask developed by the Annex 27 team. The answers of these questionnaires were compiled and discussed in detail in the semi-annual expert's meetings. Together with detailed information from a series of presentations about practical experiences and results from current research projects in different countries the results of the questionnaires are compiled to subtask reports.

This final report is based on the four subtask reports provided by the subtask leaders from Sweden (Signhild Gehlin and Olof Andersson), Denmark (Henrik Bjorn), Japan (Katsunori Nagano and Takao Katsura) and Germany (Manfred Reuss) by compiling the contributions of the experts from all participating countries - Belgium, Canada, China, Denmark, Finland, Germany, Japan, South Korea, Sweden, The Netherlands and Turkey.

Legislation

The general objective of all legislation is to protect the groundwater and the underground environment by preventing any harmful change. The significant differences in geological situations require an approach adapted to the actual site geology as it is evident that regulatory entities rely on priori that do not necessarily coincide with the geological and hydrogeological situations.

The level of legislation on construction of borehole heat exchangers is known to vary considerably between countries. Rules and regulations may also vary within a specific country (e.g. Germany and Belgium) depending on the region. Furthermore, there may be variations in the legislation depending on the size of the borehole heat exchanger system. These differences are partly due to geological situation but partly also due to the emphasis that each country places on intrusions into the underground e.g. the sheer number of systems in a given location.

The various laws, acts, codes, standards, norms, guidelines, protocols, rules, and regulations primarily focus on avoiding negative environmental effects from the construction and operation of the borehole. Information on how to construct and operate is much scarcer.

The legal enforcement is by law and a permit is given by the local environmental agency. In most countries permits will normally not need to be renewed, but nevertheless in some countries the permit is limited in time.

As ground source heating is a "new" technology compared to boreholes for drinking water and mining, it is common to see BHEs as an addition to or as an implicit part to existing rules.

Even though there are differences in scope and volume of the legislation, there are also a few important common denominators.

The various acts express a general concern about potential negative effects on the quality of the groundwater.

In countries where groundwater supplies a large part of the drinking water, the rules concerning sealing of the borehole are generally stricter and more comprehensive than in countries with less focus on the groundwater.

Environmental protection is also a point of general agreement that applies to most countries. The BHE must not cause a negative effect in terms of temperature or contaminants. Nor is it allowed to create a situation where the BHE increase the possibility for groundwater to move in or along the borehole and enter a different aquifer or a formerly dry formation or to transport and spread contaminants from the surface to deeper levels. It is also very important to avoid damages to buildings next to the BHE. Damages can be caused by swelling materials (such as anhydrite) or by subsidence. An overview of the legislative conditions can be seen in ***Table A2-1*** in the appendix.

Summed up, the legislation on BHEs focuses on avoiding adverse effects on groundwater and the environment in general. Adverse effect is generally loosely defined and how to avoid it is almost not addressed.

Glossary

This glossary defines some specific terms used in the Final Report.

Aquifer thermal energy storage (ATES)

This storage system uses the water in aquifers to store thermal energy. Extracted ground water can be used ether for heating (often in combination with a heat pump) or cooling. After the transmission of heat the water is reinjected into the aquifer. This technology is especially appropriate for a seasonal storage.

Borehole Heat Exchanger (BHE)

In this report it is used for the vertical loop in the borehole, normally consisting of a single or double plastic U-pipe. As a comment, the definition of BHE differs between countries. The reader should bear in mind that BHE can also be used to describe the total system borehole construction, including the borehole, the backfilling and the U-pipe.

Borehole Heat Exchanger Field (BHEF)

An area with several BHEs systems that are either connected or not in the same hydraulic circulation system.

Borehole Thermal Energy Storage (BTES)

BTES are used for a closed loop system with a number of vertical boreholes to actively store thermal energy (heat and/or cold) in the underground, most common seasonally. Often heat pumps are used for the extraction of heat.

Coefficient of Performance (COP)

The COP of a heat pump or refrigerator is the ratio of provided heating or cooling to work required. Higher COPs equate to lower operating costs. The COP of a heat pump often is in the range of 3 – 4.

Designer / Engineer / Contractor

Large projects with detailed planning based e.g. on system simulation are typically designed by engineers while small projects (family homes) are often carried out with planning based on experiences from similar projects in the same area carried out by a designer who is well trained but not necessarily has a higher education like an engineer.

The contractor is often a drilling company with an additional team specialized on pipe work. In large projects sometimes specialized companies were subcontracted.

Direct (geothermal) cooling systems

Direct (geothermal) cooling systems are systems, which use the underground directly as a heat sink for cooling without assistance of a heat pump/cooling machine.

Distributed Thermal Response Test (DTRT)

This advanced TRT uses optic fibers or other equipment such as wireless or submersible sensors, to measure temperature along the borehole depth. Such alternatives are available in a few countries but are yet rarely used.

Down the Hole Hammer (DTH)

Form of hammer drilling that uses a mini jackhammer screwed on the bottom of a drill string

Energy Conservation through Energy Storage (ECES)

In the future, most sustainable energy infrastructure energy (electrical and heat) storages will play an important role by dealing with periods of energy over and under production. As electricity cannot simply be stored directly, the energy is converted into another more storable form of energy. The IEA's ECES program facilitates integral research, development, implementation and integration of energy storage technologies.

Earth Energy Designer (EED)

EED is a PC-program for vertical borehole heat exchanger design and often use for planning GSHP and BTES.

Enhanced Geothermal Response Test (EGRT)

Synonym for DTRT

Geothermal Response Test (GRT)

Synonym for TRT

Ground Source Heat Pump (GSHP)

GSHP systems are closed loop systems with a vertical borehole as a heat source for a heat pump. They are designed to extract or inject thermal energy (heat or cold) from or to the underground that recovers in a passive way. The number of boreholes and heat pumps varies depending on the size of application.

High Temperature Borehole Thermal Energy Storage (HT-BTES)

HT-BTES systems are designed with the purpose to actively store **heat at high temperatures** in the underground, most commonly seasonally.

International Energy Agency (IEA)

IEA is an autonomous intergovernmental organization acting as a policy adviser and promoter of alternative energies.

Minimum Required Strength (MRS)

According to ISO 9080 the minimum required strength (MRS) at 20 °C and 50 years for a pipe with SDR 11 is 10 MPa for PE100 and 8 MPa for PE80 giving the design stress 8 MPa and 6.3 MPa, respectively and safety factor 1.25.

Polyethylene (PE)

Type of plastic

Polyethylene with cross-linked structure (PEX)

PE with a certain molecular structure

Polyethylene that can stand higher temperatures (PE RT)

Polypropylene (PP)

Type of plastic

Seasonal Coefficient of Performance (SCOP)

Annual average COP

Seasonal Performance Factor (SPF)

Synonym for SCOP

Technical Collaboration Platform (TCP)

The TCP of IEA supports the work of independent, international groups that investigate energy technologies and related issues.

Thermal Response Test (TRT)

A TRT is used to determine the thermal properties of the ground, which is vital for designing GSHP and BTES. Water circulates in a system consisting of a BHE inside a borehole and a heater or chiller. While heating or cooling with constant power the inlet and outlet temperature is measured.

1. Subtask 1: Design Phase

1.1. Preface

This report is a subtask report within International Energy Agency (IEA) Technical Collaboration Platform (TCP) Energy Conservation through Energy Storage (ECES) Annex 27 - *Quality Management in Design, Construction and Operation of Borehole Systems.* The publication is the final report for IEA ECES Annex 27 Subtask 1: Design Phase and is based on a survey on design phase considerations, answered by the 11 countries participating in the Annex.

Contributing countries: Belgium, Canada, China, Denmark, Finland, Germany, Japan, Korea, Netherlands, Sweden, Turkey

Information provided by: Wim Boydens (Belgium), Ywan De Jonghe (Belgium), Luc François (Belgium), Mathias Possemiers (Belgium) and Bertrand Waucquez (Belgium), Mark Metzner (Canada), Yang Lingyan (China), Henrik Bjørn (Denmark), Teppo Arola (Finland), Asmo Huusko (Finland), Mathieu Riegger (Germany), Roman Zorn (Germany), Hagen Steger (Germany), Claus Heske (Germany) Adinda Van de Ven (Germany), Roland Koenigsdorff (Germany), Manfred Reuß (Germany), Hanne Karrer (Germany), Takao Katsura (Japan), Kil Nam Paek (Korea), Henk Witte (Netherlands), Signhild Gehlin (Sweden), Olof Andersson (Sweden), Adib Kalantar (Sweden), Yusuf Kagan Kadioglu (Turkey), Birol Kilkis (Turkey), Aysegül Cetin (Turkey), Suheyla Cetin (Turkey), Mert Oktay (Turkey), Ersin Girbalar (Turkey).

Authors: Signhild Gehlin, Swedish Geoenergy Center, and Olof Andersson, Geostrata. September 2018

1.2. Subtask Scope and Limitations

This IEA ECES Annex 27 subtask report covers the design phase for any closed loop borehole system used for extraction and storage of thermal energy in the underground by the use of borehole heat exchangers (BHE).

From a system point of view, the subtask covers any BHE-system, regardless the size of application and the working temperatures used in the systems. The technical boundary is defined as the loop in which the heat carrier (fluid) is circulated.

The design phase typically starts with feasibility studies (preferably in two steps) and ends up with a detailed design and call for bids (tender).

The design of a BHE-system is dependent on a number of parameters, of which some are connected to the use that the system serves (typically a residential or commercial/institutional building). Another set of parameters is related to surface and underground conditions.

Depending on type of system there are also parameters linked to configuration of boreholes and energy balance. In practice there is a range of operation modes that must be considered in the design. For this reason, it is of importance to use commonly applied system definitions.

This working paper is based on answers from a questionnaire that was sent to the 11 participating countries and on discussions at the experts' meetings in Lund (EM2) and Espoo (EM3). The answers of the questionnaire are attached as tables, one for each item.

The final goal with Subtask 1 is to provide recommendations for best practice design, independent of country.

1.3. System Concepts and Definitions

The design varies with respect to borehole depth, distance between boreholes, brine working temperatures and mode of operation depending on the intended type of system. The discussions at the beginning of the Annex stated that all systems that use boreholes for exchange of heat and/or cold should be considered here. The different systems as defined within this Annex are GSHP (Ground Source Heat Pump), BTES (Borehole Thermal Energy Storage), HT-BTES (High Temperature Borehole Thermal Energy Storage) and Direct (geothermal) cooling systems. The different system definitions and other terminology used in this report are explained in the ***Glossary***.

The majority of the participating countries share these definitions, while a few do not and others may not be familiar with the terminology, see ***Table A1-1***: How are BTES and GSHP systems defined?. In countries with existing guidelines, the definitions are of a more general character (Germany and Netherlands). Regarding HT-BTES there is yet no temperature definition established.

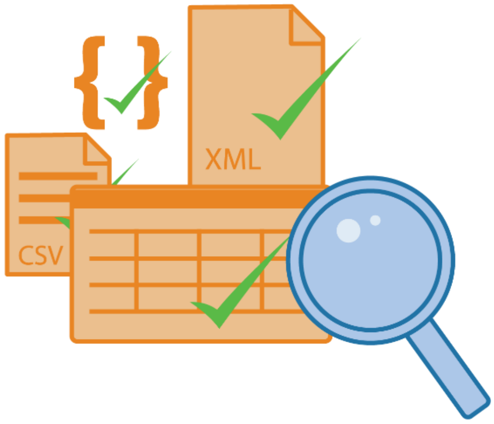
It is recommended that the definitions from this report should be used in order to establish a common terminology for different systems in order to link this Annex back to the former ones and existing guidelines.

1.4. Design Approach

1.4.1. Parameters and Tools

The design parameters are generally the same in all countries, but the tools used for design vary. Often experience, tables or simplified design algorithms are used for smaller systems, and calculation software and simulation models for larger projects.

Examples of tools used for design of BTES and larger GSHP systems are design tools, such as: EED, GLHEPRO, GEO-HAND^{light}, GEOSYST, GLD, EWS, GAIA, and simulation tools, such as: FEFLOW, DST, SBM and SMP. General building and plant simulation software suites like TRNSYS and IDA-ICE integrate complex building and plant models which include models of heat pumps, chillers, BTES and other geothermal systems, but their focus is on the overall system rather than on the geothermal plant. While design tools are user-friendly, fast and can be used to quickly model many design variations, advanced simulation tools are slower but allow for higher degrees of complexity and more detailed simulation.



Design parameters and models for simulation used in different countries are shown in ***Table A1-2***: What are the main design parameters and tools used for design?.

It is recommended that design tools are used in the feasibility stage of projects larger than single boreholes and that other, more sophisticated simulation tools be considered in the detailed design phase, especially for more complex systems. It is also recommended to consider existing or planned new ATES, GSHP and BTES systems in the neighborhood.

1.4.2. Heat and Cold Sources

The heat source for a pure extraction system is the solar and geothermal heat stored naturally in the ground. Typical heat and cold sources for storage in BTES systems would be waste heat from cooling systems and waste cold from the evaporators of heat pumps.

However, heat from solar collectors and waste heat from industrial processes (cogeneration included) are regarded as sources. The latter ones would be for high temperature storage (HT-BTES). As special cases, solar heat from asphalt surfaces and heat from sewers are applied, see ***Table A1-3***: What are common heat sources for storage (BTES)?***.***

Figure 1-1: Solar thermal collector

There are a number of other heat sources used in BTES systems, mainly for seasonal storage. The most common ones are outdoor air (condenser coolers and cooling towers), warm surface water (dams, lakes and streams), waste heat from centralized ventilation systems and excess heat from solar collectors, see ***Table A1-4***: What other heat sources are applied?***.***

Except for heat pump evaporators, cold surface water and cold air are the most common cold sources, but also snow and ice melting are used in some countries. Gas expansion in industrial processes may be another but rare application, see ***Table A1-5***: What sources for storage of cold are applied?***.***

It is recommended that available different sources of cold and heat shall be considered and studied in an early stage of any BTES applications.

1.4.3. Load Characteristics

Heat and cooling loads

Many GSHP systems and BTES systems for older or large buildings especially in colder climatic regions would typically not cover the maximum heat load. Commonly these systems are designed to cover 60 - 80% of the heat load, see ***Table A1-6***: What are the heat and cold load coverages assumed in BTES and GSHP design?***.*** The reason is that 100% load coverage in many cases would require unfeasibly large number of boreholes as well as an unfavorable size of heat pump.

In BTES systems the base cooling load would typically be covered by direct (geothermal) cooling from the storage, while the peak load is covered by the heat pump. In some designs the heat pump is working as a chiller and all cooling is produced this way. The condenser heat is then stored in the BTES and recovered during the following heating season.

New buildings, constructed according to recent building codes, are better insulated and more energy efficient. Such buildings have lower maximum loads and less pronounced peak loads. The temperature level for heating is then lower, and for cooling higher. Consequently, there may be designs that cover 100% of both heating and cooling loads. One difficulty in these designs is how to deal with the production of domestic hot water (DHW) at + 60°C. DHW production tends to make up for an increasing percentage of the total heat consumption in such buildings, especially within the residential sector.

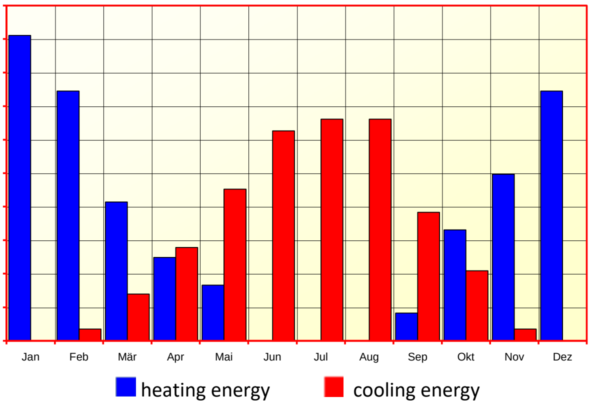


Figure 1-2: Typical heating and cooling load

It is recommended to identify the maximum heating and cooling loads, the heating and cooling temperature programs and the expected usage of domestic hot water in the early stages of the project.

Peak heat load shaving

The peak load for heating (40 – 20 %) is frequently covered by fuels that are normally used for heating in the respective countries (natural gas, oil and coal). In some countries, district heating and electric boilers are used, see ***Table A1-7***: Which auxiliary heating sources are used at peak load?. Small GSHP system often use electric or gas peak load heating. The choice of peak load source is decided for economy reasons, e.g. in Germany gas or oil is used, as that provides the least expensive alternative.

Peak load shaving should not be confused with so-called bivalent systems or hybrid systems, where multiple energy solutions are combined to cover the base load.

If peak load heat is required, it is recommended to study different solutions and chose the site specific one that is most economically feasible/environmentally friendly from a long-term perspective.

Peak cooling load shaving

Normally the peak load for cooling is covered by operating the heat pump as a chiller. The excess heat is either disposed of by using condenser coolers or cooling towers or stored in the underground. An additional chiller may be necessary if the cooling load is considerably larger than the heat load. Also, accumulators (buffer tanks) may be an option for short peaks.

For residential buildings, peak cooling load shaving is of lower interest. Direct cooling from the underground provides a base load that is better and more feasible than no cooling at all, see ***Table A1-8***: Which auxiliary cooling sources are used at peak load?.

If peak load for cooling is required, it is recommended to study different solutions, buffer tanks included, based on cooling load duration.

1.4.4. Borehole Distance

The distance between boreholes depends mainly on geological conditions (i.e. the ground thermal properties), intended final drilling depth (deeper systems using larger distance between boreholes to prevent damage during drilling) and load characteristics. For BTES applications the calculated thermal balance of the system will also be an important factor. Commonly the optimal borehole distance ends up between 3 - 10 m for multi-borehole BTES systems. However, some countries have legislations stating more specific distances. In general, the distance between boreholes would be closer for high temperature storage (HT-BTES).

Figure 1-3: Thermally interacting boreholes - BTES

Figure 1-4: Independent boreholes - GSHPs

For independent boreholes (boreholes that do not significantly interact thermally) in systems for extraction of heat or cold only, a "safe" distance of 10-25 m seems to be applied in most countries (in some cases legislated), see ***Table A1-9*** What is a typical distance between two independent boreholes?, but the distance largely depends on the ground thermal properties, existence of groundwater, direction of groundwater flow and energy load profile. The distance is also of importance in order to not create a thermal impact on neighboring properties. In the Netherlands larger borehole spacing distances (sometimes 35-45 m) are required.

It is of great importance to differentiate between GSHP and BTES when it comes to distance between boreholes. It is recommended to use a simulation tool to forecast the long-term temperature development of the system including adjacent systems in the neighborhood.

1.4.5. Borehole Depth

Urban areas with limited or restricted space to place boreholes sometimes require deep boreholes. Also deviated (angled) boreholes are sometimes used. This is the case in Scandinavian counties with crystalline rock where boreholes down to 300-400 m are applied. Pressure drop and thermal short-cutting increases significantly with increasing depth and must be considered.

However, from a technical point of view 150-200 m seems to be a practical depth limit in most other countries with mostly sedimentary rock. As shown in ***Table A1-10***: How deep is a typical borehole? Are deviated boreholes used?, some countries have regulations for maximum borehole depth. Angled (deviated) boreholes are rarely used in these cases.

It is recommended to use site-specific geological conditions and country specific regulations for the determination of borehole depth.

1.4.6. Undisturbed Ground Temperature

The undisturbed ground temperature is an essential parameter that identifies the temperature conditions in the ground before any heat extraction or injection has been done. The ground temperature strongly affects the design of GSHP systems but will not be of the same importance for BTES systems, other than as a parameter for heat losses to the surrounding geology. The undisturbed ground temperature used for design denotes the average undisturbed ground temperature calculated over the total borehole depth.

The temperature at 10-15 meters depth typically reflects the average ambient annual temperature at the site. With increasing depth, the local geothermal gradient will add a slight temperature increase, see ***Table A1-11*** How does the underground temperature vary at different locations and depth?***.*** In urban areas, heat leakage from buildings, paved surfaces, power lines, underground tunnels etc. influences the temperature profile in the ground. This thermal influence may reach more than 100 meters below the ground surface, depending on the temperature and age of the buildings and other constructions at and below the ground surface.

In the feasibility stage of a project it is recommended to estimate the undisturbed ground temperature based on average air temperature over the year at the location. Corrections should be made with respect to the local geothermal gradient, and to account for influence of densely populated areas ("heat islands"). In later stages it is recommended to measure the temperature profile as a part of a thermal response test (TRT).

1.4.7. Heat Carrier Fluid

Use of anti-freeze

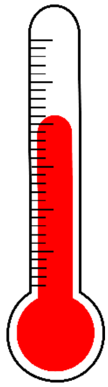
Antifreeze in the heat carrier fluid is used to allow for a working temperature below the freezing point of water.

For groundwater-filled boreholes in Scandinavia ethanol with a concentration up to 27-28% is used. This is also an option in some other countries, but for grouted boreholes most commonly glycols at a concentration up 30% seems to be used, see ***Table A1-12*** What types of antifreeze are used?***.***

The upper limit of ethanol mixture is 28%. Higher concentration will make it flammable. On the other hand, 28% will protect the fluid from freezing down to a point far below the lowest heat carrier fluid temperature, also considering freezing of the heat pump evaporator. The same is true for glycol at a concentration up to 35 %. In many cases these concentrations are significantly above what is needed and have a negative effect on fluid thermal and flow properties as well as pumping costs. In the Netherlands, higher concentrations are often used to act as a biocide (no bacterial growth), and it is strongly recommended to use pure products only, without additives (corrosion inhibitors, biocides, etc.).

It is recommended to use the country specific antifreeze, however, not at a higher concentration than necessary.

Heat carrier fluid temperature



Most applications seem to be designed for a few degrees below the freezing point as lowest and up to 30 - 35 °C degrees as highest. However, HT-BTES applications (heat storage) operate with temperatures up to 80°C, see ***Table A1-13***: What are typical working fluid temperatures in a BTES loop?**.**

It is recommended to choose material for BHE and connecting piping with regards to the temperature of the heat carrier fluid.

Freezing of boreholes

This item is mainly related to groundwater-filled (un-grouted) boreholes. However, in countries with grouted boreholes this may be an issue related to changes of the grout properties.

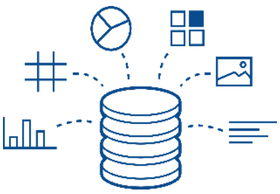
There seems to be a tendency to avoid freezing of grout in most countries due to potential damages to the grout sealing properties. This is reflected by national codes and regulations in China, Germany and Netherlands, see ***Table A1-14***: Is freezing of boreholes common and are there precautions taken to prevent damages?.

It is recommended to avoid freezing of groundwater-filled boreholes as well as grouted boreholes. If temperatures below the freezing point are used, a return fluid temperature from the heat pump to the borehole(s) of -3°C should be the lower limit.

1.5. Pre-feasibility Studies

This section relates to BTES and larger GSHP systems, where pre-feasibility studies may be a first phase in the feasibility stage. The results will normally serve as a point of decision for users to continue with the concept or to stop further development.

1.5.1. Scope



A pre-feasibility report will typically be a desktop study where the BTES or GSHP options are compared to other forms of heating and cooling, for example district heating/cooling or fossil fuel fired boilers. If the result from this initial study comes out favorably, the project may be further developed.

There seems to be consensus that a pre-feasibility report is a desktop study, see ***Table A1-15.***

It is recommended to start the development of larger BTES or GSHP projects by performing a desktop study based on information that is inexpensive and readily available.

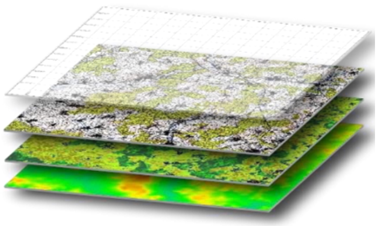
1.5.2. Lay-out and Content

Depending on the situation, the content and lay-out of a pre-feasibility report may vary. However, site plans, topographic maps, geological maps, hydrogeological maps, databases on existing wells and boreholes, energy load and temperature demands, predesign and economic calculations to compare with other energy systems are important issues to cover. As seen in ***Table A1-16***, there are slightly different views in different countries.

It is recommended to cover as much information as possible, especially on geo-conditions and energy load characteristics that may be easily found in databases.

1.5.3. Sources of Information

Geological maps



Geological maps are essential for prediction of the stratigraphy and properties of soil and rocks. Useful maps seem to be available in all countries in different scales - in some countries also borehole logs are available, see ***Table A1-17.***

It is recommended to always use geological maps as a first step to describe the local geological conditions.

Geological database

Data from existing wells and boreholes is very important for understanding the geology at any given site. Such information is more or less freely available in some countries, see ***Table A1-18.***

In countries that have free availability to geological databases, it is recommended to always use such information at the initial stage of any project. In countries that lack such information, geological expertise and local drilling contractors should be consulted.

Hydrogeological information

Hydrogeological conditions play an important role for any type of system application. The groundwater level defines the “thermally active borehole length” in groundwater-filled boreholes. Aquifers must be accounted for in all types of applications, as well as the natural groundwater flow.

Information on hydrogeological conditions can be found through hydrogeological maps and in different databases in most countries. Only a few countries have databases for existing energy boreholes, see ***Table A1-19.***

Since groundwater always plays an important role for any project it is recommended to search for information on aquifers and groundwater level(s) in a prefeasibility stage.

Underground obstacles and limitations

Restricted areas may make it difficult or even impossible to drill and install borehole heat exchangers. There could be a conflict with large underground infrastructure such as tunnels. There may also be mining areas and groundwater protection areas, see ***Table A1-20.***

To avoid damage to pipes (water, wastewater, gas, district heating grids etc.) and cables (power, IT, etc.) below ground surface prior to drilling the boreholes, these obstacles must be identified as early as possible in the feasibility stage. This may also be established later in a project development. In most of the countries, there appears to be free of change services to determine underground obstacles, see ***Table A1-24.***

It is recommended to always make a survey on underground piping and cables or other infrastructure installations beneath the surface before assigning a drill site, and to always check if a site for drilling is a restricted area.

Geotechnical conditions

There is always a certain risk for damages caused by the local geotechnical properties that may be addressed in the pre-feasibility stage. Some of these are identified in ***Table A1-21.*** In tectonic areas, such as in Turkey, special considerations must be taken. Geotechnical reports are often compiled prior to building construction. These may be found in building archives.

It is recommended to always perform a geotechnical risk analysis, mainly considering the occurrence of geological layers that may cause heaving or settlement.

Legal aspects

Legal aspects should be addressed at an early stage in any projects. As shown in ***Table A1-22***, in most countries the user of the system must own the property on which the site will be installed, or by easement use of another property. After completed installation, the system becomes a part of the property and may change ownership.

It is recommended to always check property borders as well as potential easement documents in order to place the planned drill site in accordance with legal conditions.

Environmental issues

In the pre-feasibility stage potential local environmental impacts must be considered. It is likewise important to address the environmental benefits as shown in ***Table A1-23.***

It is recommended to always perform a local environmental risk analysis at an early stage of any project and to value the global environmental benefits such as reduction of greenhouse gases. Accessibility for the drill rig should be checked. Check also for contaminated soil, as this affects how to deal with excess water from the drilling process.

Economic considerations

Customers often want to know about the economics of a system at an early stage. This means an estimate of investment, savings, and profitability. As shown in ***Table A1-25,*** this is the case in all countries.

It is recommended to make a rough estimate of the investment cost, energy savings and profitability at an early stage of the project.

1.6. Feasibility Phase

1.6.1. Scope

This phase should be a further development of the pre-feasibility phase including on-site tests (if necessary) and ends up with a more comprehensive report. Except for a few countries this seems to be common practice, see ***Table A1-26.***

Typically, one or several test-holes are drilled and documented and tested. Furthermore, detailed data (occasionally specially logged) on heat and/or cooling load characteristics as well as temperature profiles are obtained and used as basis for design. Environmental and legal aspects are also more thoroughly considered.

In Germany, the special edition of HOAI / AHO on “Services for the planning of shallow geothermal systems” specifies the services in the different project phases. The HOAI / AHO is a professional association of architects and engineers that represents their interest in business competition and remuneration. This special document has been available since 2011.

It is recommended to regard the feasibility study as a further development of the pre-feasibility study, mainly based on test-holes and detailed information on heat and/or cooling load characteristics.

1.6.2. Test-hole Drillings

Placement

There is consensus that test drillings should be placed close to or preferably inside the final borehole field to serve best. Exact location is defined by geological conditions and land availability and survey of underground obstacles, see ***Table A1-27.***

It is recommended to preferably place the test hole(s) inside the anticipated borehole field to be incorporated in the final system.

Permit for test drilling

Before the start of drilling, a permit may be needed.

As shown in ***Table A1-28*** practice varies. In some of the countries a permit is required, in others only information to authorities needs to be given, and in some countries, there is no permit requirement at all.

If a permit for test-hole drilling is required, it is recommended to have the permit before the drilling takes place.

Later use of test holes

As can be seen from ***Table A1-29*** the test holes are usually incorporated in the final system in all countries.

It is recommended to place the test-holes in a way that they can be later incorporated in the final system.

Depth of test holes

The depth of test holes is normally similar to the bore depth in final system in all countries, see ***Table A1-30.***

It is recommended to drill the test-boreholes so that its depth and size correspond to the depth and size of the final system, since it is recommended to use the test-borehole as part of the final system. In any case, the test borehole should not be shorter than the final drillings.

Number of test holes and TRT

This subject is of great importance when it comes to reliability and quality of borehole system design. In theory, the larger system the more data is required. This matter has previously been discussed within IEA ECES Annex 13 and 21.

The answers indicate that in many countries a test hole is defined as a borehole in which a thermal response test (TRT) is performed. In these countries, preferably the ones that use grouted boreholes, the number of test holes is equal to the number of TRT. In Canada there are also guidelines that tell how to document these test holes, see ***Table A1-31.*** In other countries one borehole followed by a TRT is applied, usually for large-scale projects. Some countries try to follow the recommendations stated by previous ECES Annexes with additional test boreholes commensurate larger project sizes. Not all the test boreholes are necessarily used for TRTs. It is important to keep good documentation during drilling, as this provides useful information of the homogeneity of the borehole field and thus indicates the need for multiple test holes and TRT.

It is recommended to use as many test-boreholes as required based on the size of project, site-specific geological and hydrogeological conditions and design parameter quality objectives. As a minimum requirement, it is recommended to use one test hole and TRT test for every 10-30 boreholes.

1.6.3. Documentation during Test Drilling

Stratigraphy (geological layers)

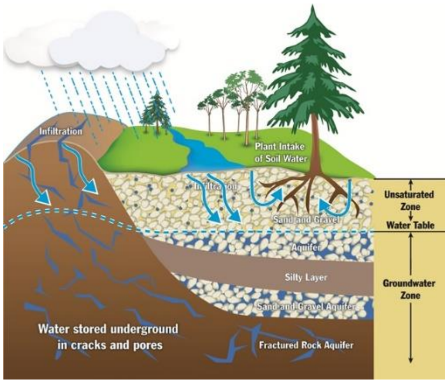
It seems like almost all countries apply geological profiling by ocular classification of cuttings by the driller and/or sampling for analyses elsewhere, see ***Table A1-32.*** In general, with production drilling for borehole heat exchanger systems, very detailed descriptions of stratigraphy (e.g. according to ASTM D2113 or ISO 22475-1:2006) is not required and usually not possible to make (because usually one only gets cuttings and it is difficult to measure the groundwater level and it is changing during the drilling process). However, during the drilling procedure, the driller should be able to identify the main layers encountered and especially be able to identify sealing layers (aquitards).

Figure 1-5: Borehole profile showing main and sealing layers

In addition to drillers' log it is recommended to document geological layers by sufficiently accurate sampling and categorizing, especially in sediments and sedimentary rock. It is of special interest to document all aquitard layers, which may in some cases require geophysical logging.

Permeable zones (productive water-holding fractures or layers)

Occurrence of one or multiple aquifers or permeable fracture zones is an important information for design of a borehole system.



The information obtained during drilling identify that permeable zones or fractures are encountered and are documented mainly by air-lifting measurements at air-drilling and loss of circulation when drilling with water or mud. It is essential for the drilling operator to be experienced, see ***Table A1-33***.

In addition to driller's log, it is recommended to measure the air-lift capacity (drilling with air) or loss of circulation (drilling with water or mud) to detect permeable layers or fractures.

Groundwater level

It is essential to know the groundwater level or hydrostatic pressure. If a geotechnical investigative report is available, consult that document to identify the groundwater level. The possibility to measure this, depends on what drilling method is applied, see ***Table A1-34.*** Drilling with air and rotary drilling with clean water allows for measurement in the borehole. However, true values will not be obtained until several hours (or even days) after the drilling is completed.

Drilling with mud will block the permeability, making measurements in borehole impossible. In such case the groundwater level may be obtained from measurements in nearby boreholes.

In boreholes drilled with air or rotary drilling with clean water, it is recommended to measure the groundwater level some hours after the drilling is completed.

Structural drilling problems

Fracture zones, unstable holes, swelling clay, large water yield, loss of drilling fluid, etc. may all cause drilling problems. Such conditions are commonly noted down in drillers log, see ***Table A1-35.***

It is recommended to instruct the driller to note down structural anomalies in the driller's log.

Drilling parameters

Documentation of drilling parameters such as rate of penetration (ROP), torque, Weight on Bit (WOB), and air pressure will help to understand the geological conditions on site. As seen in ***Table A1-36,*** this kind of documentation is seldom performed in commercial applications.

It is recommended to instruct the drilling contractor to note down as many drilling parameters as practically/commercially possible in the driller's log.

1.6.4. Thermal Response Testing (TRT)

TRT services

One or several TRTs are commonly performed after completion of test boreholes. Evaluated parameters are used for the detailed design of the borehole system. As seen in ***Table A1-37*** all countries have TRT service available. There is more information available on TRT equipment and methods within the IEA ECES Annex 21.

Apart from the standard TRT equipment and method, there is also so-called distributed TRT (DTRT) or enhanced GRT (EGRT), using optic fibers or other equipment such as wireless or submersible sensors, to measure temperature along the borehole depth. Such alternatives are available in a few countries but are yet rarely used.

It is recommended to use experienced TRT service companies for commercial projects. Advanced service (DTRT/EGRT) is recommended for complex or scientific projects. TRT measurement methods recommended by IEA ECES Annex 21 should be used.

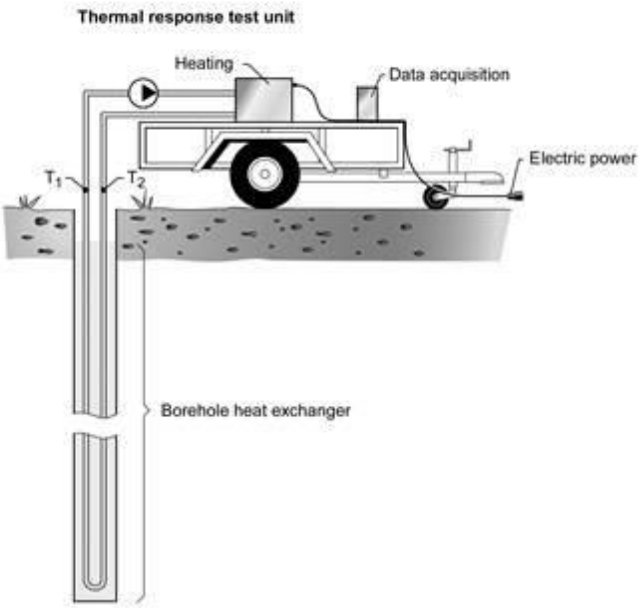


Figure 1-6: The thermal response test unit is connected to the BHE. Hot water streams down the heat exchanger into the cold ground and returns with lower temperature. By measuring the temperatures T1 and T2 the thermal properties can be determined. ***[1]***

Common duration of the test

The duration of TRT must be long enough to ensure a proper evaluation of thermal properties. According to ***Table A1-38*** most countries seem to use 48 hours or more, which is in line with former recommendations in ECES Annexes. This is consistent with recommendation from IEA ECES Annex 21, where more information is available.

With respect to the quality of data it is recommended to use duration of at least 48 hours, and - if possible - to check for convergence automatically during the ongoing measurement, to find out if a longer test duration is needed.

Evaluation method

For evaluation of data obtained from TRT's, the line source method is commonly used, see ***Table A1-39.***

The simplified line source method is an approximation. The approximation is only valid when all measured parameters are very exact, and the heating/cooling load is observed to be very stable. Groundwater flow and load variations make this method unusable. When the prerequisites for the line source approximation are not fulfilled, more advanced evaluation methods are required. The equation for a line source or cylinder source can be used at each time - step during the measurement process, and the average injected power rate between two measurement steps may be used as a step-pulse.

For more information on evaluation of TRT, see IEA ECES Annex 13 and 21.

If stable conditions are shown in the measured data, it is possible to use the line source approximation method. If this is not the case, it is recommended to use more advanced evaluation methods and check for convergence.

Report of TRT

The test report from a TRT measurement should include information about the test equipment, test duration and conditions, results and analysis as well as an error analysis. In Germany VDI stipulates how the TRT report should be done, and in Sweden there is a TRT-guideline issued by the Swedish Geoenergy Center, giving advice on reporting. Guidance is also given in the work by IEA ECES Annex 21.

It is recommended that the report in TRT measurements includes information about the test equipment, test duration and conditions, results, and analysis. Analysis of the measurement error should be included in the test report.

1.6.5. Geophysical Methods

Geophysical methods may be of importance for better understanding of the geological conditions in general.

The answers indicate that, except for Turkey, geophysical logging is rarely used, see ***Table A1-40.*** However, occasionally deviation logs and temperature logs are applied in Scandinavian countries with crystalline rocks.

If more detailed information about the geological conditions or deviation of the borehole is required, it is recommended to consider geophysical logging methods.

1.6.6. Environmental Concerns

Groundwater protection

A main environmental concern in all countries is related to protection of groundwater. In most countries this protection is regulated, but in different ways, and practice may also vary by provinces / regions. In fact, protection of groundwater is the main reason for sealing the boreholes with grout, which is mandatory in most countries. The diversity of regulations and some other ground water related concerns are shown in ***Table A1-41.***

It is a mandatory requirement to comply with laws on groundwater protection in all borehole applications and to follow any country specific or local regulation related to this issue.

Physical damages (settling, etc.)

There are a number of possible impacts from construction and operation of borehole systems that should be addressed. This seems to be a concern in most countries, see ***Table A1-42.***

It is recommended to always consider potential physical impacts in developing and operating a borehole project.

1.6.7. Predesign of the System

In the feasibility stage of a given project the borehole system is pre-designed based on the information that has been gained during test drilling, TRT evaluation and energy load profiles. This data is preferably used for simulations with EED or other similar software design tool. This seems to follow the same procedure in all countries, but with different tools and manuals, see ***Table A1-43.***

It is recommended to perform a predesign of the system based on the findings during the feasibility stage as a first step in the further project development.

1.6.8. Economic Considerations

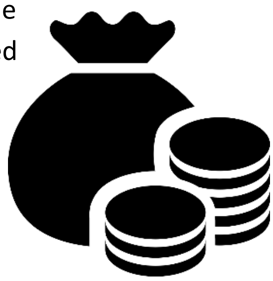
Investment cost

In general customers will be interested in the cost of the system. As shown in ***Table A1-44,*** the investment cost at this stage of a project is mainly based on experience from other similar projects.

It is recommended to perform a rough investment cost calculation based on experience from other similar projects.

Operational cost

The operational cost will be related to the efficiency of the system, often expressed as the seasonal performance factor (SPF), which is the annual delivered energy for the selected system boundary divided by the energy used to produce the delivered energy, see ***Table A1-45.***



It is recommended to make a rough estimate on the operational cost by using the expected amount of useful energy produced and the expected seasonal performance factor (SPF) using the current price for e.g. electricity.

Maintenance cost

The ground source part of a borehole system should, if correctly designed and constructed, be very low with practically no maintenance cost. Some maintenance is associated with the heat pump side of the system, and some control of pressure, purging and heat carrier fluid quality is needed. This seems to be an accepted view by all counties, see ***Table A1-46.***

It is recommended to estimate the maintenance cost for the borehole system (commonly very low) and include cost for replacement of components such as filters, circulation pumps and heat pump compressors, especially for larger systems.

Energy savings

Energy savings are basically calculated in order to show the profitability when compared to other energy system solutions in practically all countries, see ***Table A1-47.***

It is recommended to use the expected seasonal performance factor (SPF) with a system boundary including at a minimum, boreholes, circulation pumps and heat pump compressors, to estimate the energy savings from the system.

Profitability as straight pay-back time

Profitability expressed as straight pay-back time is a commonly applied method. In some countries also, the return rate of the investment is used as complement, see ***Table A1-48.***

A rough estimate of profitability may be obtained by the use of straight pay-back time and/or return rate of the investment.

Life cycle cost (LCC)

LCC analyses are not generally used and if used, there are differences concerning the estimated lifetime of boreholes and heat pumps, see ***Table A1-49.***

If life cycle cost analysis (LCC) is asked for in the feasibility stage it is recommended to use a lifetime of at least 40 years for the borehole system.

1.7. Detailed Design

1.7.1. Contractual Options

The form of contract will to some degree affect how and who is executing the detailed design. Typically, there are two options of which one is commonly known as "Turn Key Contract" (A) and the other is commonly named "Performance Contract" (B).

For option (A) the contractor will both design and construct the plant, while for option (B) the design is performed by the customer with the help of consultants/researchers. This means that there are differences in details when it comes to the tender documents. For option (A), commonly only guidelines for design are given, while for option (B) the design is detailed and fully quotable for bidders.

According to ***Table A1-50*** option A and B are both used in the countries, however option A for smaller and not too complicated plants, while most countries use option B for larger and more complex applications.

It is recommended to be aware of the type of contract that is planned for the realization of the project.

1.7.2. Turnkey Contracts

Turnkey design

A turnkey project is defined and executed slightly differently in the countries, see ***Table A1-51.*** Of importance is that this form of contract puts the responsibility for design on the contractor.

It is recommended to be aware of the fact that turnkey projects mean that the contractor is responsible for the design and function of the system based on the project frame terms of condition.

Client review

Even when the design is performed by the contractor, the client may have an option to review and comment the design. This option seems to be applied in most countries, see ***Table A1-52.***

It is recommended that the customer, with the help of experts, reviews the design prior to construction.

Performance contracts

With a performance contract it is understood that responsibility for the design is put on the contactor, commonly by using consultants and experts for the actual design work, see ***Table A1-53.***

It is recommended that customers use consultants and experts help for design and specifications of performance contract applications.

1.7.3. Modeling

Load profile over an average year

It is important to find out the load profile regarding heating and cooling energy for the building so that the modeled design is accurate. Ensure interaction between building designer and the designer of the BTES/GSHP system. Most commonly, monthly values are used, but in some countries hourly values are used, see ***Table A1-54.***

It is recommended to use monthly values for modeling of smaller and less complex projects. For larger and more complex load characteristics hourly values should be considered. Both energy demand and capacity must be accounted for. Ensure good communication with the building planner.

Temperature demands over the year

Supply and return temperatures in heating and cooling systems are essentially controlled by the site-specific outdoor temperature variation over the year. In general, most countries relate to the outdoor temperature, but in climates with moderate variations (maritime climate) a fixed temperature may be used, see ***Table A1-55.***

Note that ground temperature and heat carrier fluid temperature is not the same.

It is recommended to design the temperature program for the systems according to the site-specific climate conditions and considering that the system efficiency improves by smaller temperature difference between source and sink.

Heat load coverage

In small residential buildings for one or only a few families the demand of heat load for heating should typically be covered to 100 %. The heat load for providing domestic hot-water, will in some countries (e.g. Sweden) normally be covered by the heat pump by an in-built function, while in other countries it has to be determined for each project.

For large buildings it may not be economically feasible to cover the full heat load defined by building codes, building envelope and the building design, especially in continental climate conditions. For this reason, the systems are commonly designed to cover the base load for heating.

Heat load coverage varies from 30 up to 100 %, but most commonly 60-80 %, see ***Table A1-56.*** However, it differs depending on type of building and different climate conditions.

It is recommended to consider how much of the heat load shall be covered by the BTES or GSHP system.

Cooling load coverage (BTES systems)

The direct-cooling load from a BTES system typically does not cover the full cooling load. There are several different ways to cover the full cooling load requirement. One option is using the heat pump as a chiller, and another option is to use a single dedicated chiller. In some countries the cooling demand is the basis for design. In such cases, the chiller is designed to cover the full cooling load, and surplus condenser heat is stored in the BTES system.

According to ***Table A1-57,*** there is no standard solution. This indicates that there are several solutions that can be applied.

It is recommended to consider different system solutions in order to have the best possible coverage of a full cooling load with direct cooling.

Number of boreholes, their depths and configuration

Given the thermal parameters of the underground, the capacity of the borehole system in terms of maximum power and annual energy for extraction and injection is related to the number of boreholes, borehole depth and the distance between the boreholes. These parameters can be studied and analyzed by using simulation models.

Modeling of boreholes, depths and configuration, as well as thermal and hydraulic design regarding number of boreholes, borehole depth etc., is done in a similar way in the participating countries. See ***Table A1-58.***

It is recommended to use thermal design tools to calculate borehole depth, borehole spacing and configuration of the boreholes.

Influence of ground water level

The groundwater level is important for defining the thermally active length of the boreholes in non-backfilled applications as the piping above groundwater level is surrounded by air and has no thermal contact with the borehole wall. See ***Table A1-59.*** Groundwater tables may vary over the year.

Figure 1-7: Coaxial pipe inside a borehole. ***[1]***

For non-backfilled boreholes it is recommended to measure the groundwater level to define the thermally active borehole depth.

Influence of groundwater flow

Groundwater flow will have an impact of the thermal behavior of the borehole systems. For GSHP systems this may be a benefit, while BTES systems may be negatively affected.

Most countries are aware that ground water flow may have an impact of the system performance, but this is normally not modeled. See ***Table A1-60.*** The effect of groundwater flow is complex as the effects depend on the relative length of the borehole affected by the groundwater flow, the groundwater velocity and the energy balance achieved by the system. In general, low groundwater flow velocities and systems with a high energy balance are not much affected by groundwater flow, while systems with high groundwater flow velocity and low energy balance are affected much more.

It is recommended to consider the impact of groundwater flow in the design of borehole systems.

One of the main assumptions with virtually all software that is used in the design of borehole heat exchangers is that heat conduction is the only transport mechanism and therefore that ground water flow plays no important role. If ground water flow does affect the heat transport around the borehole heat exchanger different effects may arise depending on the context:

- *In applications dominated by either heating or cooling ground water flow will have a positive effect on the temperature response and standard design methods result in an over-design of the system.*
- *In applications that intend to store heat (or cool) in the ground the thermal losses increase and may make the store as such ineffective.*
- *In large borehole heat exchanger fields downstream boreholes may experience more adverse conditions as ground water has been thermally interacted with (i.e. become cooler or warmer than the natural background temperature).*

1.7.4. Borehole heat exchangers (BHE)

A BHE is defined as the borehole including the pipes and the borehole filling (any backfilling like clay pellets, grout or just water), which is consistent with the coming CEN TC 451, ANSI/CSA/IGSHPA C448 series-16 and the definition by the Japanese Geo heat pump association. However, in this document we are defining the BHE as a separate component installed in the borehole (CEN TC 451 uses BHE loop for this).

Figure 1-8: U-pipe inside a borehole. ***[1]***

Types of BHE

Single and double U-pipes are the dominant BHE types. To a lesser degree various types of coaxial or multi-pipe designs are used, see ***Table A1-61.***

It is recommended to choose a BHE type that meets the design criteria. If the BHE type is changed, the borehole field design must be recalculated.

Material of pipes and joints

Polyethylene pipes (PE) are most commonly used in low temperature or moderate temperature applications. Joints are welded with special electro-joints for connection to the surface pipe system. The U-bend at the bottom of the borehole is welded by the manufacturer via the butt welding method. See ***Table A1-62.***

It is recommended to use a material for BHE-pipes, horizontal pipes and welded joints that meet the design temperatures and pressures.

Diameter and thickness

For grouted boreholes DN25, DN32, DN40 and sometimes DN45, SDR 11 or SDR 13.5, is commonly used. For deeper groundwater-filled boreholes, DN40, DN 45 and DN32, SDR 17 (which has thinner walls than SDR 11), has become a standard choice. DN here refers to the outer diameter. See ***Table A1-63.***

It is recommended to use country specific standard diameters and thickness of BHE pipes, and to choose pipes so that laminar flow conditions are avoided.

PE pipes for pressure applications (such as GSHP systems) are classified by minimum required strength (MRS) based on the international standard ISO 9080. The last current generation PE pipe is known as PE 100 in which the digits show the MRS class. The previous grade, which is still used widely, is called PE80. According to ISO 9080 the minimum required strength (MRS) at 20°C and 50 years for a pipe with SDR 11 is10 MPa for PE100 and 8 MPa for PE80 giving the design stress 8 MPa and 6.3 MPa, respectively and safety factor 1.25.

HT-BTES applications will demand other types of polymer material for both BHE and horizontal piping. For HT-BTES systems, special types of polymers that can stand higher temperatures are chosen, such as PE RT type II, PP, PEX and some other thermoset materials. At present PEX would be the most temperature resistant plastic that can endure long termed exposure up to +70°C and for short durations up approximately +95°C.

The thermal degradation of pipe materials in warm and hot borehole heat exchangers (HT-BTES) is affected not only by material structure and morphology, but also by the service condition. The design temperature, pressure (resulting in stress on the heat exchanger pipes) and duration of these conditions play important roles for the heat exchanger lifetime. Obviously, higher temperatures and pressure accelerate the thermal ageing of the polymer. At elevated temperatures, the pressure class of the heat exchanger pipes is reduced. Hence temperature should be kept low to maximize the lifetime of the system. Even short term exceeding of the peak temperature can result in permanent damage of the material.

Table 1-1: Material data for polymer materials relative to PN16 [VDI 4640 Vol.2]

Material	***Permanent operation temperature for 50 years life expectancy***	***Peak temperature (Time period 1 year)***	***Thermal conductivity [W/(m·K)]***
PE 100	40 °C at 11,6 bar	70 °C at 6,2 bar	0,42
PE 100-RC	40 °C at 11,6 bar	70 °C at 6,2 bar	0,42
PE-RT	70 °C at 6,5 bar	95 °C at 5,2 bar	0,42
PA	40 °C	70 °C	0,24
PB	70 °C at 12,1 bar	95 °C at 8,1 bar	0,22
PE-X	70 °C at 8,5 bar	95 °C at 6,8 bar	0,41

Quality criteria

The strength properties of the pipe of the BHE will be different depending on BHE depth and whether grouted or non-grouted boreholes are used. Either way, the properties of the pipe of the BHE are of utmost importance.

There seems to be an agreement on bursting pressure, collapsing pressure, extension coefficient and change of strength with increased temperature, see ***Table A1-64.*** For grouted boreholes, also the contact between the grout and the pipes is of importance.

It is recommended to use strength properties that fulfill the requirements for any borehole depth and completion of a given borehole system.

Certification of material properties

The required material properties are dictated by standards and normally certified by the factory, see ***Table A1-65.***

It is recommended to always apply for certification of material properties from the BHE factory.

Manufacturing

BHE`s are mainly manufactured in each country in a controlled factory environment, but in a few countries also imported. Manufacturing and testing is obviously performed according to standards, see ***Table A1-66.*** Due to the unique construction of coaxial BHEs, this configuration of piping cannot be practically handled as a roll, particularly depending on the diameter. They are delivered to the construction site as prefabricated tubes and require welding on site at insertion in the borehole.

It is recommended to use BHEs that are manufactured in a controlled and standardized way and tested before delivery. (Coaxial pipes cannot be fully produced in factories but require some assembly on-site).

Welding methods and procedure

The BHEs are connected to the surface pipe system by electro-joints fusion (or similar) according to specifications from the joint manufacturer and/or standards. Pipes must be sufficiently cleaned and certain weather conditions avoided see ***Table A1-67.***

It is recommended to use qualified (certified) plastic pipe welders to assure a proper welding procedure.

Use of spacers

In groundwater filled boreholes, spacers make no significant difference on the borehole resistance and therefore rarely used. In grouted boreholes spacers are recommended in guidelines, but seldom used in practice, see ***Table A1-68.***

Unless specifically prescribed in tender documents, use of spacers is not recommended.

Type of manifolds (headers)

A variety of prefabricated out-door field manifolds have been developed and are commonly used. Less common are designs on site. Occasionally the manifolds are placed indoors, see ***Table A1-69.***

It is recommended to use pre-manufactured field manifolds, and to choose type of manifold with respect to the land use at the site. Groundwater conditions must be considered to avoid flooding of manholes etc.

Hydraulic concept

Except for very shallow systems the boreholes and field manifolds are connected in parallel in order to minimize the flow resistance in the system, see ***Table A1-70.***

It is recommended to connect boreholes and manifolds in parallel, unless very shallow boreholes are applied or the flow regime (normally turbulent) intended yields other configurations.

Flow control

It seems like common practice to use high efficiency heat carrier fluid circulation pump for larger systems and flow control valves on manifolds, see ***Table A1-71.***

To save electricity it is recommended to use high efficiency circulation pumps.

Backfilling material

Backfilling is mandatory in most countries and different kinds of mixtures are commercially available. In countries without mandatory backfilling, grouting may still be needed in some cases. Many countries lack manuals or guidelines for backfilling. In Germany “on-site backfilling” with self-made grouts has recently been banned and replaced by proven grouts. Materials and procedures, as well as control systems are currently the subject of on-going research, see ***Table A1-72.***

It is recommended to use pre-manufactured grout mixtures and to follow procedures given by regulations or manufacturer.

1.7.5. Horizontal Pipe Systems

Pipe material

Common practice is to use PE100 or similar for low temperature applications, and thermal resistant polymers for HT-BTES, see ***Table A1-73.***

It is recommended to use PE100 or PE80 for low-temperature applications, while various other polymer materials must be considered for HT-BTES applications.

Dimension and strength

The horizontal pipe systems must resist the weight of, for example heavy vehicles, and the collapse strength should therefore be considered.

SDR 17 in smaller dimensions is the most common practice, see ***Table A1-74.***

Depending on the bed depth of the horizontal pipes, the ground temperature can be significantly higher or lower than at the surface. Therefore, the horizontal pipes of systems with operating temperatures below the minimal ground level temperature can contribute to peak load shaving. The overall impact mainly depends on the length of the pipes and the borehole discharge temperature.

It is recommended to consider the hydraulics of the system, the depth and length of the pipe system as well as the impact from the surface to choose a suitable and safe dimension and strength.

Insulation

Usually the pipe system can be placed without insulation. However, parts that are exposed to air, or placed at shallow depth, and parts close to building foundations must be insulated. Insulation is also needed if the pipes cross or run parallel to water pipes or sewage pipes, and if the system is a HT-BTES system, See ***Table A1-75.***

It is recommended not to use insulation except for parts that are exposed to air, or situated close to a building foundation, or crossing water/sewage pipes.

Installation depth

Commonly, the horizontal pipe system is placed 0.8-1.2 m below surface, based on frost-free depth, in Canada somewhat deeper, see ***Table A1-76.*** To limit heat loss in the horizontal pipes they may be installed preferably in the un-saturated zone.

It is recommended to consider the frost-free depth when deciding the minimum depth of the trench.

Bottom bed material

Depending on different temperatures over a season the pipes will slightly move. Sharp edge material in contact with pipes may therefore cause damage.

Commonly a sand bed or native soil without stones with sharp edges is used, see ***Table A1-77.***

It is recommended to use sand without stones with sharp edges as bottom bed material.

Filling material

It seems to be common practice to embed the pipes with sand and to close that layer with a geotextile. Soil material from digging the trench is commonly used for the rest of the backfilling. See ***Table A1-78.***

It is recommended to use sand, free of stones, as an embedment layer followed by a geotextile and finally native soil material from the excavation of trenches.

1.7.6. Heat Carrier Fluid

Commonly ethanol, ethylene and propylene glycol mixed with water are used as heat carrier fluids. Ethanol is preferably used in water-filled boreholes at a concentration of maximum 28% (not flammable), and glycol in grouted boreholes at a concentration up to 30%. Propylene glycol has a comparably high viscosity which makes it less favorable as heat carrier fluid due to increased pumping costs. The ethanol mixtures may be infused with additives that make it undrinkable. Pure water is used in systems that work well above the freezing point and in systems used for storage of heat only. See ***Table A1-79.***

It is recommended to use environmentally safe heat carrier fluids and not unnecessarily high concentrations. Corrosion inhibitors and other additives should be avoided if possible.

1.7.7. Risk Analysis

Environmental risks

Environmental risk assessments are normally a part of the permit procedure in countries where permits are required. In other countries there is a lack of standard procedures how to perform this kind of analyses, see ***Table A1-80.***

It is strongly recommended to always make an environmental risk analysis showing that such risks have been considered during the project development.

Technical/economical risks

Technical and economic risks are mainly considered in the feasibility stage. More such analyses may be asked for in contracting documents, see ***Table A1-81.***

If not already done in the prefeasibility or design phase, it is recommended to ask for a risk analysis in the contracting documents.

1.8. Approval Procedures

Approval of installations is handled very differently in different countries. Furthermore, there may be provincial differences within a country. In a few countries there is no permit requirement at all, or only for larger systems. In most countries there are standard procedures and/or norms for system design (and installation), but not for the approval of the system. A common procedure is that a borehole system is assessed by local environmental authorities and a permit is given if there is no risk for, by example, groundwater contamination. Approval may be given with certain terms. The variety of country specific procedures is shown in ***Table A1-82.***

It is recommended to follow the country specific regulations and procedures for the approval of a given project.

1.9. Call for Tenders

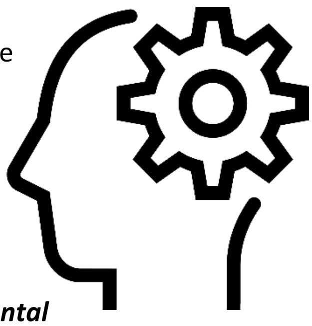
1.9.1. Form of Contract

The form of contract will to some extent govern the administrative conditions and the technical specifications in the tender documents.

As shown in ***Table A1-83*** there are a variety of forms, but not specified enough to be fully understood, when it comes to terms of conditions. However, it is clear that the construction is contractually regulated in most countries.

It is recommended to be aware of the form of contract when preparing the tender documents and specifications.

1.9.2. Quality/Skill of Contractors



The quality and skill requirements of contractors that bid on any project should be specified in the tender documents as well as reference projects, certifications of drillers and installers, CVs etc.

As shown in ***Table A1-84,*** a majority of countries require certification of drillers and installers and companies must often have Quality and Environmental Control systems.

It is recommended to ensure high quality by requiring safety, quality and environmental control certifications as well as references in the tender documents. Drillers should be certified according to national and/or local legislation.

1.9.3. Responsibility for Damages

Unforeseen damages caused by the borehole installation are of importance to regulate in the contract. In some countries this is dealt with by general clauses, in others they will be handled by the court of law.

In general, the responsibility for potential damages seems to be regulated in the contracts, at least during the guaranty time (3-10 years), see ***Table A1-85.***

It is recommended to always address the responsibility for unforeseen damages in the contract, and to demand that people responding to the tender are certified and have correct insurances in place.

2. Subtask 2: Construction Phase

2.1. Preface

This report is a subtask report within International Energy Agency (IEA) Technical Collaboration Platform (TCP) Energy Conservation through Energy Storage (ECES) Annex 27 - *Quality Management in Design, Construction and Operation of Borehole Systems.* The publication is the final report for IEA ECES Annex 27 Subtask 2: Construction Phase and is based on a survey on construction phase considerations, answered by seven of the countries participating in the Annex.

Contributing countries: Belgium, Denmark, Finland, Germany, Netherlands, Sweden and Turkey**.**

Information provided by: Wim Boydens (Belgium), Ywan De Jonghe (Belgium), Luc François (Belgium), Mathias Possemiers (Belgium) Bertrand Waucquez (Belgium), Henrik Bjørn (Denmark), Teppo Arola (Finland), Asmo Huusko (Finland), Mathieu Riegger (Germany), Roman Zorn (Germany), Hagen Steger (Germany), Roland Koenigsdorff (Germany), Manfred Reuß (Germany), Claus Heske (Germany), Henk Witte (Netherlands), Signhild Gehlin (Sweden), Olof Andersson (Sweden), Adib Kalantar (Sweden), Willem Mazzotti (Sweden), Yusuf Kagan Kadioglu (Turkey), Birol Kilkis (Turkey), Aysegül Cetin (Turkey), Suheyla Cetin (Turkey), Mert Oktay (Turkey), Ersin Girbalar (Turkey), Mark Metzner (Canada) Katsunori Nagano (Japan), Takao Katsura (Japan).

Author: Henrik Bjørn, VIA University College, Denmark, April 2019

2.2. Subtask Scope and Limitations

The IEA ECES Annex 27 subtask 2 report covers the construction phase for any closed loop borehole system used for extraction and storage of thermal energy in the underground by the use of borehole heat exchangers (BHE).

From a system point of view, the subtask covers any BHE-system, regardless the size of application and the working temperatures used in the systems.

The scope is the construction of the borehole, the grout and the grouting process, installation and control of the BHE and documentation of borehole and BHE.

This working paper is based on answers from a questionnaire that was answered by eight of the participating countries and on discussions at the experts' meetings in Horsens (EM1), Lund (EM2), Espoo (EM3), Brussels (EM4), Amsterdam (EM5), Vancouver (EM6), Osaka (EM7) and Munich (EM8). The answers of the questionnaire are attached as appendix.

As the legislation on construction of BHEs in the participating countries is different, it follows that standards and common practice varies.

The purpose of Subtask 2 is to provide recommendations for best practice for construction of BHEs. This, however, to some extent will depend on the country.

2.3. Site Preparation

2.3.1. Site Facilities

The site facilities are those that need to be present before and during the drilling process in order to avoid accidents and to support the drilling process. Apart from physical installations such as protective / construction fencing, this may include documentation such as drilling certificates and permits that need to be present. All input may be viewed in ***Table A2-2*** and ***Table A2-3.***

Figure 2-1: Fences enclose the drilling site

Figure 2-2: The drilling rig is placed on a platform, which was installed specially for this purpose

In order to prevent accidents, some countries require a Health and Safety (H & S) plan for the site and work processes. If a plan is needed or not may depend on the size of the construction site and the number of contractors/people that will be present during the work. If a H&S plan is required, it must be presented and approved by consultant and/or authorities prior to commencement of the construction.

A plan for handling drilling mud and cuttings is also required in most countries.

A general official requirement is fencing around the work site. Furthermore, it is common practice that the site owner provides electricity and water to aid the drilling, but this is not mandatory.

It is a requirement that all permits required by law are present on the site. A fence surrounding drill-site, rig, materials and other equipment related to the drilling process should be put up and maintained through the entire drilling campaign.

2.3.2. Localization of Underground Obstacles

Mapping or detection of underground installations will typically be the driller's responsibility.

Checking for soil contamination will also be a part of the investigation prior to drilling. The site owner is normally responsible for checking whether a site is contaminated. Generally, it will not be allowed to install BHEs in contaminated areas. If the driller unexpectedly hits contaminated soil, the driller has the responsibility to inform the planner and/or the authorities. the driller must also handle the contaminated soil/cuttings from the project site. The also applies to spent drilling mud and excess water.

In most countries, the use of watertight containers for drilling mud and settling of cuttings seems to be either mandatory or the norm. In some places excavated pits are still being used.

Generally, the handling of drilling mud/fluids/water is the responsibility of the driller. The deposition of these materials will normally have to be approved by the authorities.

It is recommended that all the conditions related to the drilling site are clearly stated in the contract for the drilling project. As lack of coordination regarding health and safety, underground installations, contaminated soil and handling of mud, water and cuttings will severely impact the drillers work process, it is recommended that the driller assumes this responsibility.

2.4. Drilling

In most of the participating countries, the driller will have to hold a certificate in order to get a permit to drill. See ***Table A2-4 – Table A2-8*** in **Appendix 2-3**.

Figure 2-3: Drilling rig mounted on a crawler vehicle

Figure 2-4: Drilling rig mounted on a truck

2.4.1. Drilling Methods

Figure 2-5: Tricone drilling bit

The chosen drilling method is closely related to the geology on the drilling site. (see comparison below) In unconsolidated sediments, mud rotary drillings the method of choice. This will typically be direct flush but may also be reverse flush. The expected drilling depth may also influence the choice of method. There seems to be a tendency for the boreholes to become deeper. In Sweden, boreholes of 250-300 meters are seen more and more often. Thermal short-circuiting is generally small in BHEs shorter than 300 m.

Figure 2-6: Chisel drilling bit

In hard rock the drilling will typically be made by down-the-hole hammer (DTH) with air lift to clean up.

Alternative drilling methods may be appropriate in unconsolidated sediments.

The driller must handle any situation with excessive flows of water, artesian water flows or release of underground gas and have the necessary means present at the drilling site to address these situations. This equipment will typically be packers and diverters amongst other measures.

It is required that the drillers hold a certificate that ensures their understanding of the geological and other surrounding environment they are working in, and as a minimum have an understanding of the basic working principles of a closed loop system. The applied drilling method should be appropriate in the geology in question.

Table 2-1: Comparison of borehole drilling methods. After: Guidelines for Construction of Underground Heat Exchanger Wells (Closed-Loop Edition), National Water Well Association of Japan, 2011 Ed.

Method / ***Item***	***Percussion***	***Rotary***	***Down-the-Hole hammer***	***Rotary percussion***	***Auger***	***Rotary vibration***
Excavation method	Hit with chisel, shell or clay cutter	Cutting by rotating the tri - cone bit to apply pressure	Hit with hammer bit	Hydraulic rotation, pressure application and impact	Auger rotated/ screwed into soil	Cutting and crushing by vibration to rotation
Excavation discharge	Collected by bailer	Circulation by pumping drilling fluid	Pneumatic feed by compressor	Circulation by pumping of drilling fluid	Auger extracted, cleaned at surface and reinserted into borehole	Circulation by pumping of drilling fluid
Drillhole diameter	Bits can be arbitrarily selected from small diameter to large diameter	Small diameter to large diameter by using bits of general purpose products	Small diameter to large diameter by using bits of general purpose products	Be limited to using dedicated bits	Small to very large (+1m)	Be limited to using dedicated bits
Drilling fluid	Water or drilling mud	Water or drilling mud	Air	Water or drilling mud	No fluid added	Water or drilling mud
Applicable geology/ formation	From unconsolidated formation to medium hard rock. Not suitable for hard rock	From unconsolidated formation to hard rock form-ation. Some-what inappro-priate for cob-blestone layers	From soft layers to extremely hard rock layers. Some-what inappro-priate for unconsolidated formations	Almost all strata from uncon-solidated to hard rock	Soft, uncon-solidated sediments	From soft rock to hard cobblestone layers. Somewhat unsuitable for hard rock

2.4.2. Borehole Diameter and Casing

The borehole diameter generally seems to vary between 120 mm and up to 152 mm and 178 mm with casing. Some may use a larger diameter (140 mm is a minimum in Sweden) and smaller diameters (down to 100 mm) are also employed. The smaller diameters may cause problems for the installation of the BHE. Some of the federal states in Germany have recommendations on diameter of the borehole in relation to the diameter of the BHE-pipe. BHEs with diameters of DN 45 and DN 50 seems to be moving into the market. This may result in a general increase in borehole diameter.

For the mud rotary drilling, there is the option of drilling with or without casing. It appears that drilling without casing is more common than with. If the drilling is “without”, it is still common to have a short (2-3 m) casing through the overburden in order to control the flow of drilling mud and avoid collapse of the loose overburden into the borehole.

For the DTH drillings the standard diameter is 115 mm or 4 1/2”. Casing will typically be used in the overburden and a few meters into the bedrock.

It is recommended that the borehole diameter in some sense is related to the diameter of the BHE. At a minimum, casing should be used in the overburden/topsoil for better control of the drilling.

2.4.3. Safety during Drilling

All of the participating countries have a general set of Health & Safety (H & S) rules that also apply to drilling sites. Most countries distinguish between “small” and “large” construction sites. This is typically related to the number of contractors and personnel working on the site at a given time. If the site is “larger” it is common to require a special H&S plan for that specific site. This plan must always be known to the staff working on the site.

It is required that the appropriate health and safety plan always is present on the drilling site.

2.4.4. Borehole Profile, Drilling Log and Samples

Most of the participating countries have a requirement for a drilling log that as a minimum contain information about the level of water / fluid in the borehole and the geology of the borehole. Identifying information such as site name, date, position and identification of borehole, name of company and drillmaster are also typically mandatory. The name of sample examiner is also relevant.

The frequency of the sampling varies between the countries. The demands regarding the qualifications of sample examiner (driller or geologist) also varies.

In some countries mud loss, caverns/fractures, water yield and water salinity also must be reported.

It is recommended that all observations regarding geology and hydrogeology that are done during the drilling is reported in a drilling log. The number and position of the taken samples should also appear on the log. Information that identifies the borehole, the installations in it and the company/person who carried it out must be included along with the sample description and information about who completed it.

Figure 2-7: Samples from core-drilling

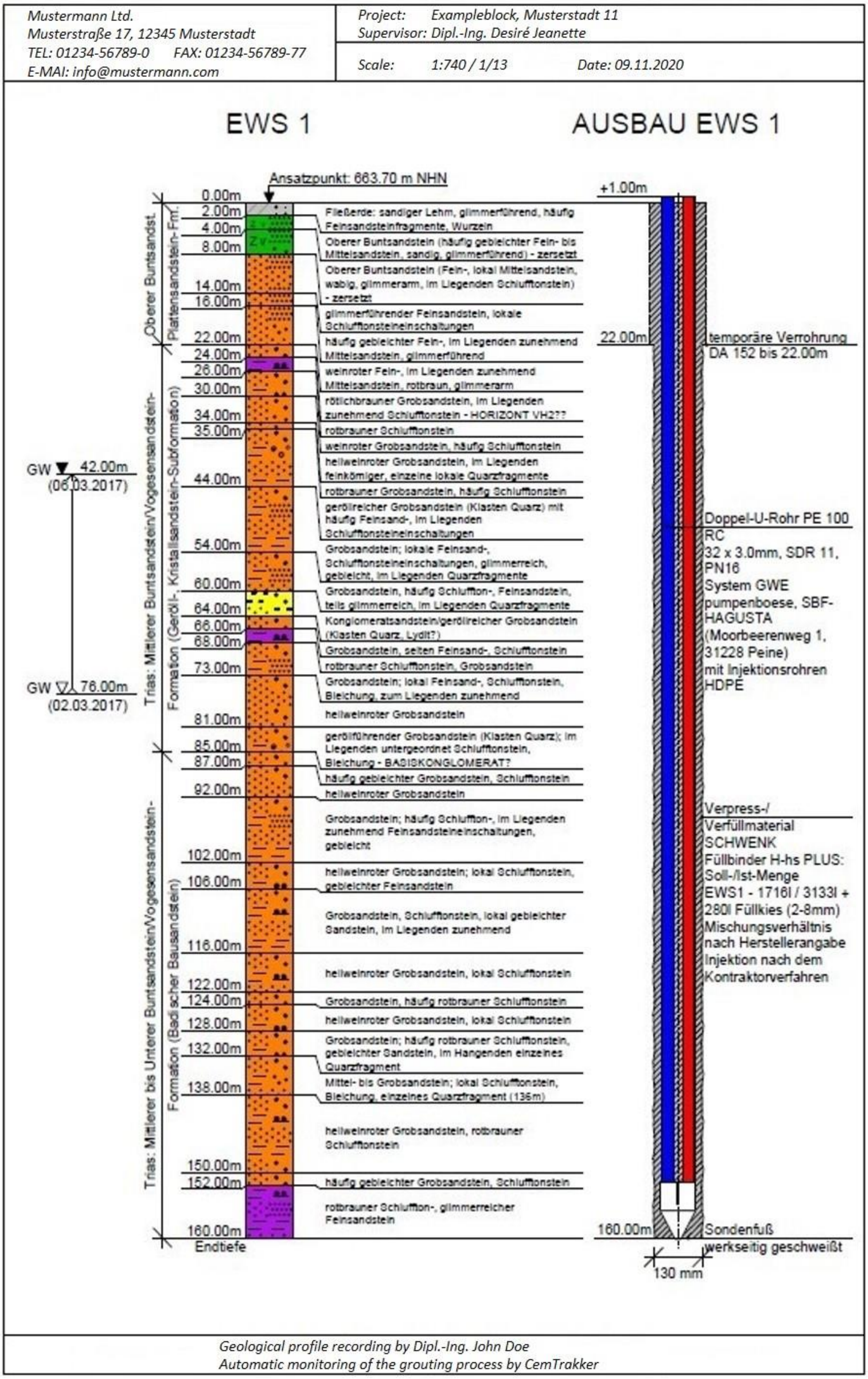


Figure 2-8: Exemplary borehole profile for an U-pipe BHE in Germany

2.4.5. Geophysical Investigations in the Borehole

Geophysical methods seem primarily to be applied for research purposes, in special geological situations or in rare cases to measure deviation of boreholes. There are no general requirements or official guidelines.

In complicated geology, it may be useful to do geophysical logging. ***Table 2-2*** gives an overview of available methods.

It is estimated that geophysical logs and interpretation of the results under normal circumstances are too comprehensive compared to the added value for a smaller shallow geothermal system.

2.4.6. Temperature, Pressure and Ground Water Flow

Temperature profiles are generally measured in relation to TRT. Because of heat generated during the drilling process it is recommendable to wait for approximately one week until the heat has dissipated.

In larger systems temperature profiles should be measured.

Table 2-2: Overview of geophysical methods for investigation of boreholes and/or BHEs. Dimension of probes and BHE loop may restrict use of some of the methods.

Measurement method	***Interpretations***	***Area of use (depending of diameter, etc.)***
Gamma Ray (GR)	Measuring of the natural gammy radiation of surrounding materials, e.g. used for lithological rock interpretation. In BHE tested with zirconia doped material	Without casing, Steel-casing, BHE tested
Gamma-Gamma-(γ-γ)-Log (GG, GGD, RRK)	Two channel Gamma- Gamma measurement method to determine the material density of rocks (standard in open holes). One channel Gamma- Gamma measurement method is available for checking quality of backfilling material in BHE	Without casing BHE tested
Neutron porosity (N-N, INN)	Two channel neutron measurement method for determination of the porosity, the lithological layering as well as the water saturation.	Without casing
Neutron-Gamma-spectrometry probe (N-G)	Comparable to the neutron measurement method. Determination of the proportion of selected elements and thus reflects the rock matrix.	Without casing
Geophon (ETB, VSP, etc.)	Determination of boundary layers and final borehole depth due to induced seismic waves	Without casing, With casing
Ultrasonic probe. (Cement bond log, combination of Gamma and ultrasonic measurements)	Continuous sensing oft borehole wall with acoustic waves, imaging of borehole wall. Recognition of fractures, layers, determination of incident direction and angle of founded structures. Adaption to BHE challenging due to limited space and inducing a suitable signal through the PE-pipes	Without casing BHE tested (research)
Electric resistivity measurements (Laterolog, etc.)	High-resolution resistivity measurement method. Determination of lithological layering, low thickness layers, clay layers, etc.	Without casing

Magnetic susceptibility	Measurement of the magnetic response. Detection of metallic components and magnetic materials (doped grouts, formation with natural magnetic components, etc.).	Without casing in combination with magnetite doped backfilling material
(Terra-hertz) time domain spectro-scopy (THz-TDS)	Contactless and non-destructive investigation of materials with electromagnetic radiation with ultra-short laser impulses. Indication water content, etc.	Without casing, Plastic BHE research
Caliber	Determination of borehole caliber. Indication for needed backfilling material. Interpretation of lithology, etc.	Without casing
Optical inspection mini-camera systems	Determination of large cracks and bends in PE pipes	With casing, BHE available
Inclination measurements (X,Y,Z orientation)	Continuous determination of trace of borehole and PE-pipes.	Without casing, With casing BHE available

The grouting and sealing of the borehole should generally ensure that all aquitards that have been penetrated are resealed so that all groundwater pressure levels are unchanged and cross – contamination does not occur.

It is recommended that undisturbed temperature profiles are measured in larger systems and whenever a TRT is carried out.

For further information see Feasibility Phase and Test drilling in Subtask 1.

2.5. Borehole Heat Exchangers

2.5.1. Installation

Figure 2-9: Reels are being unrolled during the pipe installation

The procedure to install the BHE-pipes is typically to put the single or double U pipe on a reel, either motorized or suspended from the drilling rig, and connect weights to the U-bend and fill the piping with water. The necessary counterweight needs to be calculated. The weights and the water counteract the buoyancy in the mud- or water-filled borehole to facilitate the installation of the BHE. See ***Table A2-10 – Table A2-15***.

In Finland, the BHE is filled with a mixture of alcohol and water (the brine) instead of water. This will remove the process of replacing the pure water

Figure 2-10: The down end of a single U pipe

with antifreeze but may cause complications if the BHE turns out to be leaky or there is debris in it. Flushing with clean water is benign, however, with antifreeze, there may be some concerns about spillage.

Spacers and centralizers are often required in projects but in practice, they often cause more problems than they provide advantages.

During the installation, care must be taken not to damage the pipes in the process.

In case of a water or mud-filled borehole, it is recommended to use weights and fill the BHE with water before installation.

Figure 2-11: A weight is connected to the down end of the

Figure 2-12: During the installation process the drill hole is flooded

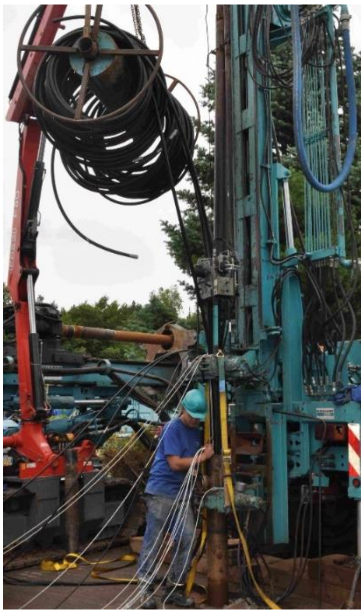


Figure 2-13: Motorized installation process

Figure 2-14: Detailed view on the pipe drive

2.5.2. Leakage Test

All participating countries are performing pressure tests or leakage tests. Most, but not all, have a procedure for the test. The duration of the test, the number of tests and the test pressure varies. The results of the tests are often found to be questionable.

It is recommended to perform a leakage test before installation. Conditions must be in compliance with local regulations.

2.5.3. Flow Test

Only Germany and Belgium seem to use a standard for flow test but most other participating countries use some form of test. The test may indicate installation errors and provides means to double check head loss calculations for the circulation pump.

It is recommended to carry out a flow test and compare the results with the expected values.

2.5.4. Horizontal Connections and Pipe Installations

Figure 2-15: Horizontal pipes connect all the widely scattered components of the whole system

Generally, there is a requirement for welding/electrofusion of the horizontal connection pipes. This must be carried out by certified PE-welders. Threaded joints are generally not allowed below ground surface. Metal joints are in some countries not allowed underground and generally should be avoided due to corrosion risk. The pipes must be placed in a bed of sand without stones or sharp particles. A marker tape above the pipes may reduce the risk of damage from later excavation work.

Figure 2-16: The pipes are connected by electrofusion

It is recommended to weld/electrofusion all joints in the horizontal pipes and place the pipes in sand without sharp-edged stones.

2.5.5. Test Protocol for BHE

Test protocols and documentation seems generally to apply to larger systems and the terms will normally be evident in the contract. There does not seem to be a standard scope for these protocols and accompanying documentation.

For smaller systems, it is necessary to document/test at least the following:

- Borehole position, dimension and depth
- Planned deviation of the borehole
- BHE length, dimension, type, pressure class
- Filling material and/or sealing material type, amount and position
- Result and conditions of leakage test
- Heat carrier fluid, type and concentration
- Result and conditions of flow test
- Flowrate, duration and result of de-aeration process

- Type of connection to horizontal pipes
- Position of the horizontal pipes
- Type, dimensions, equipment and position of manifold, if present

It is recommended to include a test protocol at least for larger systems. For smaller systems documentation and a minimum of flow and leakage test is recommended.

2.5.6. Test Protocol for Horizontal Pipes and BHE

Germany carries these procedures out according to VDI 4640. All other participants rely on tender-specific requirements on larger systems.

A visual inspection should be carried out and documented with photos before filling in the trenches.

A gradient on the horizontal pipes will facilitate air bleed.

Flowrates for purging should be noted.

It is recommended that a test protocol is composed and employed at least in larger systems. For smaller systems flow and leakage should be tested.

2.6. Filling or Grouting Process

In order to protect the subsurface against spreading of surface contamination or to avoid the risk of changing the natural groundwater flow, the boreholes will require some form of sealing. The background information on this can be found in ***Table A2-16 – Table A2-29.***

2.6.1. Filling Concept and Geology

Most of the participating countries have a requirement for the sealing of penetrated aquitards. Belgium and Germany are somewhat stricter, demanding a complete grouting of BHEs. Conversely, Sweden and Finland only have requirements for sealing the top of the borehole and a complete seal if the borehole is in a groundwater protection area or if a borehole connects two or more aquifers. Therefore, only a small number of boreholes are filled with sealing material in these countries. Aside from sealing of aquitards, it is also a typical requirement to seal the top of the borehole in order to prevent leakage of contaminants from the surface to the deeper layers.

In addition to the sealing properties, the grout generally has to ensure good heat transfer and protect the pipes against mechanical damage. The legislative demands on the grout are generally focused on the sealing properties. This again is in accordance with the general legislative focus on environmental protection.

It is recommended that all boreholes are sealed at the bottom of a permanent casing and at the top. Whenever the drill penetrates a barrier that restricts groundwater flow it must be resealed with an appropriate filling material. The seal must be installed with an appropriate method.

2.6.2. Alternative Sealing

As the legislative demands for the grout concerns the sealing properties, it is possible to use other types of materials or installations in the borehole that have the same characteristics. This could be a form of packer or cured-in-place liner. These technologies are not widely used.

Alternative sealing may be used if the concept is proven and accepted by the local authorities.

2.6.3. Grouting Methods

Figure 2-17: Continuous mixer with screw pump for high pressure grouting

When grouting is mandatory, there is a consensus, in most countries, that the boreholes must be filled by pumping the grout slurry from the bottom of the borehole. This is done through a separate pipe known as a tremie pipe. The permissible length of the tremie pipe should be calculated in order to avoid pipe bursts. In deep boreholes i.e. high flow resistance resulting in high pumping pressure, separate tremie pipes can be taken to different levels. The tremie pipes must be inserted with the BHE. In case of fractures identified during drilling it is recommended to have tremie pipes ending both under and over the fracture zone in order to ensure a sealing of the fracture.

By utilizing the fact that the grout typically is denser than the drilling mud in the borehole, the grout will displace the mud and fill the borehole completely.

A common problem with grouting is a burst tremie- or grout-pipe. This may occur when the pressure from the pump exceeds the pipes pressure rating. Several factors increase the pressure in the tremie-pipe:

- *High viscosity of grout*
- *High pumping rate*
- *Long tremie-pipe*
- *Small diameter of tremie-pipe*
- *High density of drilling mud in borehole*

In some countries drillers leave the tremie-pipe in the borehole after finishing the procedure. In other countries the tremie-pipe is retracted during filling.

Vertical and horizontal groundwater flow in the borehole will impede the construction of a tight seal as the flow may flush the filling materials away or form channels in them. Experiments have shown that a high pumping rate during the filling process and a high density of the filling material will improve the sealing properties in case of groundwater flow in the borehole.

When layered filling (resealing aquitards) is used in The Netherlands it is common to use a larger diameter pipe inserted in the borehole at the relevant depth. Pellets are then poured into the pipe to create a seal. The pipe is retracted as the seal is created.

It is recommended that resealing of an aquitard is done by pumping a grout slurry to the relevant depth interval through a separate pipe.

Figure 2-18: Vertical section of a grouted borehole

2.6.4. Filling Materials

Generally, industrial premixed filling materials are the standard in the participating countries. There are examples of on-site mixing but it seems like this approach is diminishing. The industrial products come with specifications of thermal conductivity and mixing ratios that raise the likelihood of getting the correct properties from the filling.

Special attention must be shown in saline areas. High salinity will inhibit the swelling properties. In these cases, a sulfate resistant filling material is required.

It is recommended always to use premixed industrial products that are approved for use underground and in contact with aquifers.

2.6.5. Material Contents

Bentonite is the most typical constituent to achieve the sealing properties. Quartz, in some form, seems to be the typical thermal enhancer. This may be as fine-grained sand or a quartz flour. Others use graphite to enhance the thermal properties further.

Some manufacturers add cement to achieve a high physical stability

In order to be able to document the position of a seal, magnetite can be added to a filling material (doped grout). It must be pointed out that smaller voids may go undetected.

One of the issues with the pumped grout is the friction in the pipe. This often leads to pipe bursts. Adding a liquefier similar to those used in concrete may reduce this problem. However, the chemical composition of that liquefier must be approved for use in contact with aquifers.

When full-hole grouting is performed in Sweden, it is preferably done with cement- and bentonite- grout that contains silica sand and/or graphite as thermal enhancers.

When filling materials are used, it is recommended to pay attention to the material properties with regard to sealing, physical and chemical stability, pump-ability, thermal conductivity and environmental safety.

2.6.6. Mixing of Filling Materials/Grout

Continuous mixers are frequently used, primarily because of ease of use (only one piece of equipment is necessary). However, there are issues with the mixing ratio of the produced grout.

Batch mixing will have a higher security for getting the correct mixing ratio.

In Germany colloidal mixers are gaining a footing and they seen to replace the two above mentioned technologies. The mixing procedure ensures a homogenous product mixed in the correct ratio. Mixing and pumping is two separate processes.

It is recommended to use batch mixing for pumped grout.

Figure 2-19: Batch mixer

2.6.7. Chemo-physical Properties

There seems to be a high confidence in the information from the manufacturers' data sheet. This is despite of known differences in datasheet information and laboratory measurements. In the data sheet, there must be references to the standard methods and norms used in testing the material.

Sedimentation rate is a useful parameter in describing the material's physical properties. However, it is normally too time-consuming to carry out on the worksite.

Viscosity tested by marsh funnel and density are two parameters that are relatively rapid and can be easily tested on-site.

It is recommended that viscosity and density be checked on site before injection.

2.6.8. Loss of Fluid

Only Germany seem to have a procedure for this situation. If the injected amount is the double or more of the calculated amount, the work must stop, and the authorities must be informed. Gravel, sand or grout of a higher density or a packer may help solve the problem.

It is recommended that the driller always be prepared to handle situations with loss of fluid.

2.6.9. Geophysical Measurements during and after Grouting

This is generally used if there is a suspicion that something has failed with the grouting/sealing.

A short TRT and temperature logs may give some useful indications on the grout sealing. When using a short TRT to identify grouting problems it is necessary to measure an undisturbed temperature log before the TRT. After the termination of the TRT another temperature log should be measured.

Gamma-gamma logs can also be used to give information about the consistency of the grout plug. If the grout in question has been doped with magnetite it is possible to get an indication about loss of suspension. Magnetite doped material allows for the automated controlled backfilling process and subsequent measurement and controlling of the BHE. Such an automatic grouting control must be used in some parts of Germany (at the moment only in Baden-Württemberg).

Cemtrakker is a relatively new and promising method developed for controlling the quality of the sealing of a borehole during the grouting process.

It is recommended that TRT and temperature logs are used as a first investigation method if there is a suspicion that the grouting has failed or is missing.

2.6.10.Use of Marker Materials

Magnetite is frequently added to grout in parts of Germany. The Netherlands and Belgium are sometimes using magnetite-enhanced grouts.

If there is a wish to be able to control position of a sealing plug or if a borehole has been grouted from bottom to top, it is recommended to use magnetite spiked grout.

2.6.11.Curing Time of Grout

There seem to be no general requirements. However, experiments made in Germany indicate that a curing time of one month before the grout is subject to low temperatures greatly reduces the risk of exfoliation of the grout.

It is recommended to wait 30 days after grouting before starting to put thermal (heating and/or cooling) loads on the BHE.

2.7. Additional Methods

2.7.1. Geophysical tests

No standard tests are being employed. From time to time technologies are being tested for research - an overview is given in ***Chapter 2.4.***

In general, there might be some geophysical methods that could be applied to BHE. The challenge for using these methods is the limiting space of BHE's and the interpretation of the measured signals. There is space needed for electronics, transmitters, and receivers, etc. (usually a certain distance is required between receivers and transmitters). There are some special geophysical developed probes already applied in BHE's, but they are not common and not often used. Gamma-Gamma-density logs (Gamma-Gamma-(γ–γ) log) could provide indications of the grouting quality if there is a large density contrast e.g. in the case of large completely non-backfilled sections. Problematic is also the use of an active radioactive source on the investigation side. Ultrasonic measurements might also be an option for testing BHE's. The wave propagation and reflection is highly material dependent and thus potentially promising for use in BHE, but the resolution and interpretation of measured signals are quite challenging. Perhaps electromagnetic wave technologies could be also an option for testing BHE's, because of the permittivity contrast of the system BHE (water, air, surrounding underground, backfilling, See ***Table A2-30 – Table A2-34.***

No recommendations.

2.7.2. Thermal Response Test

Figure 2-20: TRT-rig on site

TRT is generally only employed in larger projects. It should be applied whenever it adds value to the project. See Annex 21, final report and Subtask One.

It is recommended to use TRT in larger projects where it is required for the design and whenever it adds value to the project.

2.7.3. Other Methods

Wireless probe method

Wireless probes for temperature measurement are commercially available.

No recommendations.

Fiber optics

Have primarily been used for research projects. Enhanced Geothermal Response Test with hybrid cables (heating wire in combination with fiber optic cable) are sometimes used an alternative thermal response test method. An EGRT gives indications about deep oriented thermal properties of the underground.

No recommendations.

2.8. Supervision of the Construction Process

For bigger projects, it is generally the norm to have a consultant independent of the drilling company do a periodic check up on the construction process but there is no standard as such. Sweden and Germany have somewhat more regulated procedures. See ***Table A2-35.***

Turn-key contracts will typically have different conditions from trade or general contracts. E.g. supervision by consultant is much reduced or non-existing.

It is recommended to have some level of supervision during the construction process. The extent of supervision is related to the size of the project and the type of contract.

2.9. Start-Up

2.9.1. Functional Check

Normal conditions for system delivery apply. Sweden, Germany and The Netherlands have quite comprehensive functional checks of both functionality and performance. The rest is more or less relying on the procedures from the heat pump supplier. See ***Table A2-36 – Table A2-39.***

In Sweden there are 2 and 5 years follow-up checks for larger systems. As BHEs tend to show indications of under-dimensioning after some years, this is a sensible approach.

It is recommended to carry out a proper check of function and performance of the system at commissioning. A follow up check on function and performance after 5 years is suggested.

2.9.2. Commissioning

There is a general reference to the normal conditions for deliveries. Check-ups are primarily concerning mechanical parts, HP coolant and antifreeze levels. For further information, see Subtask 3.

It is recommended that larger systems are equipped with performance monitoring.

2.9.3. Instructions for the Operator

Sweden, Germany and The Netherlands have well defined standards for this.

It is recommended that the operator receive instructions that provides a basic understanding of how to run the system.

2.9.4. Documentation

Sweden, Germany and The Netherlands have comparable and high levels of documentation and instructions that are delivered to the system owner. The main elements are:

- Documentation for planning approval
- Description of system (with as – built drawings)
- Function of system
- Description, manufacture and datasheets for main components
- Protocols for self-control
- Instruction for maintenance and operation
- Efficiency calculation and Environmental Impact Assessment is mandatory in some countries

The following exemplifies the level of documentation commonly requested in larger turnkey projects in Sweden. The documentation is performed by the contractor and handed over at the commissioning:

- System flow chart with all components and controlling/monitoring instruments included (covers the total system)
- Technical data of pump for brine circulation and controlling/monitoring recorders on the brine loop
- Documents of the borehole field design (normally TRT-tests and EED-simulations)
- Borehole field plan drawing containing (1) all borehole correctly numbered, (2) coordinates for all boreholes, (3) placement of shafts for connecting horizontal pipes, (4) placement of manifolds, (5) material specifications (pipes and collectors)
- Photographs of open trenches for documentation of trench bedding conditions and placement of pipes
- Drilling protocols, one for each borehole, containing information on borehole depth, length of installed collector, geological/hydrogeological information, and drilling problems (if any)
- Protocols of leakage tests (what pressure level used and duration)
- Protocols of flow tests for head loss determination (performed after purging the system)
- Analyses of alcohol content in the brine (heat carrier fluid)

It is recommended that full documentation including performance calculations are handed over.

2.10. General Questions

See ***Table A2-40*** and ***Table A2-41.***

2.10.1.Key Performance Indicators

The main key performance indicators are identified as the following:

- Energy load, capacity for heating and/or cooling
- Temperature levels
- Heat pump COP/SCOP values (coefficient of performance/seasonal coefficient of performance)
- Free cooling COP

Other indicators may be relevant depending of the size and nature of the project.

2.10.2.Safety Margins

The level of safety margin in a given project is generally very much up to the specific tender documents or the supplier.

3. Subtask 3: Operation Phase

3.1. Preface

This report is a subtask report within International Energy Agency (IEA) Technical Collaboration Platform (TCP) Energy Conservation through Energy Storage (ECES) Annex 27 - *Quality Management in Design, Construction and Operation of Borehole Systems.* The publication is the final report for IEA ECES Annex 27 Subtask 3: Operation Phase and is based on a survey on operation phase considerations, answered by the countries participating in the Annex.

Contributing countries: China, Denmark, Germany, Japan, Netherlands, Sweden, Turkey

Information provided by: Yang Lingyan (China), Henrik Bjørn (Denmark), Mathieu Riegger (Germany), Roman Zorn (Germany), Hagen Steger (Germany), Adinda Van de Ven (Germany), Roland Koenigsdorff (Germany), Manfred Reuß (Germany), Takao Katsura (Japan), Katsunori Nagano(Japan), Henk Witte (Netherlands), Signhild Gehlin (Sweden), Olof Andersson (Sweden), Adib Kalantar (Sweden), Yusuf Kagan Kadioglu (Turkey), Birol Kilkis (Turkey), Aysegül Cetin (Turkey), Suheyla Cetin (Turkey), Mert Oktay (Turkey), Ersin Girbalar (Turkey).

Authors: Takao Katsura and Katsunori Nagano, Hokkaido University. April 2019, Revised January 2020

3.2. Subtask Scope and Limitations

From a system point of view the subtask covers any BHE-system, regardless the size of application and the working temperatures used in the systems. The technical boundary is defined as the loop in which the heat carrier (fluid) is circulated.

The Subtask 3 scope has the objective of the supervision, the monitoring procedure, the motoring items, the monitoring points, the sensors, checking points and analyzing procedures.

This working paper is based on answers from two questionnaires. The first one answered by seven of the participating countries and discussed at the experts' meetings in Vancouver (EM6). The answers of the questionnaire are attached as appendix. The second one answered by four of the participating countries and discussed at the experts' meetings in Osaka (EM7). The contents of Section 2.4 (New technologies related to monitoring) were introduced based on the information from the participants of Annex27 working group.

The object of Subtask3 is to provide recommendations for best practice for operation of BHEs.

The IEA ECES Annex27 Subtask3 report covers the operation phase for any closed loop borehole system used for extraction and storage of thermal energy in the underground by the use of borehole heat exchangers (BHE).

3.3. Objectives of Supervision, Monitoring Procedures and Suggested Monitoring Items

The favored procedure of data acquisition for monitoring purposes depends on the size of the BHEs and the corresponding GSHP system. There are two main procedures for data acquisition: manual meter reading and automatized data acquisition. Monitoring of small size GSHP systems can be easily and economically carried out via manual meter reading. It is recommended to carry out a manual meter reading on a regular basis and at least monthly. Meanwhile, for middle or large size GSHP system, an automatized data acquisition procedure should be employed. The boundary between small and middle or large size is dependent on the countries (See **Appendix 3-1**) and the range is 12 ~ 30 kW. However, the small size GSHP systems is generally considered for residential buildings and the middle or large size GSHP system is considered for non-residential buildings.

The suggested monitoring items are summarized in ***Table 3-1*** and ***Table 3-2.*** They are summarized by referring to the questionnaire answers from experts in each country (See **Appendix 3-1**). According to the answer, the liquid temperature, pressure, and flow rate in the BHE side are the most important monitoring points in the small systems. Error messages displayed on the heat pump are also considered to be important. In the middle or large systems, the monitoring items to evaluate the efficiency are added and automatized data acquisition is required. Also, it is better to equip the temperature sensor and flow meter with high accuracy such as the Pt-100 and the electro-magnetic type flow meter because this is required to calculate the heat extraction/injection rate and the heating/cooling output. The data logging interval less than 60 minute is suggested (Usually the data logging interval is 1 min, 5 min, 10 min, 15 min or 60 min).

The purpose of monitoring is management and reliability of BHEs and GSHP systems for small size systems. For the middle size systems, energy performance of the BHEs and GSHP systems is also the major purpose. Influence on ambient underground environment and groundwater is considered for some large size systems. These are commonly recognized in each country (See **Appendix 3-1**).

Guideline documents on instrumentation, measurement, analysis and benchmarking of larger ground source heat pump system performance indices are currently being processed within the IEA HPT Annex 52 – Long-term performance measurement of GSHP systems serving commercial, institutional and multi-family buildings (https://heatpumpingtechnologies.org/annex52/). Steps are taken to standardize methods and analyses that will support widespread performance monitoring of ground-source heat pump systems.

Careful monitoring of GSHP and BTES system performance is important for several reasons. It will help to confirm that the installed GSHP/BTES system meets the intended design criteria, it will provide fault-detection possibilities, and help to improve and optimize design and system control. Feed-back provided by the performance monitoring is of use to building owners and management staff as well as to designers and component manufacturers.

The monitoring of BHEs and GSHP systems offers the following information:

- ***Management, reliability, and fault-detection of BHEs and GSHP systems***
- ***Energy performance of the BHEs and the GSHP systems***
- ***Influence on ambient underground environment and groundwater***

Table 3-1: Suggested monitoring items for small size GSHP systems or BHE systems

System Boundary			*Monitoring point*	*Monitoring item*	*Unit*
Boundary III	Boundary II		BHE side	Inlet and outlet liquid temperature	°C
Boundary III	Boundary II		BHE side	Flow rate of liquid	l/min
Boundary III	Boundary II		BHE side	Liquid pressure	MPa
Boundary III	Boundary II	Boundary I	Heat pump	Electric power	kW
Boundary III	Boundary II	Boundary I	Heat pump	Error messages	-
Boundary III	Boundary II	Boundary I	Heat pump	Refrigerant pressure (or temperature)	MPa
Boundary III	Boundary II	Boundary I	Heat pump	Outlet set temperature to heating or cooling side	°C
Boundary III			Heating or cooling side	Inlet and outlet liquid temperature	°C
Boundary III			Heating or cooling side	Flow rate of liquid	l/min
Boundary III			Heating or cooling side	Liquid pressure	MPa
			Ambient	Air temperature	°C

Table 3-2: Suggested monitoring items for middle or large size GSHP systems or BHE systems

System boundary	*Monitoring point*	*Monitoring item*	*Unit*	*Suggested sensor*	*Suggested data logging interval*
Boundary III, Boundary II	**BHE side**	Inlet and outlet liquid temperature	°C	Pt-100	1~15min*
Boundary III, Boundary II	**BHE side**	Flow rate of liquid	l/min	Electromagnetic type	1~15min*
Boundary III, Boundary II	**BHE side**	Liquid pressure	MPa	Pressure gauge	-
Boundary III, Boundary II	**BHE side**	Electric energy of circulation pumps	kWh	Electric power meter	1~15min*
Boundary III, Boundary II, Boundary I	**Heat pump**	Electric energy	kWh	Electric power meter	1~15min*
Boundary III, Boundary II, Boundary I	**Heat pump**	Error messages	-	-	-
Boundary III, Boundary II, Boundary I	**Heat pump**	Refrigerant pressure (or temperature)	MPa	Depending on manufacturing company	1~15min*
Boundary III, Boundary II, Boundary I	**Heat pump**	Outlet set temperature to heating or cooling side	°C	Depending on manufacturing company	-
Boundary III	**Heating or cooling side**	Inlet and outlet liquid temperature	°C	Pt-100	1~15min*
Boundary III	**Heating or cooling side**	Flow rate of liquid	l/min	Electromagnetic type	1~15min*
Boundary III	**Heating or cooling side**	Liquid pressure	MPa	Pressure gauge	-
Boundary III	**Heating or cooling side**	Electric energy of circulation pumps	kWh	Electric power meter	1~15min*
Boundary III	**Backup heater**	Electric energy	kWh	Electric power meter	1~15min*
	Ambient	Air temperature	°C	Thermistor	1~15min*
	Inside of BHEX	Temperature	°C	Thermocouples	1~15min*
	Observation well	Temperature	°C	Thermocouples	1~15min*
	Observation well	Ground water level	m	Groundwater level sensor	1~15min*
	Observation well	Ground water quality	pH	-	-

*calculating hourly average data is also desirable

System boundary description

The definition of the system boundaries is effective to determine the system boundaries that should be monitored. ***Figure 3-1*** shows the system boundaries. They are defined in the following way ***[2]***:

- System boundary Ⅰ: GSHP
- System boundary Ⅱ: BHE + GSHP
- System boundary Ⅲ: BHE + GSHP + Back-up heater
- System boundary Ⅳ: BHE + GSHP + Back-up heater + Heating/Cooling system

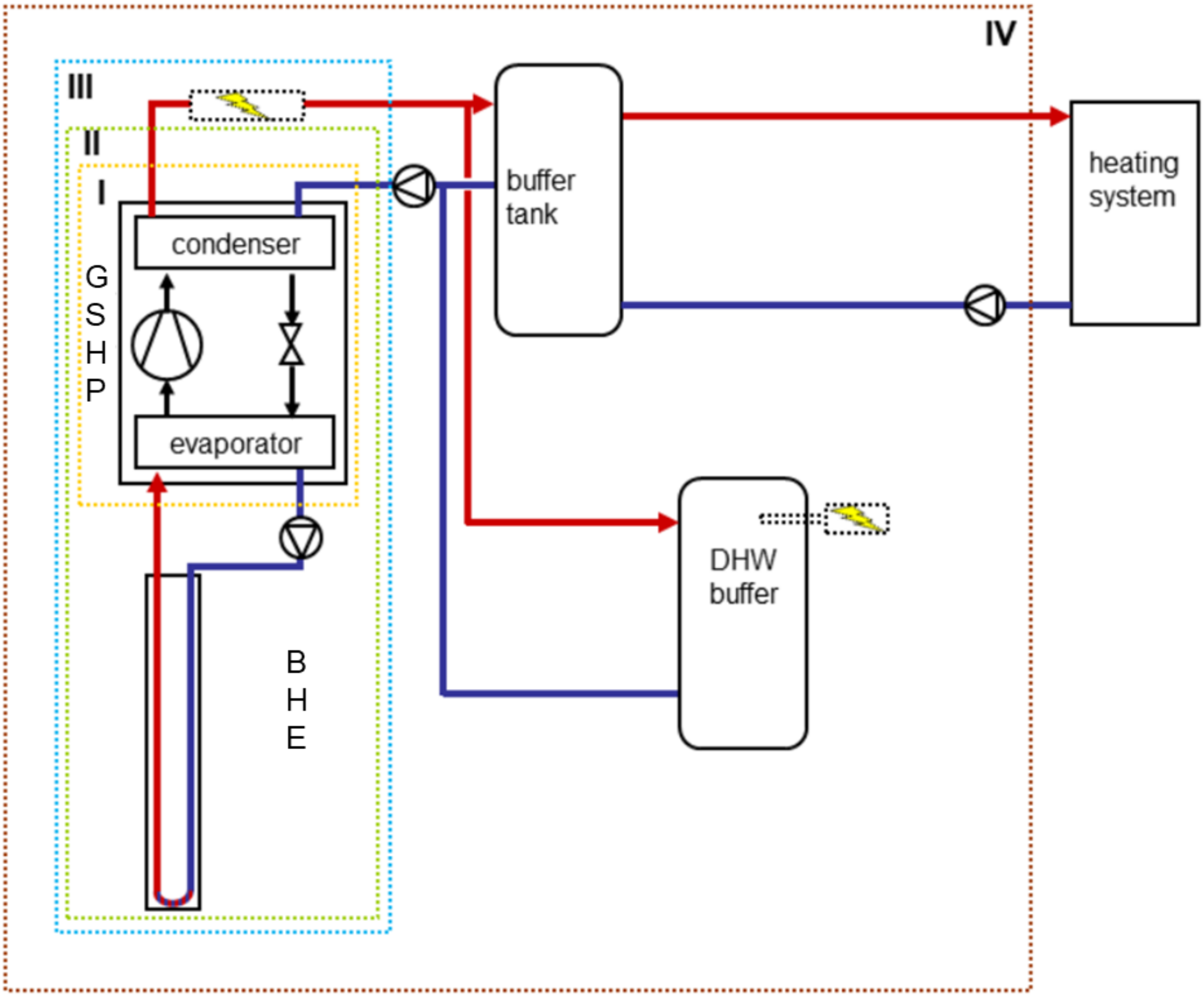


Figure 3-1: System boundaries ***[2]***

3.3.1. Management, Reliability, and Fault-Detection of BHEs and GSHP Systems

The GSHP system with BHEs requires very little maintenance. However, in order to operate GSHP system reliably, the following data can be easily checked:

- Minimal and maximal temperatures into the BHE
- Pressure drops over time in the geothermal loop
- Error messages of the GSHP

The minimum and maximum temperatures into the BHE can be assumed to correspond to the discharge temperatures of the brine out of the heat pump (evaporator or condenser) or out of the heat exchanger for direct geothermal cooling. These data can be picked up from most heat pumps (The details are introduced in **chapter 3.4.2**).

Furthermore, it might be worthwhile monitoring the actual amount of heat extracted/injected from/into the ground, especially if a change in the use of the building occurs. If the amounts exceed the design parameters c, measures must be taken to avoid too low or too high subsurface temperatures. In general, the energy extracted/injected from/into the ground can be determined from the heat pump as well.

For reliability purposes, it is recommended to monitor the control system boundary II shown in Figure 3-1, especially the temperatures and the pressure of the geothermal loop.

3.3.2. Energy Performance of the BHEs and the GSHP Systems

The energy performance of a GSHP system is decisively determined by the efficiency of the heat pump. Therefore, the system boundary for the energy performance calculation has to include the geothermal loop and the heat pump including an electrical backup heater (Boundary III in ***Figure 3-1***). This boundary represents the energy delivered by the generator and allows a neutral comparison with other heating systems. The system performance can be determined if the energy delivered by the heat pump and the energy extracted out of the subsurface or the energy consumed by the heat pump is known. Detailed analyses of the energy performance during operation crossing the III-boundary usually requires extra costs for metrology data acquistion. Therefore, this is only recommended for large size or costly (in purchase and/or operation) systems.

It is recommended to determine a uniform nationwide procedure both for manual meter reading as well as for automatized data acquisition to determine the energy performance of a GSHP system regarding the energy-delivered-by-generator-boundary (III).

3.3.3. Analyzing Influence on ambient Underground Environment and Groundwater

The influence of BHEs on the ambient underground environment and groundwater can be estimated by monitoring the discharge temperatures of the evaporator (in heating mode), the condenser (in mechanical cooling mode) or the heat exchanger for direct geothermal cooling (in direct geothermal cooling mode). If analyses that are more precise are required, costly investments might be necessary, e.g. additional drillings to monitor / control the groundwater level, regular sampling etc. Therefore, it is recommended to monitor the temperatures into the BHEs. If the temperatures drop or rise beyond design limits, additional measures have to be considered.

If there are no obligations for a detailed monitoring of the ambient underground environment and groundwater, it is recommended to just monitor the temperatures into the BHEs. If these first analyses are inadequate, additional measures can be implemented.

3.4. Monitoring for Small Size Systems

3.4.1. Monitoring Points and their Arrangement

Figure 3-2 shows the example of monitoring points and their arrangement for small size GSHP systems. As mentioned above, monitoring of small size GSHP systems is carried out via manual meter reading. The values displayed on the manual meter in the GSHPs are measured by the sensors equipped in the GSHPs. The sensors equipped in the GSHPs were investigated by providing the questionnaires to the GSHP manufacturing corporations in each country and collecting the answers. The results are shown in **chapter 3.4.2**. However, the some GSHPs do not have sensors at the suggested monitoring points in ***Table 3-1***: Suggested monitoring items for small size GSHP systems or BHE systems**.** In this scenario, it is required to equip the system with simple and economical sensors at the suggested points.

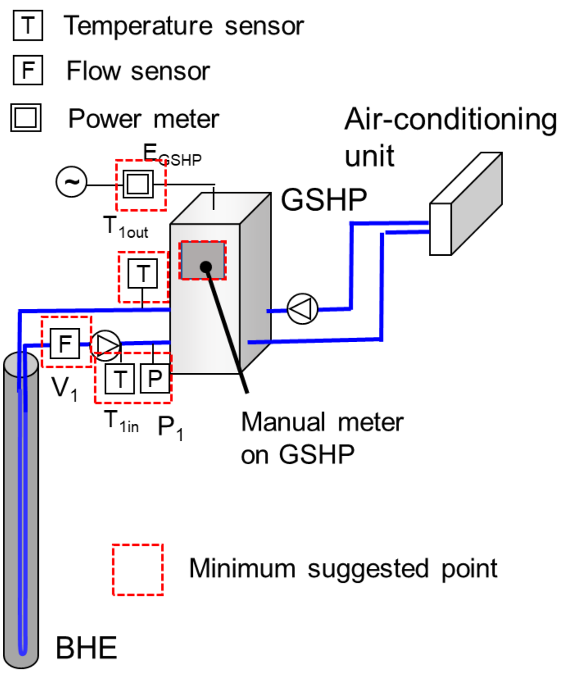


Figure 3-2: Monitoring points and arrangement for small size GSHP systems

Figure 3-3 shows an example of simple digital temperature sensor and direct reading type flow meter. Instead of simple digital temperature sensor, the direct reading type temperature sensor ***[3]*** shown in Figure 3-4 is available. Figure 3-5 is an example of direct read type liquid pressure gauge ***[4]***. Also, the electric power consumption of GSHP can also be measured by using a watt checker ***[5]*** shown in ***Figure 3-6***. This equipment does not have the data logging function, however, they are available at a fairly low cost (< 100 USD/sensor).

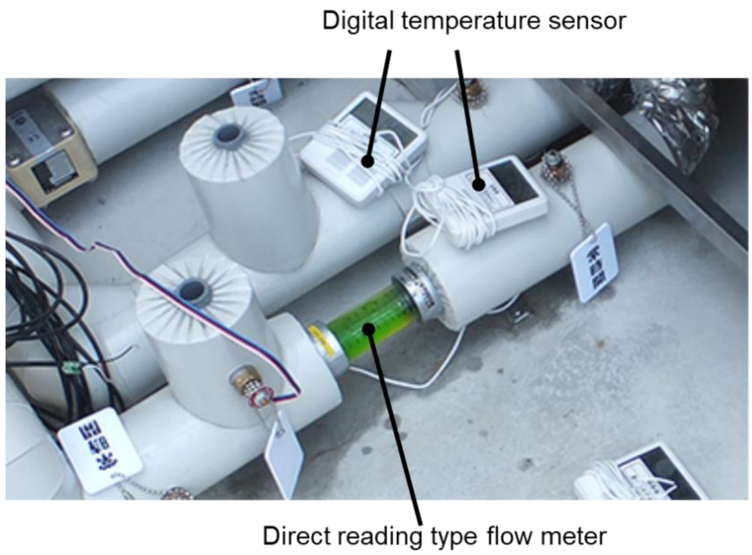


Figure 3-3: An Example of simple digital temperature sensor and direct reading type flow meter

Figure 3-4: An example of direct reading type temperature sensor

3.4.2. Monitoring Sensor in Heat Pump

As mentioned above, the manual meter reading can be carried out by using the measured value displayed on the GSHP if the GSHP has the monitoring sensors. The authors distributed the questionnaire related to the monitoring inside heat pump to the manufacturing companies.

Figure 3-5: An example of direct reading type pressure gauge ***[4]***

The questions were as follows:

- Is the monitoring carried out at the point?
- If 1-1 is ○, what kind of sensor is used for monitoring?
- If 1-1 is ○, is it possible to display the data or collect the data?

Table 3-3 summarizes the answer to question 3-1 (see **Appendix 3-1**). In Japan, the only Japanese manufacturer of small size heat pumps answered as shown in ***Table 3-3***. European small size heat pump manufacturers elected not answer the questionnaire due to confidentiality issues... However, the answers as shown in ***Table 3-3*** were obtained by collecting the general answers from the Swedish Heat Pump Association. These results indicate that the inlet/outlet temperatures for both Borehole and HVAC sides are generally monitored. Flow rate are sometimes monitored. In Germany, for some funding programs the overall heat supplied by the heat pump as well as the overall amount of electricity consumption of the heat pump has to be measured, although the monitoring points are not indicated in ***Table 3-3***.

Figure 3-6: An example of watt checker

With regard to the answer to question 3-2 (see **Appendix 3-1**), the Pt-100 sensors or NTC thermistors are used to measure the temperature. In Germany, the Pt-1000 temperature sensors are also used. Pressure sensors are dependent on the product supplier. Flow sensors are commonly used to measure the fluid flow rates and heat meters are also sometimes employed. As the answer to question 3-3 (see **Appendix 3-1**), the monitored data commonly is displayed but not be collected / logged. In addition, the monitored data is directory indicated on a display on the heat pump itself as shown in ***Figure 3-8***. Recently, if the heat pump is connected to the internet, it may be displayed using manufacturers applications. In addition, it is possible to collect the monitoring data with smart phone applications.

Summarizing the above, almost all heat pumps have the monitoring points that satisfy minimum suggested points and provide the monitoring data directly. Therefore, the small size BHEs and GSHP systems usually can be managed by using manual meters (Data display on the heat pump).

Table 3-3: Existence or nonexistence of monitoring points in heat pump obtained by questionnaire (The monitoring points are indicated in Figure 2.2.6)

Monitoring point		***Japan – Heat pump manufacturer***	***Sweden – General***
Liquid in borehole side	Inlet temperature $T_{1, in}$	○	○
	Outlet temperature $T_{1, out}$	○	○
	Pressure P_1	X	X
	Flow rate V_1	○	X
Liquid in HVAC side	Inlet temperature $T_{2, in}$	○	○
	Outlet temperature $T_{2, out}$	○	○
	Pressure P_2	X	X
	Flow rate V_2	○	X
Refrigerant side	Suction temperature of compressor $T_{Com, in}$	X	○
	Suction pressure of compressor $P_{Com, in}$	X	Δ
	Discharge temperature of compressor $P_{Com, out}$	○	○
	Discharge pressure of compressor $P_{Com, out}$	X	Δ
	Outlet temperature of condenser $T_{Con, out}$	○	X
	Outlet pressure of condenser $P_{Con, out}$	X	X
	Outlet temperature of expansion valve $T_{Ex, out}$	○	X
	Outlet pressure of expansion valve $P_{Ex, out}$	X	X
	Outlet temperature of evaporator $T_{Eva, out}$	X	X
	Outlet pressure of evaporator $P_{Eva, out}$	X	X
	Electric power of compressor	○	X
	Compressor frequency	X	X
	Opening of expansion valve	X	X

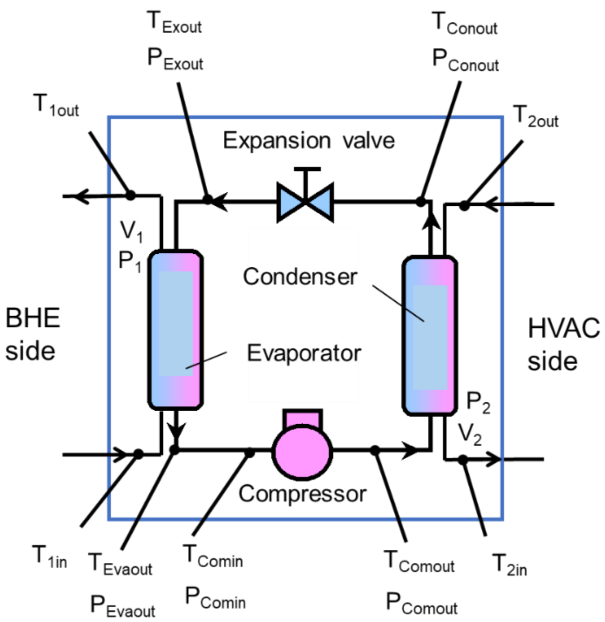


Figure 3-7: Monitoring points in heat pump

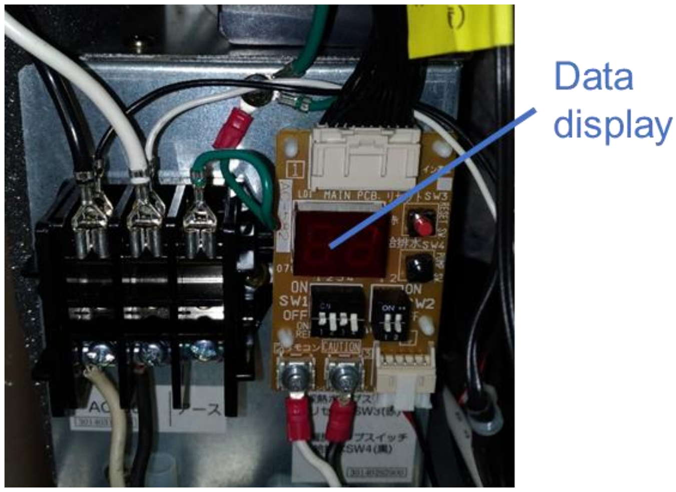


Figure 3-8: Example of data display on heat pump

3.4.3. Check Points

The check points are described as the following:

- Liquid temperature in BHE side: -10 °C < Temperature < 40 °C
- *Temperature difference of liquid between inlet and outlet in BHE side*: 3 °C < ΔT < 6 °C
- *Liquid pressure in BHE side*: 0.1 MPa < Pressure < 0.5 MPa
- Discharge refrigerant temperature at compressor: Temperature < 100 °C
- Error messages: Message part
- Liquid temperature in heating/cooling side: 7 °C < Temperature < 65 °C
- *Temperature difference of liquid between inlet and outlet in heating/cooling side*: 3 °C < ΔT< 20 °C
- *Liquid pressure in heating/cooling side*: 0.1 MPa < Pressure < 0.6 MPa

3.5. Monitoring for middle or large size systems

3.5.1. Monitoring Points and their Arrangement

The sensors equipped in the GSHPs were also investigated by providing the questionnaires to the GSHP manufacturing corporations in each country and collecting the answers. The results are shown in **chapter 3.5.2**. However, in the middle or large size systems, it is required to install further system sensors in addition to the sensors within GSHPs. ***Figure 3-9*** shows the example of monitoring points and their arrangement for middle or large size GSHP systems.

Points to keep in mind to install the sensors are described in the following.

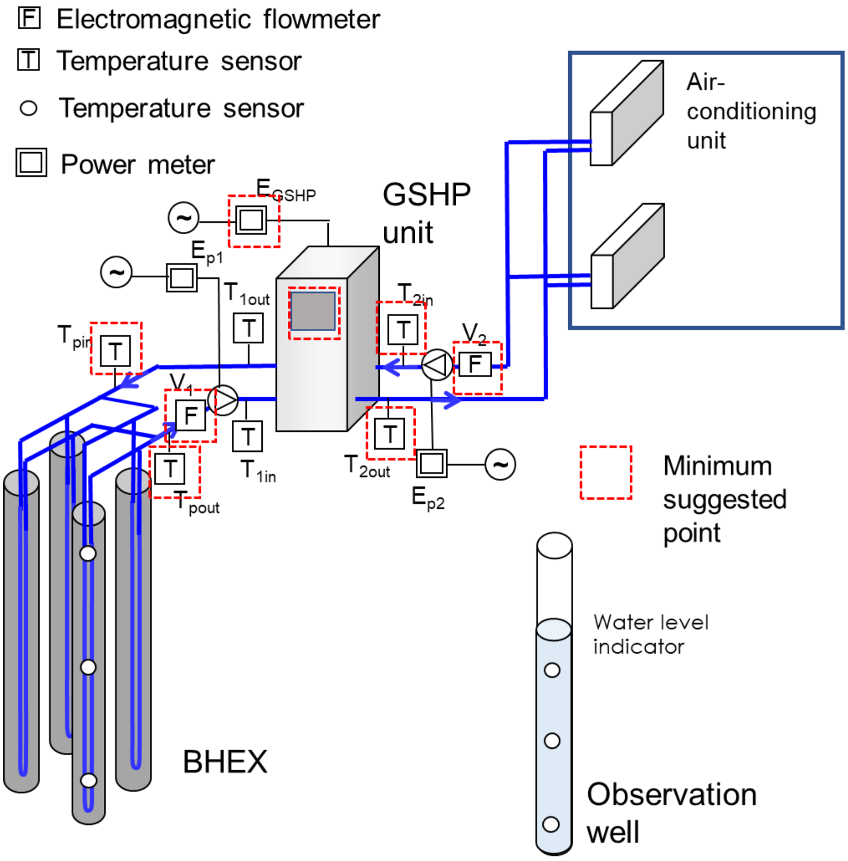


Figure 3-9: Example of monitoring points and their arrangement

Liquid temperature

For proper measurement of the liquid temperatures in the BHEs and GSHP systems, the temperature sensors shall be integrated as shown in ***Figure 3-10 [2]***. The most accurate sensor integration is position "a" in ***Figure 3-10*** and the example of accurate sensor integration is shown in ***Figure 3-11.***

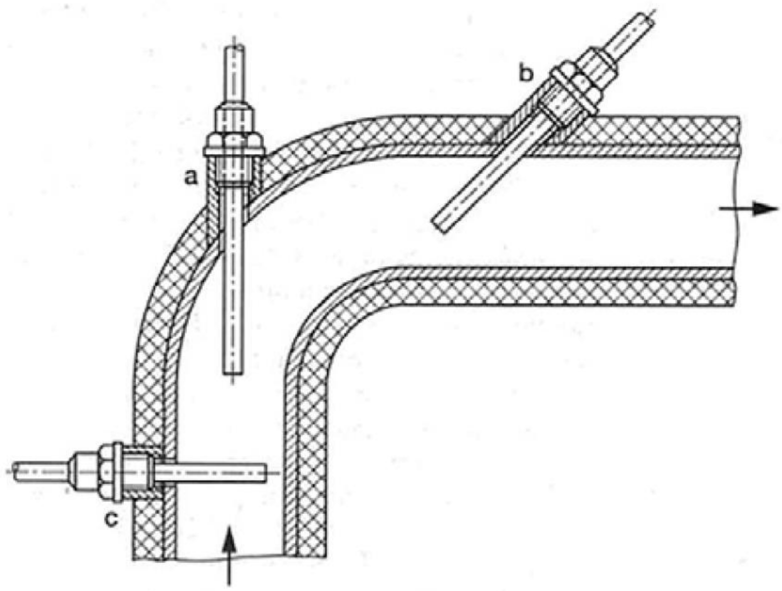


Figure 3-10: Liquid temperature integration

Flow meter

For installing the flow meter, it is necessary to have certain upstream (A) and downstream (B) sensors as shown in ***Figure 3-12 [2]*** to avoid turbulence in the flow meter. The flow meter shall be assembled as recommended by the manufacturer and the flow direction needs to be checked. The correct flow direction is shown by arrow on the flow meter (***Figure 3-13***). The integration of the flow meter shall be assembled as recommended by the manufacturer.

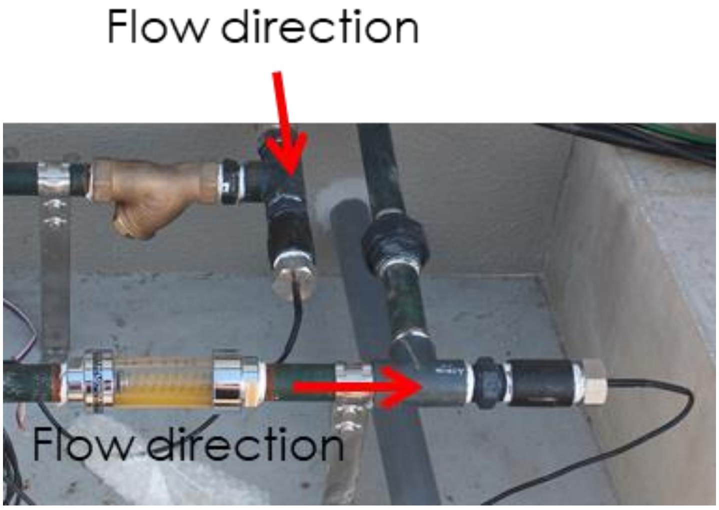


Figure 3-11: Example of accurate sensor integration

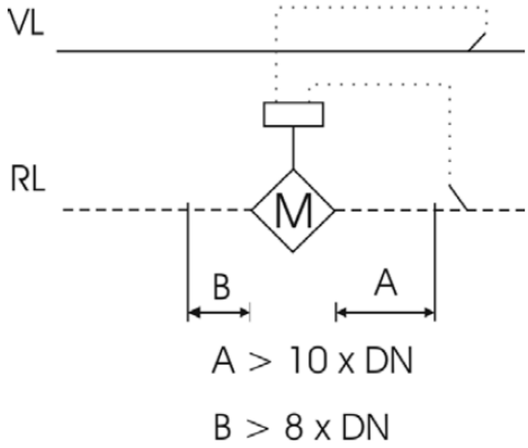


Figure 3-12: Inlet zone and downstream of the flow meter ***[2]***

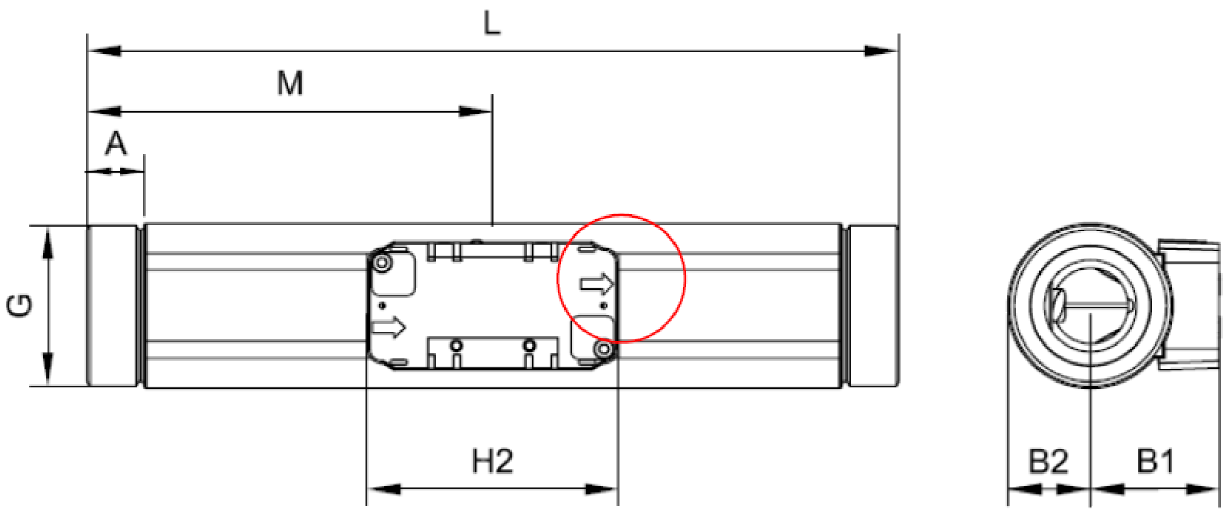


Figure 3-13: Flow direction ***[2]***

Power meter

Because there is the danger of electric shock in case of installing the power meter, it is required to take care to prevent the electric shock. For installing the power meter, voltage should be measured in the secondary side of breaker as shown in ***Figure 3-14 [6]***. ***Figure 3-15*** shows the example of current measuring ***[6]***.

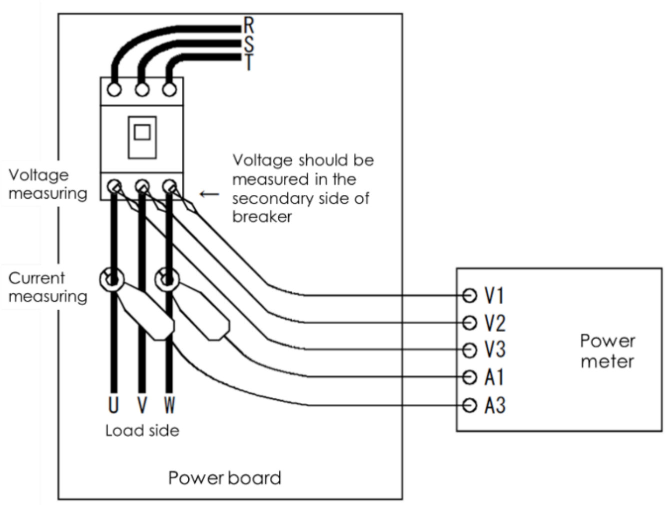


Figure 3-14: Installing power meter ***[6]***

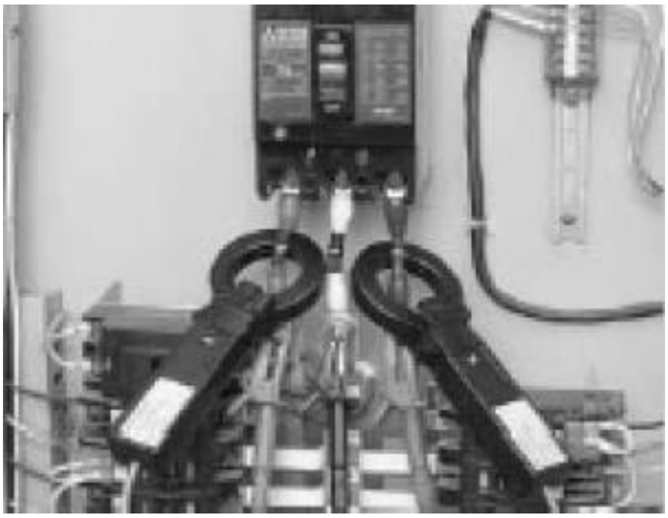


Figure 3-15: Example of current measuring ***[6]***

3.5.2. Monitoring Sensor in Heat Pump

As mentioned above, the manual meter reading can be carried out by documenting the measured value displayed on the GSHP if the GSHP has these monitoring sensors. The authors distributed the questionnaire related to the monitoring inside heat pump to the manufacturing companies.

The questions are the followings:

- Is the monitoring carried out at the point?
- If 1-1 is ○, what kind of sensor is used for monitoring?
- If 1-1 is ○, is it possible to display the data or collect the data?

Table 3-4 summarizes the answer to question 1-1 (see **Appendix 3-1**). In Japan, although some heat pump manufacturers (There is equipment from Japanese and European heat pump manufacturers available in Japan) did not answer due to the manufacturers' confidentiality requirements, three Japanese heat pump manufacturers answered as shown in ***Table 3-4***. One of heat pump manufacturers has two types heat pump (Heat pump chiller and VRF), therefore two answers were provided. All heat pumps have sensors for temperatures of liquid at the inlet/outlet at both Borehole and HVAC sides. In addition, there are some monitoring points in the refrigerant circuit, but the monitoring points of heat pumps differ from one manufacturer to the other. On the other hand, the monitoring of flow rate and pressure are rarely provided. It is required to set the sensors external of heat pump to measure the flow rate and pressure. In Sweden and Germany, the heat pump manufacturers also did not answer due to the manufacturers' confidentiality requirements as was the situation with small size heat pump. However, the answers as shown in ***Table 3-4*** were obtained by collecting the general answers from the Swedish Heat Pump Association. In Germany, the answers as shown in ***Table 3-4*** were obtained based on the AMEV (Arbeitskreis Maschinen- und Elektrotechnik staatlicher und kommunaler Verwaltungen)-Recommendation "Technical monitoring". The monitoring points for heat pumps with a nominal capacity of > 50 kW are listed. The temperatures of liquid at the inlet/outlet in the both sides are measured as well as in Japan. There is no information of monitoring of the refrigerant circuit because the majority of heat pump manufacturers did not answer. In Canada, one heat pump manufacturer answered. The monitoring points are similar to the monitoring points of Japanese heat pump manufacturers.

The answers to question 1-2 and 1-3 (see **Appendix 3-1**) are summarized in ***Table 3-5.*** They are only answers from Japanese heat pump manufacturers. Most of heat pump manufacturers choose the NTC thermistors for temperature measurement and Pt-100s are sometimes used. Diaphragm pressure sensors and CT are commonly used to measure the pressure and electric power consumption, respectively. With regard to the answer to question 1-3 (see **Appendix 3-1**), two heat pump manufacturers answered that it is possible to collect the data by using the additional data logging systems. However, if the monitoring and data monitoring is required, the there is an additional cost charged. One manufacturer answered that it is possible to display the data, but it is impossible to collect the data. In Sweden, the data can be displayed as shown in ***Figure 3-16*** and data series can be accessed and collected for the larger heat pumps. Data is stored locally and transferred to a database on an annual basis. Some calculated data is calculated and shown locally. Also, in Sweden, the display and data collection are considered optional. In Germany, the kinds of sensors are dependent on the producer and designer of the system. The AMEV-Recommendation defines minimum requirements for the design of monitoring reports. The central information of the reports is to transfer data to determine if the target values of the planning have been achieved and/or maintained in operation. In addition, a few manufacturers offer the possibility to export the data to be viewed externally.

Summarizing the above, some heat pumps have monitoring capabilities which can satisfy the suggested monitoring points, and the monitoring data can be optionally collected. Therefore, using the additional monitoring systems provided by the heat pump manufacturers is effective to evaluate the energy performance of the BHEs and the GSHP systems.

Table 3-4: Existence or nonexistence of monitoring points in heat pump obtained by questionnaire (The monitoring points are indicated in Figure 2.2.6)

Monitoring Point		***Japan***				***Sweden***	***Germany***	***Canada***
		Heat pump manufacturer 1-1 (Heat pump)	Heat pump manufacturer 1-2 (VRF)	Heat pump manufacturer 2 (Heat pump)	Heat pump manufacturer 3 (Heat pump)	General	General	Heat pump manufacturer
Liquid in borehole side	Inlet temperature $T_{1, in}$	○	○	○	○	○	○	○
	Outlet temperature $T_{1, out}$	○	○	○	○	○	○	○
	Pressure P_1	Δ (Option)	X	X	X	X	X	○
	Flow rate V_1	Δ (Option)	Δ (Option)	X	X	X	○	○
Liquid in HVAC side	Inlet temperature $T_{2, in}$	○	-	○	○	○	○	○
	Outlet temperature $T_{2, out}$	○	-	○	○	○	○	○
	Pressure P_2	Δ (Option)	-	X	X	X	X	X
	Flow rate V_2	Δ (Option)	-	X	X	X	○	X
Refrigerant side	Suction temperature of compressor $T_{Com, in}$	○	○	○	X	X	X	○
	Suction pressure of compressor $P_{Com, in}$	X	○	○	○	X	X	○
	Discharge temperature of compressor $P_{Com, out}$	○	○	○	○	X	X	○
	Discharge pressure of compressor $P_{Com, out}$	○	○	○	○	X	X	○
	Outlet temperature of condenser $T_{Con, out}$	X	○	○	○	X	X	○
	Outlet pressure of condenser $P_{Con, out}$	X	X	X	X	X	X	X
	Outlet temperature of expansion valve $T_{Ex, out}$	X	○	X	○	X	X	X
	Outlet pressure of expansion valve $P_{Ex, out}$	X	X	X	X	X	X	X
	Outlet temperature of evaporator $T_{Eva, out}$	X	○	X	X	X	X	X
	Outlet pressure of evaporator $P_{Eva, out}$	X	X	X	X	X	X	X
	Electric power of compressor	Δ (Option)	Δ (Option)	X	○	○	○	X
	Compressor frequency	○	○	○	X	X	X	○
	Opening of expansion valve	X	○	○	X	X	X	X

Table 3-5: Sensor names and display, data logging at monitoring points in heat pump obtained by questionnaire

Monitoring Point		***Japan***								***Canada***	
		Heat pump manufacturer 1-1 (Heat pump)		Heat pump manufacturer 1-2 (VRF)		Heat pump manufacturer 2 (Heat pump)		Heat pump manufacturer 3 (Heat pump)		Heat pump manufacturer (Heat pump)	
		Sensor Name	Display, Data logging	Sensor Name	Display, Data logging	Sensor Name	Display, Data logging	Sensor Name	Display, Data logging	Sensor Name	Display, Data logging
Liquid in BHE side	Inlet temperature $T_{1, in}$	Pt-100	C	Pt-100	C	NTC Thermistor	B	NTC Thermistor	C	NA	C
	Outlet temperature $T_{1, out}$	Pt-100	C	Pt-100	C	NTC Thermistor	B	NTC Thermistor	C	NA	C
	Pressure P_1	Diaphragm	C							NA	C
	Flow rate V_1	Electro-magnetic flow sensor	C	Electro-magnetic flow sensor	C					NA	C
Liquid in HVAC side	Inlet temperature $T_{2, in}$	Pt-100	C			NTC Thermistor	B	NTC Thermistor	C	NA	C
	Outlet temperature $T_{2, out}$	Pt-100	C			NTC Thermistor	B	NTC Thermistor	C	NA	C
	Pressure P_2	Diaphragm	C								
	Flow rate V_2	Electro-magnetic flow sensor	C								
Refrigerant side	Suction temperature of compressor $T_{Com, in}$	NTC Thermistor	C	NTC Thermistor	C			NTC Thermistor	C	NA	C
	Suction pressure of compressor $P_{Com, in}$			Diaphragm	C	Diaphragm	B	Diaphragm	C	NA	C
	Discharge temperature of compressor $P_{Com, out}$	NTC Thermistor	C	NTC Thermistor	C	NTC Thermistor	B	NTC Thermistor	C	NA	C
	Discharge pressure of compressor $P_{Com, out}$	Diaphragm	C	Diaphragm	C	Diaphragm	B	Diaphragm	C	NA	C
	Outlet temperature of condenser $T_{Con, out}$			NTC Thermistor	C	NTC Thermistor	B	NTC Thermistor	C	NA	C
	Outlet pressure of condenser $P_{Con, out}$										
	Outlet temperature of expansion valve $T_{Ex, out}$			NTC Thermistor	C	NTC Thermistor	B				
	Outlet pressure of expansion valve $P_{Ex, out}$										
	Outlet temperature of evaporator $T_{Eva, out}$			NTC Thermistor	C						
	Outlet pressure of evaporator $P_{Eva, out}$										
	Electric power of compressor	CT	C	CT	C	CT	B				
	Compressor frequency	Inverter Information	C	Inverter Information	C			Inverter Information	C	NA	C
	Opening of expansion valve			Controller Information	C			Controller Information	B		

Remarks:

- A: The sensor is used for only control, it is impossible to display the data.
- B: It is possible to display the data but it is impossible to collect the data
- C: It is possible to collect the data by using the additional data logging system

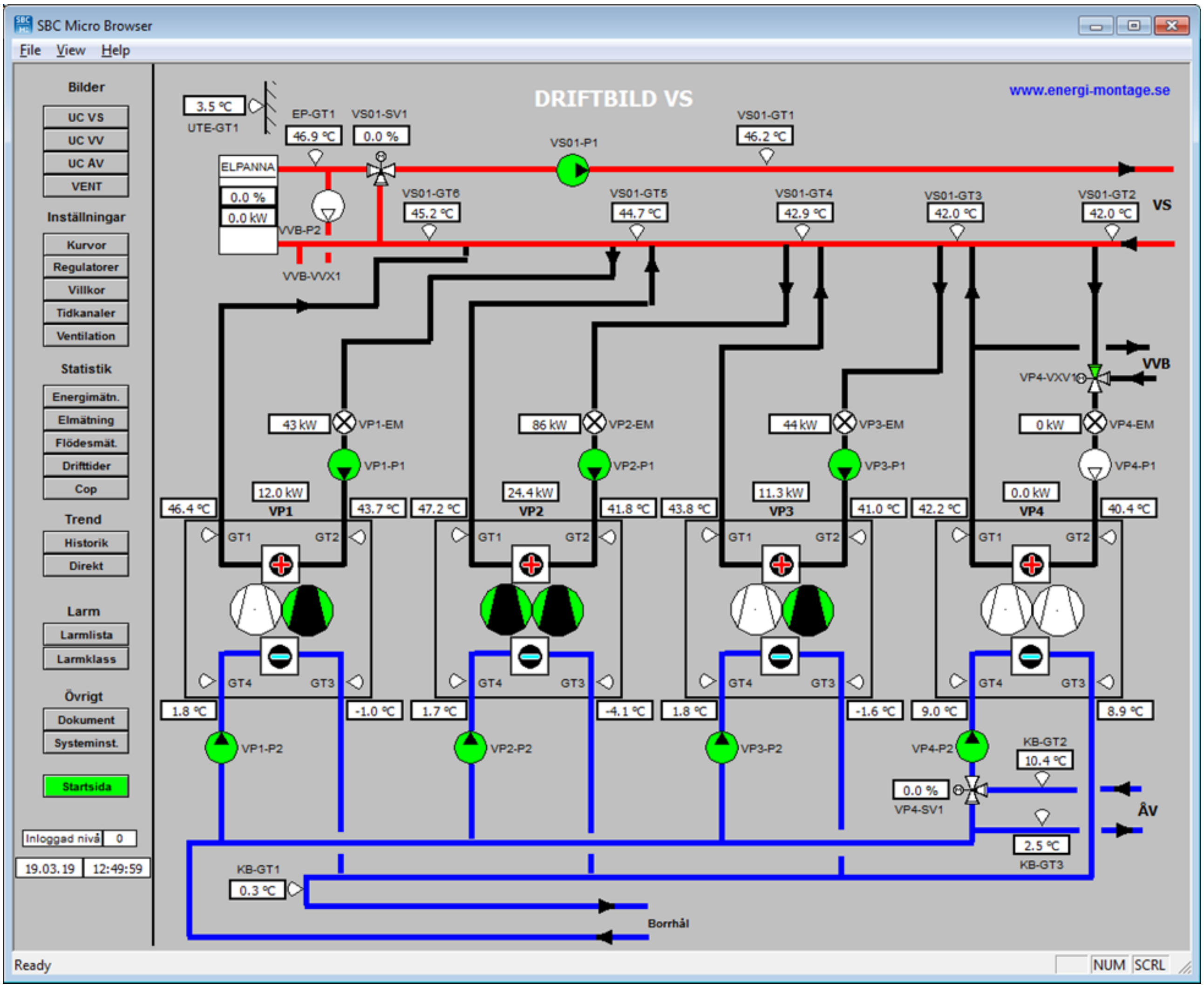


Figure 3-16: Example of monitoring display

3.5.3. Analyzing Procedure

The following basic analyzing procedures are explained in this section.

- Temperature variation of liquid
- Temperature variation of inside of borehole heat exchanger and underground temperature surrounding borehole heat exchangers
- Variation of flow rate
- Amount of exchanged heat by BHEs
- Thermal output from GSHP system
- Electric power consumption of the heat pump and subsystems (e.g. Circulation pump, auxiliary electric heater)
- COP and SPF
- Energy saving
- Reduction of CO_2 emission
- Temperature variation of liquid according to amount of injected/extracted heat into/from borehole heat exchanger (To validate design and simulation tool)
- Electric energy of heat pump and subsystem or COP and SPF before and after the optimization

The symbols which are used for the equations below are shown in ***Figure 3-9.***

Temperature variation of liquid

Temperature variations of liquid ($T_{1,in}$, $T_{1,out}$, $T_{p,in}$, $T_{p,out}$ in ***Figure 3-9***) are used to confirm the long-term operation of BTES and GSHP system. The example of temperature variation of liquid is shown in ***Figure 3-17.*** It is recommended to use the average data of 1 hour when the long-term data for more than 1 year is analyzed.

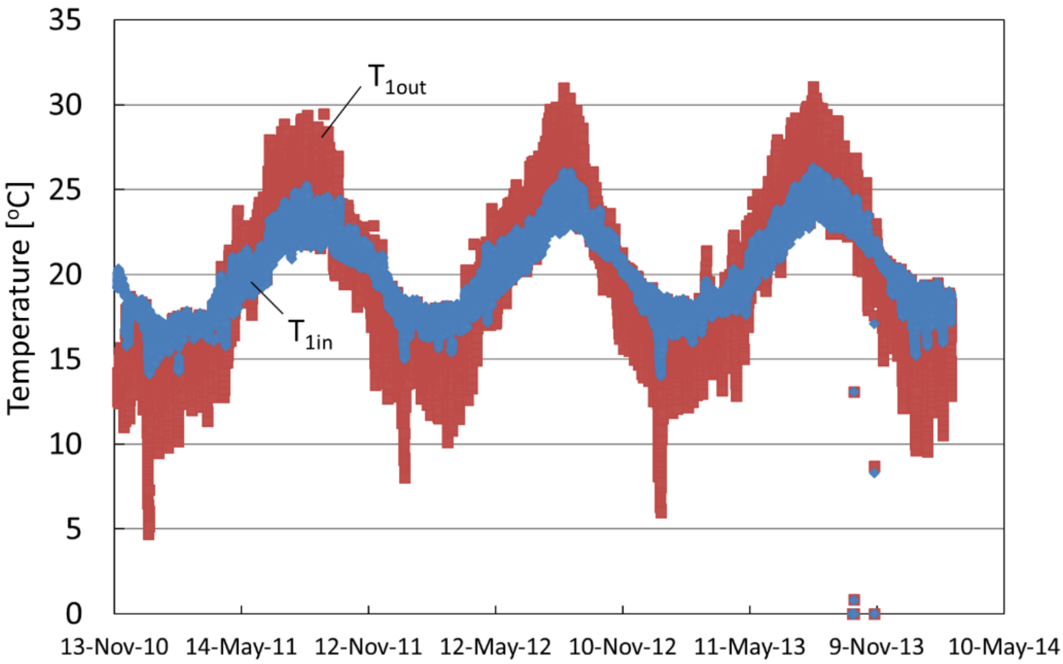


Figure 3-17: Example of temperature variation of liquid (Time interval of data is 1 hour)

Temperature variation of the inside the borehole heat exchanger and underground

- Temperature variations of the inside of borehole heat exchanger and underground are also used to confirm the long-term operation of BTES and GSHP system. In addition, if the vertical temperature profile is monitored, it is possible to understand the local ground water flow. The example of temperature variation inside of BHE is shown in ***Figure 3-18.***

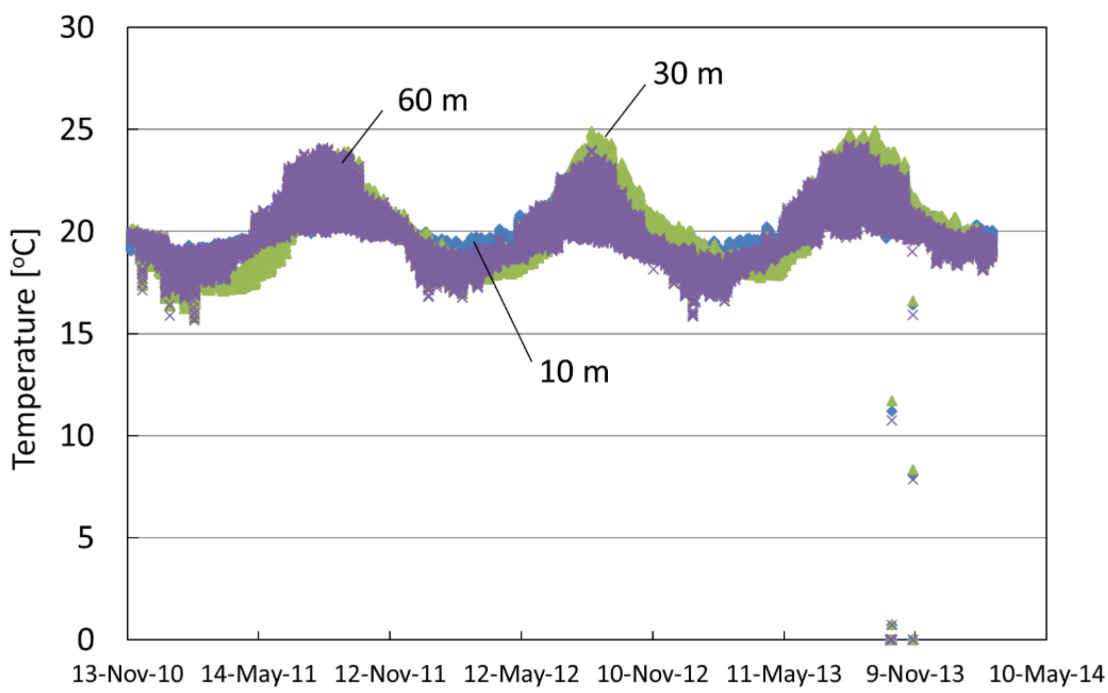


Figure 3-18: Example of temperature variation inside of BHE (Time interval of data is 1 hour)

Variation of flow rate

Variation of flow rate is used to check the operation of BTES and GSHP system. ***Figure 3-19*** shows example of variation of flow rate. If the operation of BTES and GSHP system are checked, the data in a short period of time (daily ~ weekly) is analyzed as ***Figure 3-19.*** In this example, the data for a short time interval (second ~ minute) is used.

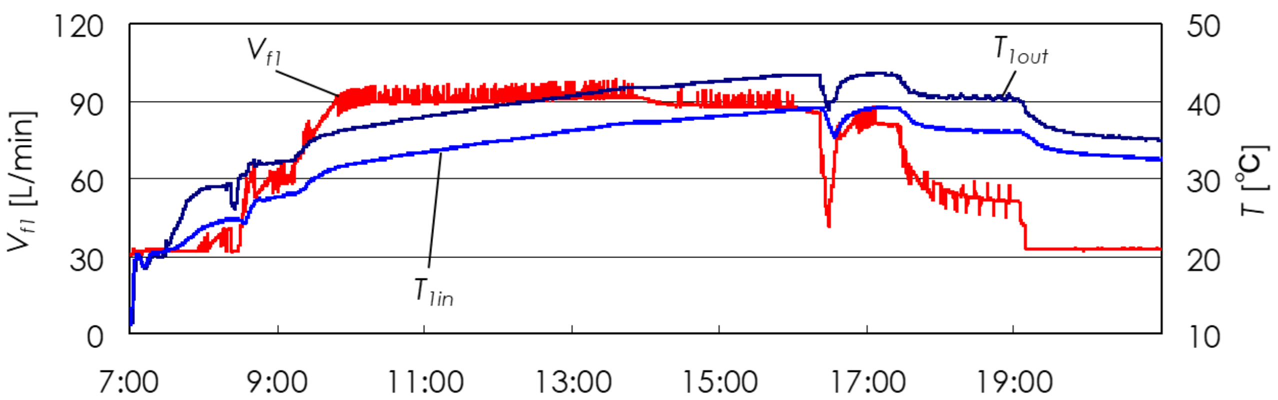


Figure 3-19: Example of variation of flow rate (Time interval of data is 1 minute)

Heat extraction/injection rate from/into BHEs

The amount of extraction/injection rate from/into BHEs is used to evaluate the performance of BHEs. The amount of extraction/injection rate from/into BHEs Q_{BHEX} [kW] can be calculated by the following equation.

$$Q_{BHEX} = c_{p1}\rho_1 V_1 (T_{pout} - T_{pin}) \qquad (3\text{-}1)$$

- c_{p1}: *Specific heat of liquid in BHEs side of GSHP [kJ/kg]*
- ρ_1: *Density of liquid in BHEs of GSHP [kg/m³]*
- V_1: *Flow rate of liquid in BHE side of GSHP [m³/s]*
- T_{pout}: *Liquid temperature at outlet of BHEs [°C]*
- T_{pin}: *Liquid temperature at inlet of BHEs [°C]*

If we can assume that there is no heat loss or heat gain in the pipeline in ***Figure 3-9***, $T_{pout} = T_{1in}$, $T_{pin} = T_{1out}$. Therefore, it is possible to calculate Q_{BHEX} by the following equation.

$$Q_{BHEX} \cong c_{p1}\rho_1 V_1 (T_{1in} - T_{1out}) \qquad (3\text{-}2)$$

- T_{1out}: *Liquid temperature at outlet in the primary side of GSHP [°C]*
- T_{1in}: *Liquid temperature at inlet in the primary side of GSHP [°C]*

The example of variation of Q_{BHEX} is shown in ***Figure 3-20.*** Also, the example of integrated value of Q_{BHEX} is shown in ***Figure 3-21.***

Also, plotting the relation between the heat extraction rate and the temperature difference is effective to evaluate the borehole heat exchangers. ***Figure 3-22*** is the example of relation between the heat extraction rate and the temperature difference. The temperature difference ΔT is calculated by the following equation.

$$\Delta T = \frac{(T_{pin} + T_{pout})}{2} - T_{s0} \qquad (3\text{-}3)$$

- T_{s0}: *Undisturbed ground temperature [°C]*

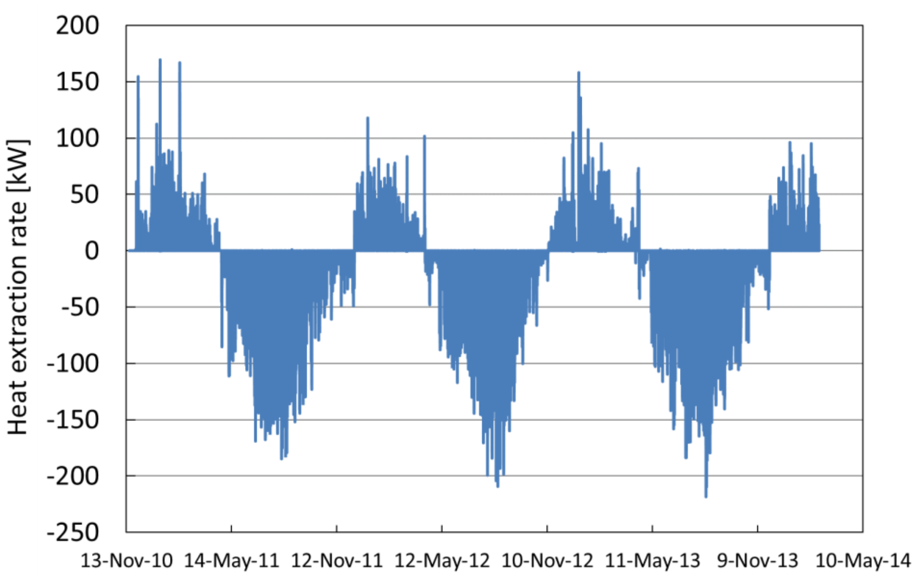


Figure 3-20: Example of variation of Q {BHEX}, (Time interval of data is 1 hour)

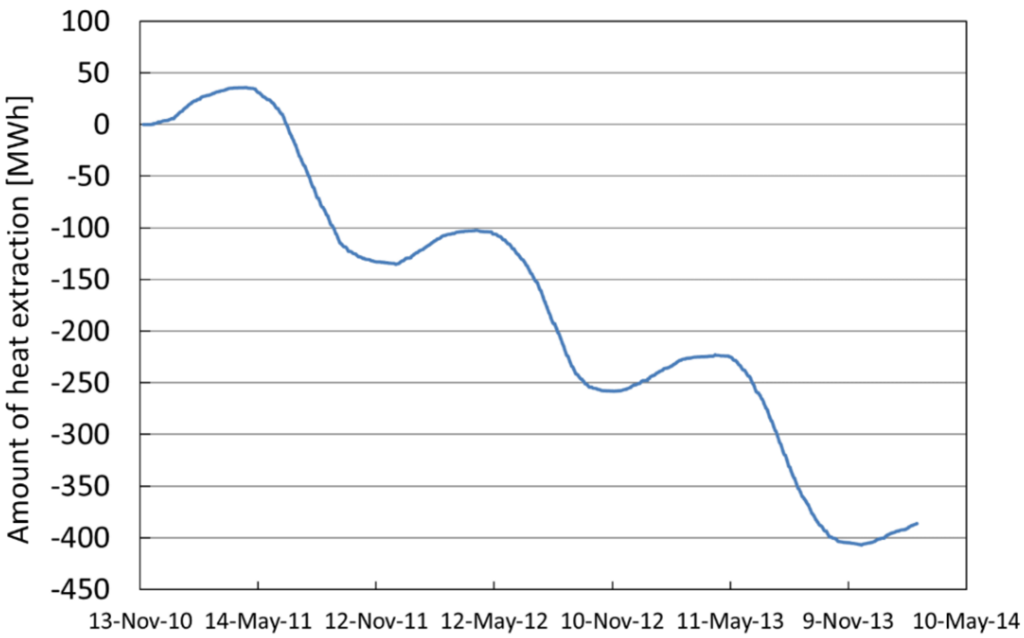


Figure 3-21: Example of integrated value of Q_{BHEX}, (Time interval of data is 1 hour)

Thermal output from GSHP

Here, the heating output is expressed as the positive value and cooling output is expressed as the negative value. The thermal output from GSHP system Q_{GSHP} [kW] can be expressed by the following equation.

$$Q_{GSHP} = c_{p2}\rho_2 G_2 (T_{2out} - T_{2in}) \qquad (3\text{-}4)$$

- c_{p2}: *Specific heat of liquid in the heating/cooling side of GSHP [kJ/kg]*
- ρ_2: *Density of liquid in the heating/cooling side of GSHP [kg/m3]*
- V_2: *Flow rate of liquid in the heating/cooling side of GSHP [m3/s]*
- T_{2out}: *Liquid temperature at outlet in the heating/cooling side of GSHP [oC]*
- T_{2in}: *Heat carrier fluid temperature at inlet in the heating/cooling side of GSHP [oC]*

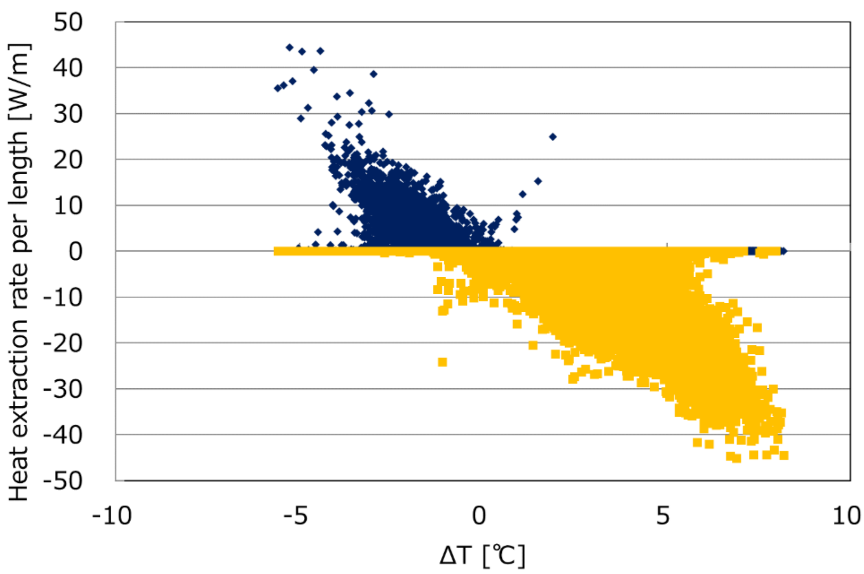


Figure 3-22: Relation between heat extraction rate and temperature difference (Time interval of data is 1 hour)

In addition, if the heating/cooling side is the direct expansion type, the thermal output Q_{GSHP} is calculated by using the exchanged heat Q_{BHEX} and the electric power of compressor - W_{com}.

In the case of heating operation, Q_{GSHP} is expressed as the following.

$$Q_{GSHP} = Q_{BHEX} + W_{com} \cong Q_{BHEX} + W_{GSHP} \quad (3\text{-}5)$$

In the case of cooling operation, Q_{GSHP} is,

$$Q_{GSHP} = Q_{BHEX} - W_{com} \cong Q_{BHEX} - W_{GSHP} \quad (3\text{-}13)$$

- *W_{com}: Electric power of compressor [kW]*
- *W_{GSHP}: Electric power of GSHP unit [kW]*

The example of variation of Q_{GSHP} is shown in ***Figure 3-23.***

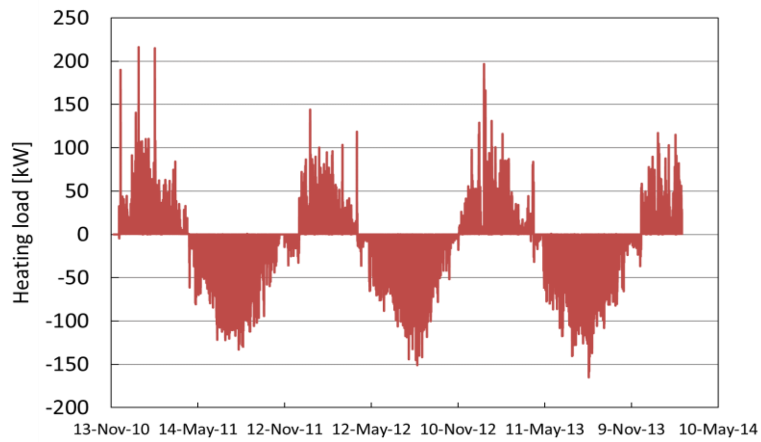


Figure 3-23: Example of variation of Q_{GSHP}, (Time interval of data is

Electric power of heat pump and subsystem (e.g. Circulation pump, auxiliary electric heater)

Electric power consumption of heat pump and subsystems is used to check the operation of GSHP system. If degradation of GSHP's COP is due to short cycling times, using the data with short time intervals is recommended (Second ~ Minute). ***Figure 3-24*** shows an example of variation of Q_{GSHP} and W_{GSHP}.

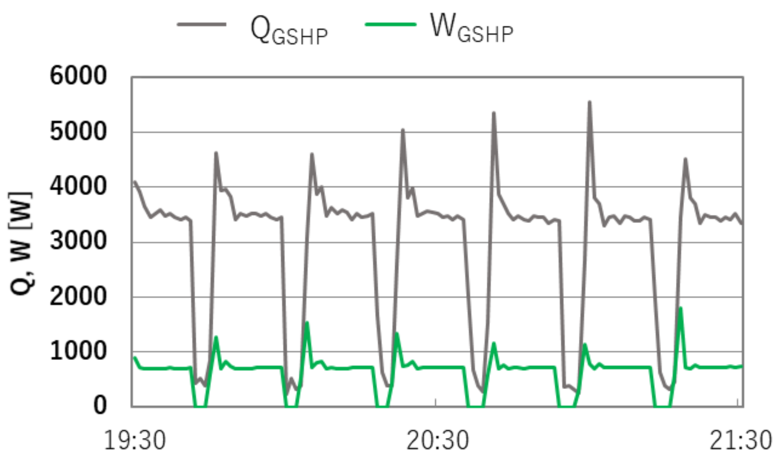


Figure 3-24: Example of variation of Q_{GSHP} and W_{GSHP} in the short time period (Time interval of data is 1 minute)

COP and SPF

SPF_1 includes only the heat pump unit itself (Boundary Ⅱ in ***Figure 3-1***). Thereby SPF1 is similar to the average COP according to the measured period.

$$\mathrm{SPF}_1 = \frac{\int_{t_{start}}^{t_{end}} Q_{GSHP}\, dt}{\int_{t_{start}}^{t_{end}} W_{GSHP}\, dt} \tag{3-14}$$

- t_{start}: *Start of monitoring [h]*
- t_{end}: *End of monitoring [h]*

SPF_2 consists of the electric energy of heat pump unit and the equipment needed to make the heat source available the heat pump (Boundary Ⅰ+Ⅱ in ***Figure 3-1***).

$$\mathrm{SPF}_2 = \frac{\int_{t_{start}}^{t_{end}} Q_{GSHP}\, dt}{\int_{t_{start}}^{t_{end}} (W_{GSHP} + W_{P1})\, dt} \tag{3-15}$$

- W_{p1}***: Electric power of circulation pump in the primary side [kW]***

SPF_3 includes the electric energy of auxiliary heating equipment (Boundary Ⅲ in ***Figure 3-1***).

$$SPF_3 = \frac{\int_{t_{start}}^{t_{end}} Q_{GSHP}\, dt}{\int_{t_{start}}^{t_{end}} (W_{GSHP} + W_{P1} + W_{bu})\, dt} \tag{3-16}$$

- W_{bu}***: Electric power of auxiliary heating equipment [kW]***

SPF_4 also includes the electric energy in the heating/cooling side (Boundary Ⅳ in ***Figure 3-1***).

$$SPF_4 = \frac{\int_{t_{start}}^{t_{end}} Q_{GSHP}\, dt}{\int_{t_{start}}^{t_{end}} (W_{GSHP} + W_{P1} + W_{bu} + W_{P2})\, dt} \tag{3-17}$$

- W_{p2}***: Electric power of circulation pump in the secondary side [kW]***

Figure 3-25 shows an example of monthly variation of $\int_{\mathrm{t_{start}}}^{\mathrm{t_{end}}} \mathrm{Q_{BHEX}}\, \mathrm{dt}$, $\int_{\mathrm{t_{start}}}^{\mathrm{t_{end}}} \mathrm{Q_{GSHP}}\, \mathrm{dt}$, $\int_{\mathrm{t_{start}}}^{\mathrm{t_{end}}} (\mathrm{W_{GSHP}} + \mathrm{W_{P1}} + \mathrm{W_{bu}} + \mathrm{W_{P2}})\, \mathrm{dt}$ and SPF_4.

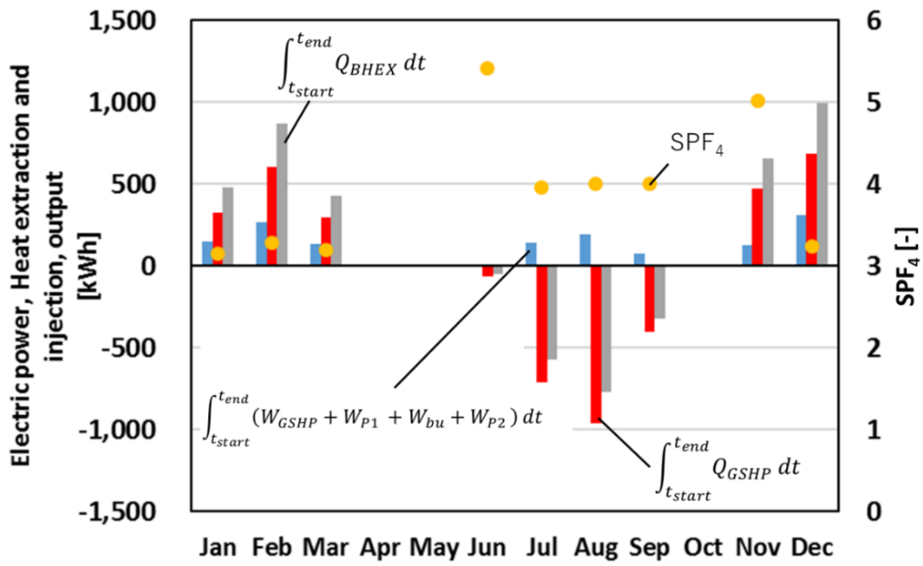


Figure 3-25: Example of monthly variation of $\int_{t_{start}}^{t_{end}} Q_{BHEX}\,dt$, $\int_{t_{start}}^{t_{end}} Q_{GSHP}\,dt$ $\int_{t_{start}}^{t_{end}} (W_{GSHP} + W_{P1} + W_{bu} + W_{P2})\,dt$, *and* SPF_4

Energy saving and reduction of CO2 emission

The value of energy saving can be evaluated by comparing the energy consumption between the GSHP system and conventional systems. The primary energy consumption of the GSHP system E_{GSHP} [MJ] is generally obtained by using the measured electric energy and the following equation.

$$E_{GSHP} = \int_{t_{start}}^{t_{end}} (W_{GSHP} + W_{P1} + W_{bu} + W_{P2})\,dt \times CC_{ee} \tag{3-18}$$

- CC_{ee}*: Conversion coefficient from the electric energy to the primary energy consumption [MJ/kWh]*

On the other hand, the primary energy consumption of the conventional system E_c is estimated by assuming that the thermal load Q_{GSHP} is covered by the conventional system instead of the GSHP system. The calculation equation of E_c is expressed as

$$E_c = \int_{t_{start}}^{t_{end}} Q_{GSHP}\,dt / COP_{con} \times CC_{ee} \tag{3-19}$$

- COP_{con}*: Coefficient of performance of the conventional system [-]*
- CC_{ee}*: Conversion coefficient from the electric energy to the primary energy consumption [MJ/kWh]*

If the energy resource of conventional system is gas (or oil), the conversion coefficient from gas (or oil) to the primary energy consumption. ***Figure 3-26*** shows an example of SPF criterial primary energy consumption between the GSHP system and the conventional gas and oil boiler systems.

If the CO_2 emissions are compared, the CO_2 emission of GSHP system can be calculated by changing the conversion coefficient.

$$CO_{2GSHP} = \int_{t_{start}}^{t_{end}} (W_{GSHP} + W_{P1} + W_{bu} + W_{P2})\,dt \times CC_{eCO2} \tag{3-20}$$

- CC_{eCO2}*: Conversion coefficient from the electric energy to the* CO_2 *emission [kg-*CO_2*/kWh]*

As well, the CO_2 emission of conventional system can be calculated by the following equation.

$$CO_{2c} = \int_{t_{start}}^{t_{end}} Q_{GSHP}\, dt / COP_{con} \times CC_{ee} \tag{3-21}$$

- CC_{eCO2}*: Conversion coefficient from the electric energy to the* CO_2 *emission [kg-*CO_2*/kWh]*

Figure 3-27 shows an example of comparison of CO_2 emission between the GSHP system and the conventional gas and oil boiler systems.

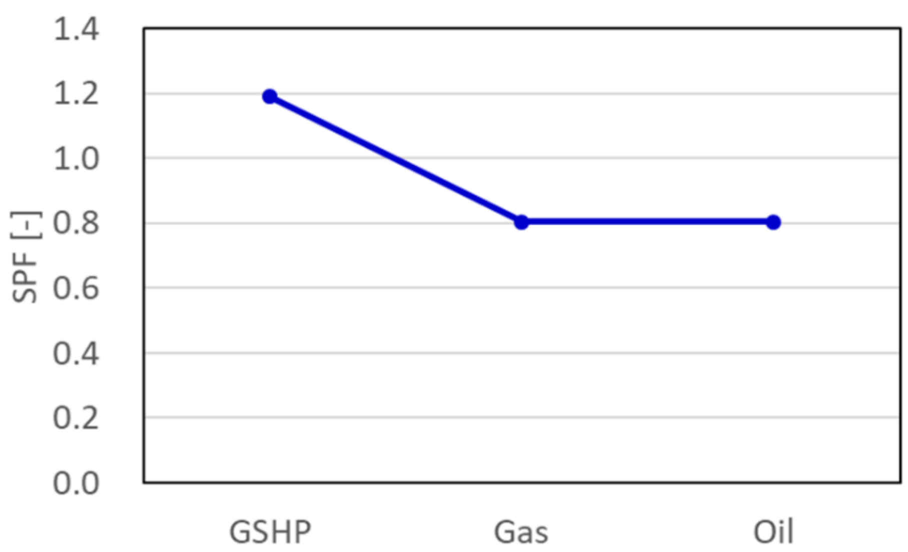


Figure 3-26: An example of comparison of SPF criterial primary energy consumption between the GSHP system and the conventional gas and oil boiler systems

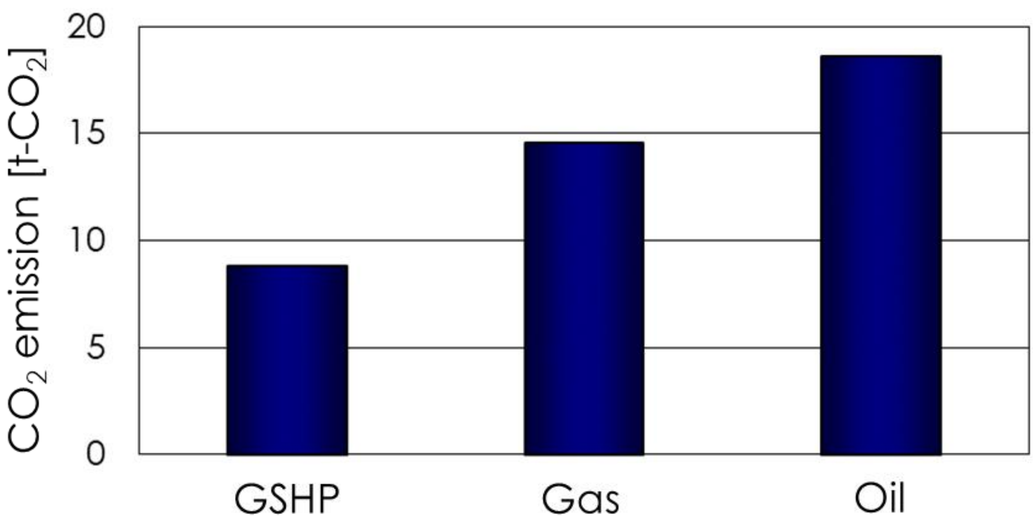


Figure 3-27: An example of comparison of CO2 emission between the GSHP system and the conventional gas and oil boiler systems

Temperature variation of heat carrier fluid according to amount of injected/extracted heat into/from borehole heat exchanger (To validate design and simulation tool)

The temperature variation of heat carrier fluid (or the variation of the ground temperature) according to the amount of injected/extracted heat into/from borehole heat exchanger is used for validation of the design by the simulation tool. Usually, the amount of injected/extracted heat into/from borehole heat exchanger is given as the calculated value, the temperature variation is calculated, and the calculated temperature variation is compared to the measured temperature variation. ***Figure 3-28*** shows an example of the amount of injected/extracted heat into/from borehole heat exchanger and ***Figure 3-29*** shows an example of the comparison of temperature variation between the measurement and calculation.

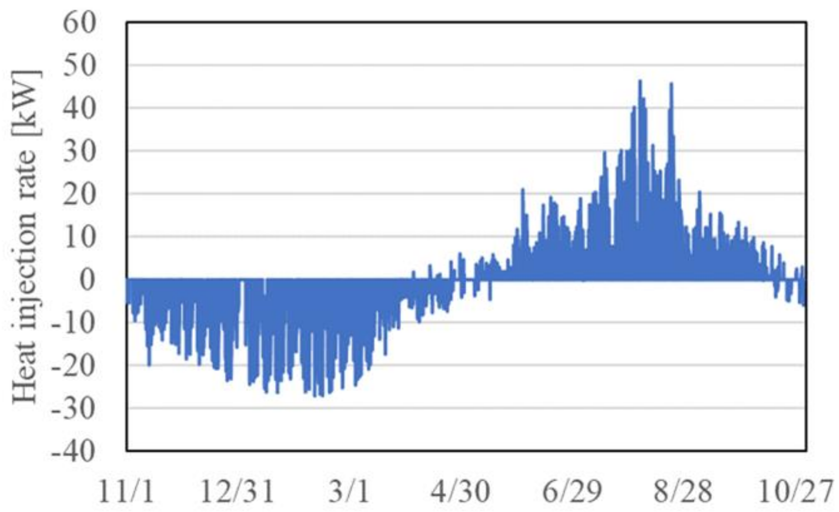


Figure 3-28: Example of amount of injected/extracted heat into/from borehole heat exchanger

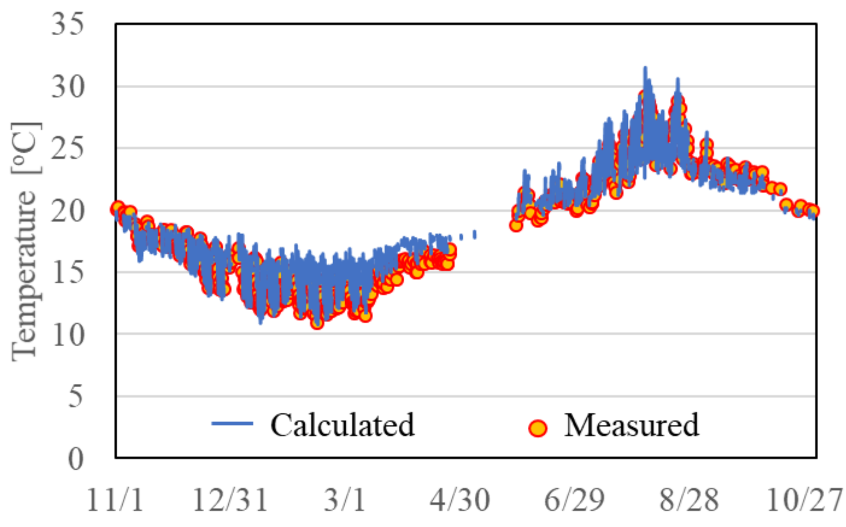


Figure 3-29: Example of temperature variation between the measurement and calculation

Electric energy consumption of the heat pump and subsystems or SPF (COP) before and after the optimization

In the BTES and GSHP system, it seems that the optimization of operation generally attempts to yield the maximize SPF or COP. Therefore, integrating the electric power consumption before and after the optimization and calculating the SPF and COP by using the integrated value is important. ***Figure 3-30*** shows example of comparison of the electric energy consumption for hybrid GSHP system combined with ASHP system before and after the operating optimization.

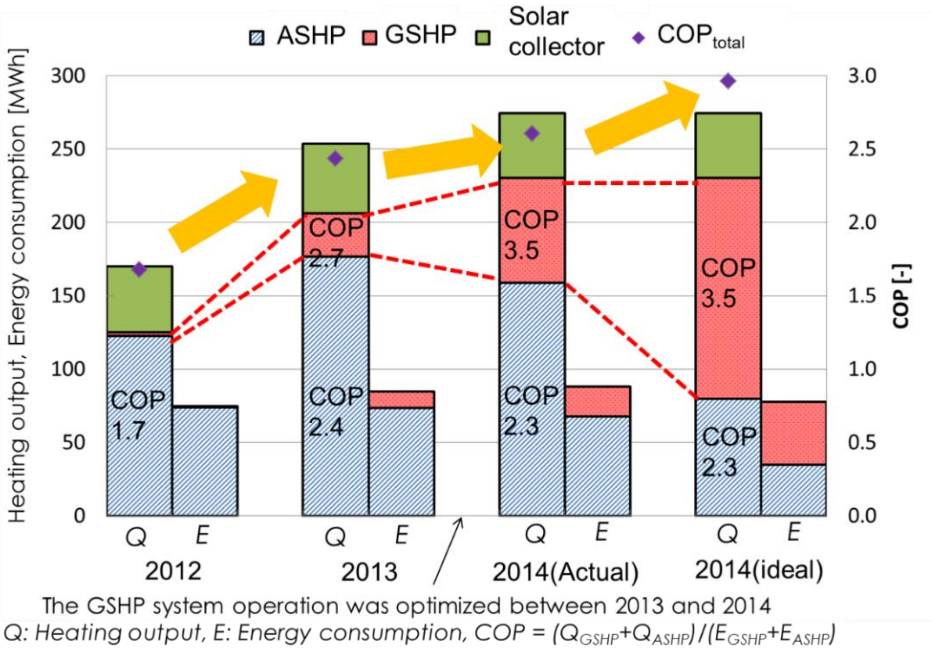


Figure 3-30: Example of comparison of the electric energy for the hybrid GSHP system combined with the ASHP system before and after the operating optimization

3.6. New Technologies related to Monitoring

3.9.4. Monitoring Systems or Services with Internet for Small Size Systems

Recently, the monitoring systems or services with internet access for small size systems are gradually becoming available. Heat pump manufacturing companies mainly provide the systems or services as shown in ***Figure 3-31 [7] [8]***.

One manufacturing company assigns a serial number to each heat pump. If the user inputs the serial number and password at the web site as shown in ***Figure 3-32 [7]***, the user can get an overview and the present status of heat pump as shown in ***Figure 3-33 [7]***. It is also possible to export the values to .csv format (opened in Excel for example).

Another manufacturing company provides a smartphone application that can show the operating parameters. In addition, the heat pump can be controlled by a smartphone if the application is used. ***Figure 3-34 [9]*** introduces an example of display in the smartphone application.

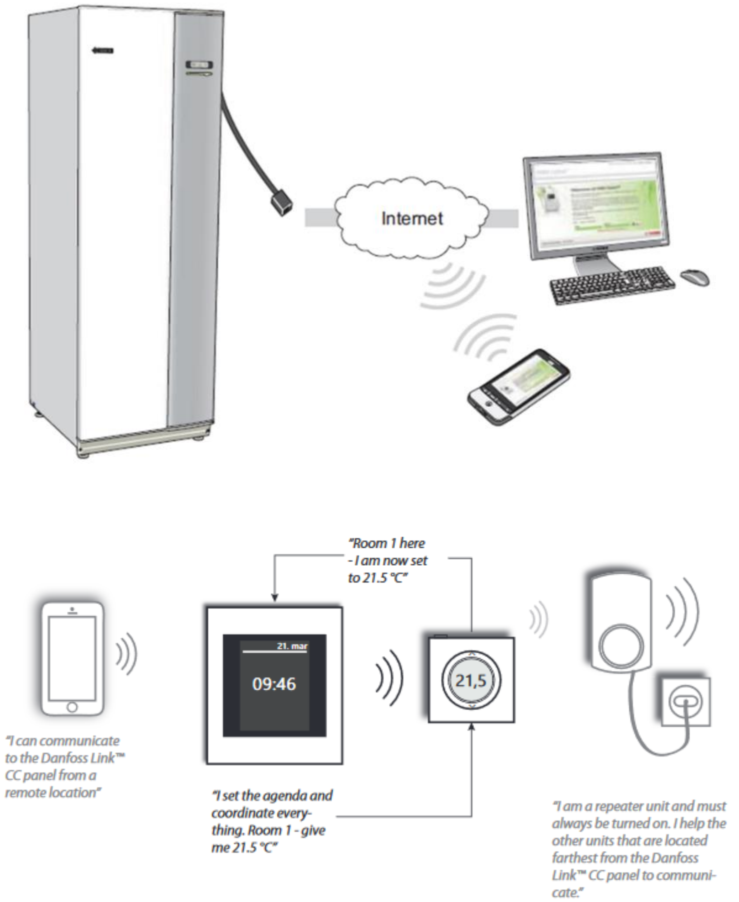


*Figure 3-31: Examples of monitoring systems or services with internet **[7] [8]***

Figure 3-32: An example of login screen ***[7]***

Figure 3-33: An example of overview screen ***[7]***

Figure 3-34: An example of display for monitoring and control in the smartphone application ***[9]***

3.6.1. Heat Meters (Calorie Meters) for Middle or Large Size Systems

The heat meters (calorie meters) are used to measure the heat extraction/injection rate of BHE. The meters comprise an electric calculator unit, a flow meter and two temperature sensors. The heat meter is extremely simple to install and is practically maintenance free. Examples of heat meters and the installation are shown in ***Figure 3-35 [10], [11]*** and ***Figure 3-36 [10]***, respectively. The turbine type or electromagnetic flow sensor is used as the flow meter. For measuring temperature, Pt-100 or NTC sensors are used. The electric calculator unit calculates heat extraction/injection rate by using the measured flow rate and temperatures. These heat meters are available not only for small systems but also large systems.

Figure 3-35: Examples of heat meter ***[10] [11]***

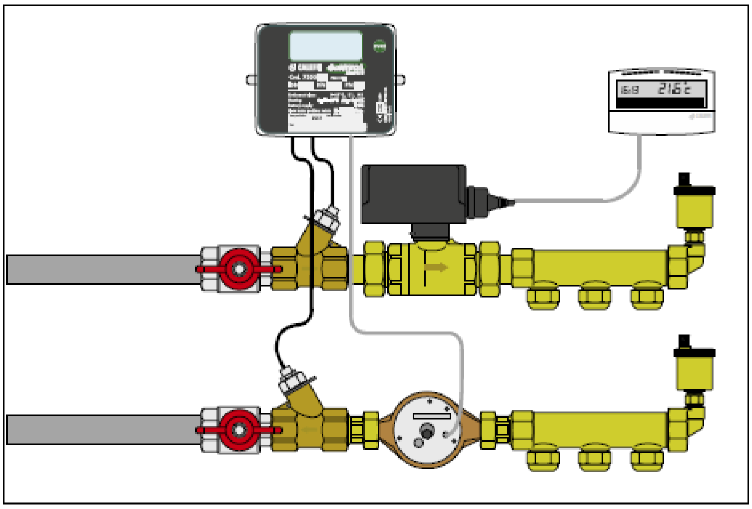


Figure 3-36: An example of heat meter installation ***[10]***

3.6.2. GEOsniff® Measurement Technology

GEOsniff® ***[12]*** shown in ***Figure 3-37*** is a miniaturized sensor system (measurement pig) for BHEs. This sensor can measure parameters such as pressure and temperature inside the BHE and sends all measurement data wirelessly to a web portal to visualize and analyze the data.

In addition, if the auto bypass system as shown in ***Figure 3-38*** is installed, the sensor is circulated through the BHE and the temperature distribution during operation can be obtained.

Figure 3-37: Appearance of GEOsniff® ***[11]***

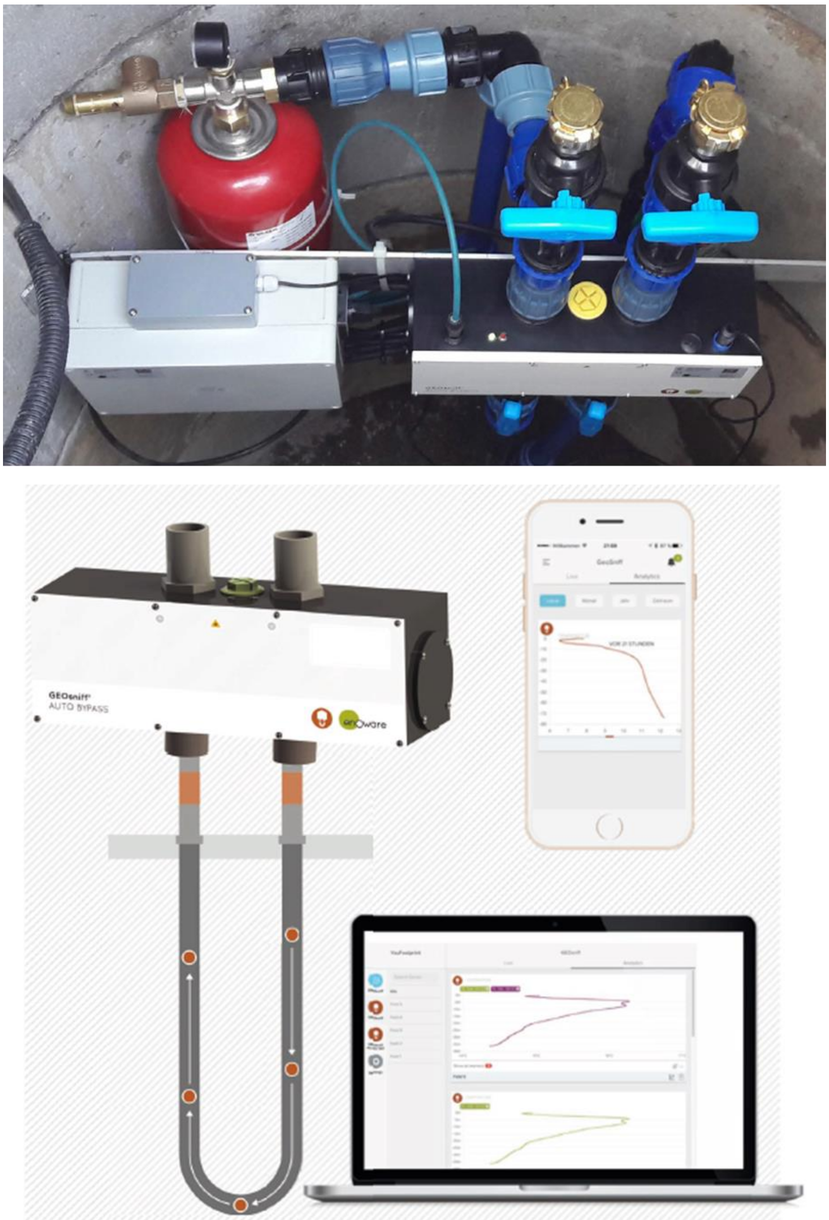


Figure 3-38: GEOsniff® auto bypass system ***[11]***

3.6.3. Fiber Optics DTS

As introduced in Annex 21 report, the fiber optics DTSs have been used to measure the temperature distribution in BHE during the thermal response test.

Recently, the fiber optics DTSs are applied to monitor the large scale ATES, BTES and GSHP systems. ***Figure 3-39 [13]*** shows an example of application of the fiber optics DTSs for the large scale ATES. If the fiber optics DTSs are applied, the effect of groundwater flow can be evaluated by using the monitoring data.

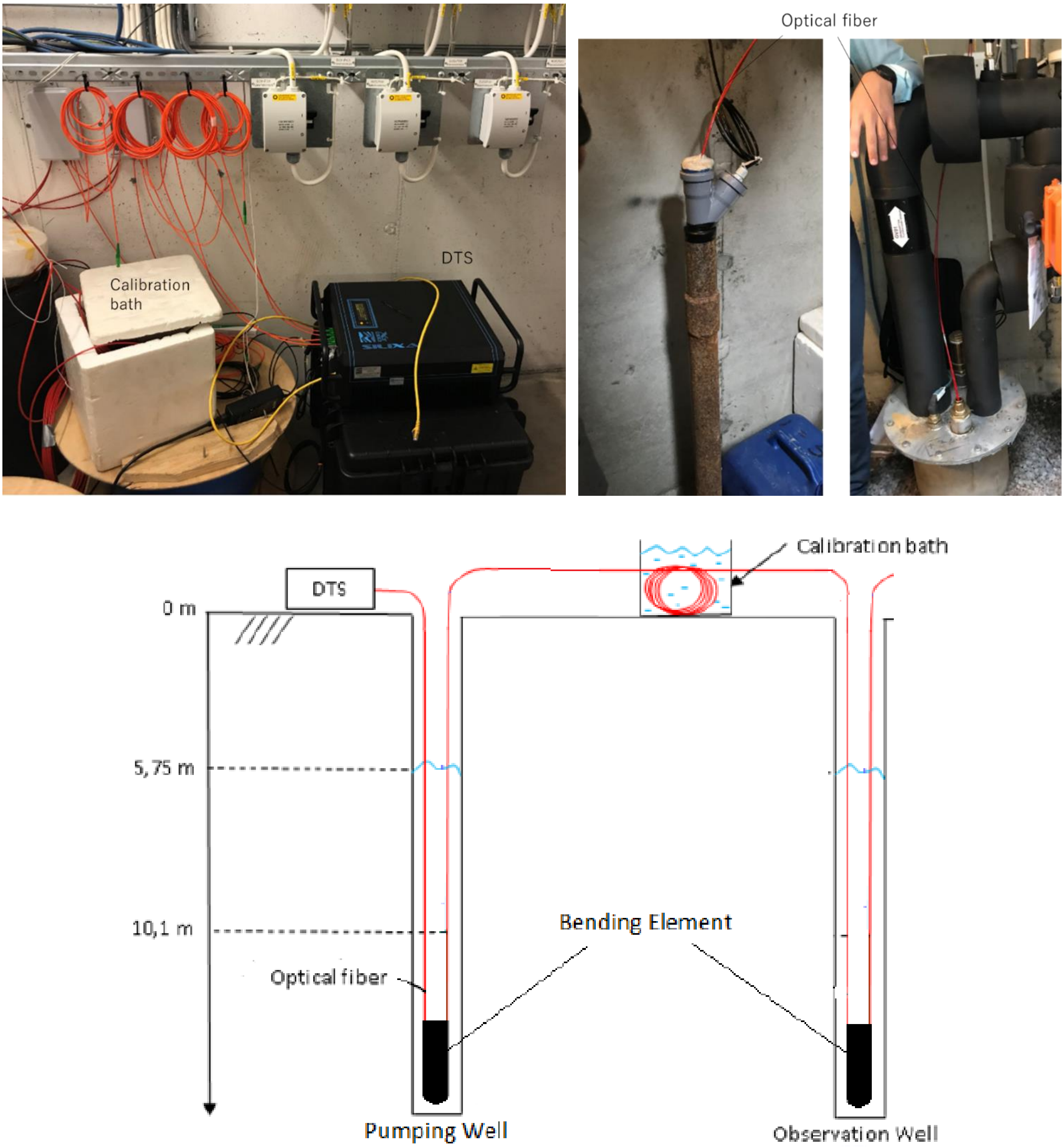


Figure 3-39: An example of application of the fiber optics DTSs for the large scale ATES ***[13]***

4. Subtask 4: Prevention and Solutions of Problems and Failures

4.1. Preface

This report is a subtask report within International Energy Agency (IEA) Technical Collaboration Platform (TCP) Energy Conservation through Energy Storage (ECES) Annex 27 - *Quality Management in Design, Construction and Operation of Borehole Systems.* The publication is the final report for IEA ECES Annex 27 Subtask 4: "Prevention and Solutions of Problems and Failures" and is based on a survey on Problems and Failures and their Solution, answered by the countries participating in the Annex.

Contributing countries: China, Denmark, Germany, Japan, Netherlands, Sweden, Turkey

Information provided by: Henrik Bjørn (Denmark), Mathieu Riegger (Germany), Roman Zorn (Germany), Hagen Steger (Germany), Claus Heske (Germany), Adinda Van de Ven (Germany), Roland Koenigsdorff (Germany), Manfred Reuß (Germany), Hanne Karrer (Germany), Markus Proell (Germany), Erdal Tekin (Germany), Immo Kötting (Germany), Takao Katsura (Japan), Henk Witte (Netherlands), Signhild Gehlin (Sweden), Olof Andersson (Sweden), Adib Kalantar (Sweden), Aysegül Cetin (Turkey), Halime Paksoy (Turkey).

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4.2. Subtask Scope and Limitations

Worldwide, there are millions of shallow geothermal systems in operation, most of them installed during the last 20-25 years. In principle they extract thermal energy from the underground that is used for space heating and in many cases also cooling. These thermal systems are regarded as renewable. As a result, these systems contribute significantly to minimizing CO_2 emissions in the ongoing battle against climate change.

The market for shallow geothermal applications is steadily growing, especially for lager systems with vertical boreholes. Apart from heat or cold extraction, these systems are often used for seasonal storage of thermal energy. The systems regarded in this Annex are defined as GSHP (Ground Source Heat Pump) and BTES (Borehole Thermal Energy Storage) respectively. Both these systems have vertically drilled boreholes in which Borehole Heat Exchangers (BHE) of different kinds are installed, and in most countries backfilled with grout.

The installations are generally safe, with damages affecting the local environment being very rare. Still there have been a couple of severe accidents that have raised the question of system security both from a technical and environmental point of view. These questions are forming the basic objectives for this Subtask 4 report.

Borehole heat exchangers have proven to be very robust, reliable and consistently reliable systems for energy efficient heating and cooling. Yet there are several potential risks involved regarding both technical and environmental issues. The boreholes penetrate the earth's concealed subsurface strata with often complex geological and hydrological conditions. To avoid mistakes in the design, these conditions must be known, fully understood and addressed in advance of project commencement. Construction approaches with different methods and materials raise another set of questions regarding material choice and quality as well as construction methods. With that in mind, it is important to know about potential risks and effects, and to be aware of these and handle them with suitable strategies in order to prevent undesired events and outcomes.

The potential risks are mainly covered by the following issues:

- Erratic design of systems due to misinterpretation of the underground and its thermal properties.
- Hydrogeological risks such as the occurrence of multi-aquifers with different pressure potential or penetration of artesian aquifers.
- Geochemical and geophysical reactions, such as anhydrites forming gypsum or swelling clay.
- Drilling problems due to unexpected difficulties in the underground geological features
- Geotechnical risks such as settling at the surface level causing damage to buildings or infrastructure components.
- Operational risks, both short-term and long-term, resulting in the decreased efficiency of the plant.
- Problems related to erratic construction or installation or failing components and material.

The risk potentials mentioned above can overlap and are explained in more detail in the report.

The main objective has been to define the risk potential and then address how to prevent these risks in the design and construction phases of any given project.

Inputs from the participating countries were derived through a questionnaire from which the answers are summarized in this report. The reader should bear in mind that participating countries have different knowledge related to the level of applications.

A significant difference is also the fact that Sweden and Finland are using groundwater-filled boreholes without grout and that these boreholes are much deeper than boreholes in the other countries where grouted boreholes are mandatory.

4.3. Literature Survey

As an introduction part of the questionnaire, participating countries were asked to perform a literature survey concerning published reports on failures related to GSHPs and BTES systems. The results of this survey are summarized below. Related references are found in the literature chapter.

In ***Canada,*** there have been no in-depth studies published with respect to failures in ground source energy systems. Minor reports have been produced but as of August 2019 have not been submitted for peer review and as such cannot be cited at this time.

In ***Denmark,*** studies mainly focus on horizontal systems. In the available publications, it is recommended to perform oversight control prior to operation. Furthermore, it is recommended to document the system implementation, and it is also stated that the installation should be placed at a proper distance from water supply wells ***[15], [16].***

In ***Finland,*** problems in borehole heat exchanger (BHE) and ground heat exchanger (GHE) projects have increased as a result of a large market growth. Artesian conditions dominate the groundwater related problems in BHEs. Other damage events like heat carrier fluid leakage and damage by ground excavation on the horizontal pipe system have been reported. Design failures and insufficient heating capacity are not common.

Regarding antifreeze in the heat carrier fluid, a ban of using methanol in GHEs is outstanding and has been submitted to the authorities.

The most common problem is linked to geological conditions with collapsed boreholes and stranded heat exchanger pipes as a result.

Furthermore, interaction between the contractor and the customer is insufficient and needs to be improved. Sensitivity about environmental impacts of GSHP systems needs to increase and clear communication between these actors is required. The reintroduction of the refrigerant qualification requirement for GSHP installers is advised ***[17].***

Another study about contradictory procedures caused by inadequate juridical regulation concerning permits for GSHP systems in the Finnish regional administration has been submitted but not yet responded to ***[18]***.

In ***Germany,*** reports on vertical GSHP systems mention cases with considerable economic losses, mostly due to cross connection of aquifers due to leaky annular space grouting ***[25], [29], [30], [34], [36], [38].*** Of special note are the unique geological conditions in Southern Germany, with swelling formations such as anhydrite-bearing layers, and required additional examination to identify suitable remedies ***[25]***. Examples of settlements and uplifting in the area of the BHE as well as flooding by (artesian) discharge, connection of different aquifers and CO_2-diffusion into the BHE-pipe ***[27]*** have occurred ***[25], [26], [28], [29], [31], [32], [33]*** and have partially been addressed with subsequent sealing ***[25]***. Furthermore, groundwater quality and other environmental aspects are likely to be influenced ***[21], [22]*** (detailed analysis also about the impact on ecology). Yet, damage detection proves to be difficult and small incidents are not reported to public services. Therefore, detailed official statistics on composition of installed systems and on damages by GSHP systems requires improvement. A nationwide regulatory framework, guidelines, decision models ***[22]*** and geothermic categories ***[37]*** offer further possibilities. Local conditions and possible threats should be included in the approval process ***[21]*** (detailed scheme). Here, geographic information systems (GIS) with attached local investigation results and feasibility studies as additional tools would prove very useful. ***[21]***. Lack of knowledge on best practices due to the economic focus on the side of the contractors ***[37]*** and misguided customer requirements often contributes to damage events. Thus, prevention methods consist of periodic on-site quality checks of drilling company operations, training and awareness of involved workforce, realistic evaluation of GSHP system capabilities and development of regional and hazard-specific handbooks (as causes of negative ramifications often remain complex) ***[19], [20], [21], [23]***

Additionally, prohibition of drillings and GSHP systems in water protection areas and installation of heat meters for sustainable management are advised ***[21]***. One case of successful restoration method is mentioned in Boeblingen ***[26]***.

In the ***Netherlands*** most (if not all) studies regarding failures in ground source energy systems relate to Aquifer systems (ATES). These are mainly concerned with well-clogging and low performance. For borehole heat exchangers, there has been a theoretical study on the probability of leakage of coolant and traversing aquitards ***[39]***.

Another study investigated the risk of unwanted thermal interactions between open and closed systems ***[40]***.

There is also an RIVM publication about the effects of anti – freeze agents on ground water ***[41]***.

Recently, there have been some publications concerning drilling contractors that do not comply with the government regulations – the Dutch Inspection (ILT) has found a relatively large number of infractions mainly concerning the correct sealing of boreholes.

In ***Sweden*** the most frequent problems in GSHP systems are related to drilling or drill site issues, borehole heat exchangers and piping. The problems are typically discovered after installation and the start of operation. There are also incidences of rare cases of uplift, bursting (e.g. by trapped exhaust air), and land sinking after drilling.

Concerning borehole heat exchangers, impediments and borehole “shortcutting” occur with some frequency. This can sometimes be averted by home-made “blow out preventers”. On-site pressure tests prevent potential problems caused by improper pipe welding. Leakage arising in the long-term operation can be prevented through careful design and planning. ***[42]***.

The disposal of excess drilling water has become a growing concern. This issue has been examined in a Master Thesis work ***[43]***. Depending on the ecological and geological circumstances, additional treatment e.g. using containers to prevent deposition is regarded as necessary.

A national guideline for groundwater protection includes a procedure for drilling of GSHP boreholes and specifies some general requirements for drilling procedures and casing installation. It also states some general requirements for backfilling ***[44]***.

Although freezing of heat extraction boreholes occurs in Sweden in wintertime, it rarely causes any deformation of the heat exchanger. The Swedish boreholes are typically filled with groundwater, and unless there is uneven freezing in the boreholes due to fractures or deep steel casing, deformation or “squeezing” of pipes rarely occurs. ***[45]***.

In Sweden complete borehole backfilling with grout is rarely required. The steel casing used for sealing into the bedrock eliminates contamination from the surface. In the rare cases when a complete borehole grouting is required, geological and hydrogeological factors must be considered as well as the grouting process and grouting materials ***[46], [47]***. Apart from that, proper sealing for artesian flows is often required. In such a case, specially made packers for partial backfilling are typically used ***[42]***.

A legal issue occurs when part of a borehole is drilled so that it crosses the border to an adjacent property. Swedish regulations are currently inconclusive regarding the part of a borehole trespassing on an adjacent property ***[48]***.

In ***Turkey***, there are some studies that relate to the drilling process only but do not specifically address GSHP systems ***[49]***.

4.4. Potential Failures and their Solutions

Over the last half-century, several million ground heat exchanger systems have been installed world-wide. Considering the very large number of installations, the incidence of problems related to GSHP and BTES systems is very limited. In a few cases, severe problems have occurred that have caused severe damage resulting in tremendous costs. These exceptional incidents tend to require substantial remedial actions - and therefore harm the confidence in the entire technology among decision makers and the public.

The vast majority of GSHP and BTES systems in the world have not experienced problems or failures at all. However, a small fraction has experienced minor failures. The nature of these failures is typically not of a severe nature, can normally be remediated, and could most likely have been foreseen and prevented.

This section lists various mistakes or failures that have been reported to occur, what symptoms these may cause, how to solve and prevent such problems.

In this section potential design, construction and operational errors are listed and described. The inputs are given by country specific answers in the questionnaire, discussions at expert meetings and from the Subtask reports 1-3.

The structure of presentation is based on three levels, starting with a description of a potential failure, followed by generated symptoms, and solutions and prevention. Finally, some specific remarks and recommendations are given.

The full answers for each specific item are given in **Appendix 4-1** and **Appendix 4-2.**

4.5. Design Mistakes

4.5.1. Undersized Borehole System

Description:

It is important that the number and depth of boreholes are sufficient to support a properly functioning GSHP or BTES system. In the design of the system it should address certain heating and cooling load demands. If the capacity of the boreholes is insufficient, heating and cooling capacity shortfall may lead to increased energy costs and potentially failures in the overall system. This may not be critical the first few years of operation but will manifest itself in later years.

Symptoms:

- A gradual lowering of the heat carrier fluid temperature in heat extraction dominant systems
- Increased electricity consumption of the heat pump
- Frost damages of the grouting material and frost heaving
- Freezing of groundwater-filled boreholes for heat extraction
- Buckling of BHE in frozen boreholes due to increased pressure

Solution/Prevention

- Shut down the heat pump in critical times (short-term solution)
- Adding additional peak load resources
- Increasing the geothermal energy resource by additional boreholes
- Adding additional heat sources as a complement to boreholes
- Restore frozen groundwater-filled boreholes allowing them to thaw followed by the addition of more boreholes

Remarks and recommendations

Common additional heat sources combined with boreholes are solar thermal and exhaust air from ventilation systems (Sweden).

If a system shows signs of being undersized it is recommended to look into the possibilities to use additional heat sources, such as solar thermal or other forms of renewable heat.

4.5.2. Oversized Borehole System

Description

This is usually not problematic for heating, but might cause a problem running the cooling mode in a BTES system. Running in the heating mode, an oversized borehole field would probably generate better performance than expected.

Symptoms

- The temperature of the heat carrier fluid is not lowered as expected
- The temperature of the heat carrier fluid is too high for proper delivery of free cooling
- The heat pumps must be run for cooling for longer periods than designed

Solution

- If recognized as an unwanted situation, disconnect a number of boreholes
- Connection of additional loads (if any) to the system in order to improve the economics

Remarks and recommendations

Oversized borehole fields are very uncommon and seldom lead to any form of actions.

If a corrective action is considered, it is firstly recommended to look for additional heat loads to connect to the system.

4.5.3. Oversized Heat Pump Capacity

Description

There are several reasons for oversized heat pumps in the GSHP and BTES systems. One is that unexperienced installers sometimes tend to oversize the heat pump for “safety reasons”. Another is that HVAC engineers for the same reasons overestimate the heating and cooling demands of a building. A third cause, especially for smaller units, may be that the heat pump supplier could not deliver the right size and thus uses the next larger heat pump size.

Symptoms

- Too many starts and stops of the heat pump (frequently on/off)
- Too low COP (low efficiency) compared to the expected value
- In long run a shorter technical lifetime of the compressor

Solution

- Installation of larger buffer tank capacity
- Using frequency controlled compressors that can adjust to lower heating power
- Connection of additional loads (if any) to the system

Remarks and recommendations

Oversized heat pumps are fairly common and in many cases this issue is solved by installation of increased buffer tank volume. In modern installations with frequency-controlled heat pumps, the problem is less pronounced and would typically not lead any corrective measures.

In new installations, it is recommended to use heat pumps with frequency-controlled compressors as well as in retrofits.

For older installations, it is recommended to increase the volume of buffer tanks.

4.5.4. Undersized Heat Pump Capacity

Description

As long as the boreholes are properly designed and the buyer of the system is aware of the extra external heat source, this is less of a problem. However, if the design and expectations are overestimated it may cause unexpected heating (and cooling) cost for the customer.

Alternatively, the full load running hours will be larger and that will have a positive effect on the operation and performance of the heat pump.

Symptoms

- Heating and cooling demands cannot be fully delivered compared to designed values
- The supply with external heat and cold is higher than expected
- The running hours are longer than expected

Solution

- Installation of more heat pump capacity
- Installation of more boreholes to compensate for the new heat pump (if needed)
- Expand systems with an additional renewable energy source (e.g. solar thermal)

Remarks and recommendations

Undersized heat pumps are rarely observed and provide few technical problems. If this is a design mistake, the solution is to enlarge the total capacity of the system by adding more heat pump capacity.

If more heat pump capacity is added it is recommended to carefully investigate that the boreholes are capable to meet the new demand on the heat source side.

4.5.5. Erratic Load Estimation

Description

Inaccurate estimates of the building heating and cooling loads lead to the same issue. This is particularly true for new buildings which lack historic load data. Many times, the loads are over-estimated for such buildings due to a conservative estimate done by the HVAC engineers.

Changes in building user behaviour and climate change are long-term causes for the building energy load to deviate from design values. Other sources of deviating energy loads may be caused by incorrect use of building energy load calculation tools.

Symptoms

- Will have the same symptoms as for over- and undersized heat pumps

Solution

- Monitor actual heat and cooling load and operational parameters
- In case of load higher than expected, see “Undersized Heat pumps”
- In case of load lower than expected, see “Oversized Heat pumps”

Remarks and recommendations

See “Undersized heat pumps” and “Oversized heat pumps” respectively.

4.5.6. Misunderstanding of the Geological Conditions

Description

The underground composition and properties form the most important boundary conditions for designing the boreholes and the borehole installations.

For small GSHP systems the geology, temperature and conductivity are known well enough by using geological databases and drillers experiences.

For larger systems, test borehole drillings and Thermal Response test (TRT) improve knowledge. Even so, unpredicted geological properties sometimes occur. Mistakes may arise if a geologist/hydrogeologist has not been involved. The geology may vary in an unpredictable way over the borehole field in both vertical and horizontal directions. Groundwater flow during a TRT may lead to incorrect evaluation results. Collectively, these mistakes may result in a poorly designed borehole field that adversely affects overall system performance.

Symptoms

- Change of thermal behaviour over area of the borehole field
    - For oversized, see “Oversized Borehole field”
    - For undersized, see “Undersized Borehole field”

- Inaccurate determination of ground properties
    - For oversized, see “Oversized Borehole field”
    - For undersized, see “Undersized Borehole field”
- Inaccurate determination of underground temperature
    - Lower than expected: Possible freezing of underground in heat extraction applications
    - Higher than expected: Negative influence on (free/direct) cooling application
- Unexpected/not identified groundwater flow may transport induced heat/cold from or to the boreholes.
    - Possible positive/negative influence on adjacent borehole fields
    - Groundwater flow can affect the storage efficiency in BTES applications

Solution

- See “Oversized Borehole field”
- See “Undersized Borehole field”
- Sufficient test borehole drillings and TRTs to properly size the borehole field
- Usage of geologist/hydrogeologist at site investigations.

Remarks and recommendations

See under “Oversized borehole field” and “Undersized borehole field” respectively.

In addition, it is highly recommended to consult the Subtask 1 report and the recommendations here given for site investigations to prevent geologically based errors and mistakes.

4.5.7. Hydraulic Layout

Description

There are two major mistakes that can occur:

- the layout of the circulation pump
- hydraulic balancing of several boreholes connected in parallel

Circulation of the heat carrier fluid (“brine”) may cause problems if the circulation pump is not correctly sized. The pump is designed based on a certain flowrate for the BHE and a calculation of head losses. For larger systems the pumps are often frequency controlled. However, many small and medium sized installations use heat pumps with built - in circulation pumps. This arrangement is acceptable for a single heat pump with one or two boreholes.

If the circulation pump is oversized and has no frequency control, the consequence would be an overconsumption of electricity for the circulation, but also a somewhat higher COP on the heat pumps. For systems with several heat pumps in parallel, there are examples showing that this leads to undersized circulation of the brine. In such cases, a number of operational disturbances will occur and in the worst-case scenario will lead to a shut-down. Except for an undersized circulation, the primary reason for high pressure in the brine loop is too few boreholes to split the flow rate capacity over, or flow resistance caused by gas or other obstacles.

If there is no hydraulic balancing of different boreholes connected in parallel to a collecting circuit, there may be an uneven flow distribution to the different BHEs due to incorrect pressure drop calculation or missing compensation valves.

Symptoms

Layout of the circulation pump:

- Increased/too large brine ΔT over the evaporator
- Repeated alarm indications on displays of the heat pumps
- Lowering of the heat pump COP
- Vacuum pressure on the suction side (shown on manometer or pressure devise)
- Cavitation of circulation pump (noise indicated)

Hydraulic balancing:

- Unequal flow through the different BHEs
- Unequal extraction rate of the different BHEs
- Lowering of the heat pump COP

Solution/Prevention

Layout of the circulation pump:

- Check of reasons for high pressure/low flow rate by measuring (trouble shooting)
- Purging (if gas in the system)
- Installation of a pressure rise pump on the brine loop (for increased flow rate and pressure)
- Increase the system pressure (for prevention of cavitation)
- Additional boreholes (if the friction losses are too high for built – in circulation pumps)
- Additional monitoring on the brine loop

Hydraulic balancing:

- Check for correct pressure drop calculation
- Install compensation valves
- Adjust equal flowrate through each BHE
- Avoid connection according to Tichelmann principle, it is fault-prone and expensive due to additional piping amount.

Remarks and recommendations

There may be several reasons for an improper brine circulation in the loop and before measures are taken to solve the situation, the reason must be clarified. It is also of great importance to install additional monitoring devices to trace potential problems.

Since there are several reasons for circulation problems, it is recommended to do troubleshooting before deciding on the type of action to be taken.

4.5.8. Wrong Interpretation of Thermal Response Test (TRT) Results

Description

A TRT is used to define the on-site ground thermal properties at the borehole field. Properly performed and interpreted, the results will be an excellent basis for the design of the system. However, there are several potential mistakes that may occur, and which will affect the design.

Mistakes that may occur are

- The Rb-value (borehole thermal resistance) obtained from the TRT conducted with water has not been adjusted for the type of heat carrier fluid used in the actual ground loop

- Groundwater influence has not been considered in the calculation of the effective ground thermal conductivity
- Ground thermal conductivity (and ground water influence) may vary significantly with depth. This may lead to an error if the depth of test drilled borehole does not correspond to the depth of the final borehole field.
- TRT evaluated for heat injection for a system constructed for heat extraction and heat transport in the ground differs for injection/extraction.

Mistakes like these may cause both negative and positive effects on the operation and lead to an undersized or oversized borehole field as earlier described.

Symptoms

- See under “undersized borehole field”
- See under “oversized borehole field”

Solution

- See under “undersized borehole field”
- See under “oversized borehole field”

Remarks and recommendations

See under “Oversized borehole field” and “Undersized borehole field” respectively.

In addition, it is highly recommended to consult the Subtask 1 report and the recommendations here given for performance and interpretation of Thermal Response Tests.

Furthermore, it is recommended to consult the results of former ECES Annex 21 and ongoing HTP Annex 52 for more information of TRT and performance of GSHP systems by using the links below.

4.5.9. Link to ECES Annex 21

The overall objectives of Annex 21 are to compile TRT experiences worldwide in order to identify problems, carry out further development, disseminate gained knowledge, and promote the technology. Based on this overview, a TRT state–of–the–art, new developments and further work are studied. The final report is available on the IEA ECES webpage (https://iea-eces.org/annexes/thermal-response-test/).

4.5.10. Link to HPT Annex 52

Within the IEA HPT Annex 52 (https://heatpumpingtechnologies.org/annex52/) long-term performance measurement of GSHP systems serving commercial, institutional and multi-family buildings, instrumentation, measurement and analysis procedures that help diagnose poor performance and opportunities for system performance improvements are investigated. It is done through a survey of published long-term performance measurements, and by reporting from a large number (>40) case studies featuring GSHP system performance measurements for systems around the world. These case studies help defining best-practice as well as common error sources in the design, construction and operation of GSHP systems and give advice on how unanticipated consequences of the design may be ameliorated.

4.6. Construction Mistakes

In this chapter, the construction phase of any GSHP or BTES system is covered and potential mistakes and failures are described.

The content of the chapter is based on inputs from participating countries, see **Appendix 4-2** and have been further analysed and discussed in expert meetings.

Additional information about the topic can be found in the Subtask 2 report.

4.6.1. Revision of the Design

Description

While drilling the borehole field it may occur that drilling cannot be performed as intended due to unexpected and less favourable underground conditions. In most instances it only takes minor adjustments to overcome the drilling challenges, however, there can be substantial differences in underground conditions that were expected and the solutions can be drastic and costly.

Changes in the drilling program due to unexpected subsurface conditions encountered and the construction of the borehole field should be corrected or adjusted according to contractual conditions.

Symptoms

- Final depth of boreholes cannot be reached
- Too much water is produced during drilling (when drilling with air)
- Loss of circulation (when drilling with mud)
- Unexpected artesian flow with high pressure
- Insertion of BHE will not reach full length
- Unexpected, severe loss of grout

Solution

- Collect factual information from the drilling company
- Define the contractual responsibility for making changes in design
- After approval, define changes necessary to fulfil the design (minor changes)
- After approval, assess performance of a re-design (worst case scenario)

Remarks and recommendations

In most cases, these types of aberrations are covered by contractual conditions and result in large extra costs for project. Actions taken must for this reason be approved prior to both any re-design and any further construction.

It is strongly recommended to find out contractual responsibilities prior to changes being made or a re-design is performed.

4.6.2. Aberrations during Drilling

Description

Drilling with a down-the-hole hammer (DTH) with compressed air is the pre-dominant method for drilling in hard rock (crystalline and fully consolidated sedimentary rocks). Basically, all boreholes drilled in Scandinavia are drilled with this method, see the State of Art report for Sweden ***[42]***.

The dominating method in less consolidated and unconsolidated sedimentary rocks would be conventional rotary drilling method, using water or mud as drilling fluid.

Symptoms at hammer drilling Down-The-Hole (DTH)

- Too much groundwater entering the borehole making the hammer stop (air pressure used to evacuate the water)
- Fracture zones or other deformation zones with unstable fractured rocks and/or swelling clay makes it difficult (or impossible) to reach target depth
- Difficulties to insert the U-pipe to full length
- Hydraulic connection with previously drilled boreholes

Solutions

- A booster compressor may help to reach target depth in water-producing boreholes
- Injection of cement may help stabilize deformation zones (drilled through after hardening)
- Second cleaning of unstable boreholes with short U-pipes may help to reach full length
- Collect factual information from the drilling company
- Define the contractual responsibility for extra work or additional boreholes
- Approval to re-design with additional boreholes or shallower borehole design

Symptoms with conventional drilling methods

- Loss of fluid entering karst cavities, fractures or highly permeable gravels
- Clogging of fluid channels when drilling through sticky clay
- Stuck pipe due to collapse of borehole, often due to striking artesian water flows
- Difficulties to insert U-pipe to full length, due to debris at the bottom of the borehole

Solutions

- More bentonite in the mud/or adding nutshells, etc. may minimize losses of fluid
- Adding a surfactant to drilling fluid may prevent clogging by sticky clay
- By adding heavy components, like barites, to mud may balance artesian pressure
- Specific mud components, like bentonite or polymers, may stabilize borehole wall
- Drilling a few meters deeper may help to overcome residues at the bottom of the borehole

General solutions

- Collect factual information from the drilling company
- Define the contractual responsibility for extra work or additional boreholes

Remarks and recommendations

These types of difficulties can only be predicted, and perhaps avoided, by a proper site investigation in the design phase of a project. Even so, these kinds of difficulties may still arise.

As a general remark by experience, it often takes less cost to drill a new borehole instead of coping with a problematic one.

In most cases, unforeseen drilling problems are covered by contractual clauses but will add to the construction cost. Further borehole drilling or addressing problematic boreholes must be approved in advance.

It is strongly recommended to find out contractual responsibilities prior to extra work in problematic boreholes and/or changes of the drilling contracted plan.

It is recommended to consider drilling new boreholes instead of dealing with problematic boreholes.

4.6.3. Further Issues Related to Drilling

Annex participants brought up further drilling methods and experiences regarding drilling. The main part of these issues, including solutions, are summarized below. Additionally, examples are mentioned, which are described in more detail in chapter 4.10.

Too small drilling diameter

- Sonic drilling (a vibration drilling method) is sometimes used. It is promoted as being cheaper and faster than other drilling methods, but small drilling diameters may result in limited space for installation of U-pipe and tremie pipe for grouting.

Solution:

- The solution is to use a larger borehole diameter, which results in increased costs.

Introduction of compressed air in the overburden

- Having compressed air introduced in the overburden may cause damage to buildings. This is an experience from Sweden which has had a couple of such examples over the last decade. To prevent such situations, drillers are trained to be cautious while installing steel casing in risk areas. In Sweden this is a prerequisite of the driller’s certification.

Solution:

- A technical solution is to install the steel casing with a water hammer.

Wrong drilling method

- In rare occasions the wrong drilling method for the site’s geological conditions is selected – e.g. - conventional rotary adopted for hard crystalline bedrocks, or DTH drilling with air adopted for unconsolidated formations.

Solution:

- These are severe mistakes and the obvious option is to change to the correct method.

Improper or missing tools and materials at the construction site

- While drilling in an artesian aquifer without a diverter an uncontrolled outflow can occur (e.g. Wiesbaden).

Solution:

- In these situations the authorities should be contacted and the use of flow diverter applied. Potentially grout or packer should be used to stop the flow. Often site-specific solutions are needed.

Wrong drilling rig or/and too short casing

- When drilling with a rig that is too small, the hook load can be too low for a sufficiently long casing. Under special geological conditions, sub-erosion and subsidence can then take place (e.g. Kamen-Wasserkurl).

Solution:

- In such a instance the authorities must be contacted and site-specific sealing be applied as well as monitoring.

Poor documentation of geological conditions

- Poor documentation of geological conditions while drilling boreholes is a common issue in most countries.

Solution:

- To prevent this, it is important to apply specifications as part of the drilling contracts and well-educated drillers should be contracted.

Penetrating gas pockets while drilling

- In several provinces in Canada there are examples of gas pockets having been penetrated while drilling.

Solution:

- If hazardous gas is at encountered, authorities should be contacted, and a gas detector and a blow-out preventer should be used.

Unknown or unidentified underground mining shafts

- In many countries there are unknown or undocumented mining shafts that risk being penetrated while drilling. This may cause a severe collapse of the surface.

Solution:

- If a shaft is penetrated the drilling must stop and authorities contacted. The solution would be site specific.

Collapsing of boreholes in general

- Collapsing of boreholes may occur for many reasons as earlier described.

Solution:

- At shallower depths, a solution could be to re-drill and insert a temporary casing. If collapsing happens during installation of U-pipes or during grouting, the solution would be the same, but in latter case an attempt should be made to pull out the installed U-pipe.

Deviated boreholes

- Boreholes can turn out to be deviated, commonly due to tectonically induced structures or differences in hardness of rock layers. To investigate and document the straightness of the borehole, a deviation measurement is needed but is seldom performed.

Solution:

- From a technical point of view, decreasing the rate of penetration by lowering the weight on bit could be helpful, as well as using stabilizers and other tools for straight drilling.

Comments and recommendations

Most of the issues stated above are generally rare. However, they must be taken seriously as many issues can arise during the drilling process.

Its recommended to perform a risk analysis prior to construction drilling in order to look for potentially abnormal conditions, hazards and obstacles other than conditions identified during pre-investigations.

4.6.4. Issues related to Borehole Installation and Horizontal Piping

This topic covers installation of U-pipes, grouting of boreholes, linkage of boreholes with a pipe system and filling/purging the total system with brine.

Experiences from the participating countries are summarized below, with possible solutions included.

Leakage of pipes due to improperly welded connection

- Leakage of pipes occurs occasionally, mostly due to improperly welded connection between the U-pipe and the horizontal pipe system.

Solution:

- This will in most cases be observed during pressure testing prior to backfilling of the trench. However, it takes carefully performed leakage tests to also detect minor seeping leakages. From Sweden, there is one example of a test that took several days to perform before a small leakage was located and repaired.

Pipe clogging

- Pipe clogging is not common. If it occurs, it will be shown as increased hydraulic pressure in the pipe system combined with a decreased flowrate and increased delta T over the evaporator. It could be caused by solid particles like sand and gravel that were introduced at construction. However, in most cases it is due to remaining air in the system.

Solution:

- The solution would be to flush the system with brine at a high flowrate combined with purging. This is typically done with circulation through an open tank.

U-pipe buckling or bending during grouting

- U-pipe buckling or bending during grouting is a potential failure. Buckling is caused by the pressure difference between grout and brine.

Solution:

- The normal procedure to prevent buckling is to have the U-pipe totally water-filled and each shank closed at top with a plug or valve. If buckling still occurs there is no solution other than to abandon the borehole and replace it with a new borehole.

U-pipe cannot be inserted to its full length due to miscalculation

- The density of PE100 U-pipes is approximately 0.95. Additional weights are needed in order to insert the U-pipes in the boreholes. Depending on the density of mud (or water) and borehole depth, a bottom-weight may be needed. It has occurred that the U-pipe cannot be inserted to its full length due to miscalculation.

Solution:

- The solution is to pull out the U-pipe, if possible and add a larger weight.

U-pipe shanks drop below the grout

- After grouting it could happen that the U-pipe shanks drop below the grout when the temporary casing is pulled out of the borehole.

Solution:

- To minimize this risk the shanks should be fixed to the surface, for instance with clamps or securing chains / straps.

U-tube with leakage

- Leakage tests after inserting U-tubes may reveal leakage.

Solution:

- The tube must be pulled out and replaced by a new one if possible.

Missing reel while inserting the U-pipe

- Normally a reel is used at U-pipe insertion. Installation without a reel may lead to several disadvantages in handling such as heavy lifting due to weight for compensating of uplift, filling of pipes with water to compensate for pressure differences, high and uncontrollable installation velocity, forced installation, etc. with the resulting danger of damage.

Solution:

- The solution is to always use a reel.

Disregarding proper storage procedures of material at the drill site

- Occasionally proper storage of material at the drill site is disregarded. This may lead to damage of the U-pipes and grouting material and potentially failures when it is applied in the boreholes.

Solution:

- The solution is to always keep material in a protected way and grout should be kept under dry conditions.

Corrosion of metal parts such as valves

- All pipes and ancillary components are developed and manufactured to high quality standards. In the past, U-bends on BHE and welded plastic joints sometimes failed. There is now a tendency to select above-ground manifolds instead of underground manifolds. In - ground manifolds often have problems with moisture leading to corrosion of metal parts such as valves.

Solution:

- To avoid corrosion of valves, etc. above-ground manifolds should be used wherever possible.

Improper air purging

- Air purging is an essential procedure performed after filling the system with brine. The first step is to use ventilation valves typically placed on the manifold and on high points on the indoor piping system. These valves are then closed and the fluid is circulated through an open vessel until no more air is observed.
  If not properly done, air may be entrained in the system causing an increased head loss and less efficient heat exchange. There are known cases in which a secondary air purging had to be undertaken due to open air valves.

Solution:

- To avoid secondary purging, the solution is to have all air valves closed at start of operation and preferably install an automatic vacuum air purge on the suction side of the brine loop.

Comments and recommendations

Most of the issues stated above are important to prevent and are addressed by using standard materials, proper installation methods and carefully performed calculations. Congested and dirty construction sites are a challenge at the best of times, however, extra efforts by installation crews can lessen the impacts of contaminants during the purging process.

It is recommended to use standard material and procedures for the installation of borehole heat exchangers and grouting and also to keep material on the drill site safe and protected.

It is strongly recommended to consult the Subtask 2 report for detailed information on construction issues.

4.6.5. Issues regarding Poor Grouting

The reason for grouting is to seal the boreholes prevent vertical groundwater infiltration. Failures in grouting may therefore have serious consequences.

The response from the participating countries regarding grouting is summarized below.

Borehole not filled to the top

- Commonly the borehole will not be filled to the top once the casing has been withdrawn.

Solution:

- In such cases the simple solution is to “top up” the borehole with grout.

Thermal conductivity lower than designed

- It may turn out that the thermal conductivity of the grouting material is lower than designed for.

Solution:

- The solution may be to drill additional boreholes. Otherwise it will lead to lower fluid temperatures and thus to somewhat lower COP of the heat pump system.

Use of too few tremie pipes

- For deeper boreholes (approx. < 150 m) more than one tremie pipe should be used.

Solution:

- If only one is installed to the bottom, a second one may be installed later from top. The option of pulling the tremie pipe as the grouting proceeds is sometimes not successful.

Wrong mixed water/grout ratio

- It may not always be easy to have the water/grout ratio correctly mixed.

Solution:

- If this is noticed while grouting, then replace the mixed barrel and mix a correct ratio before continuing. If it is noted after hardening, new boreholes have to be drilled to replace the failed boreholes. The solution is to have a continuous supervision/ratio control during grouting.

Use of inappropriate mixer

- It may happen that the mixer used is not appropriate for the used material.

Solution:

- The simple solution is to replace the mixer.

Accidental connection of aquifers

- Accidental connection of aquifers with different pressure levels or water quality or high differences in water temperature is a main issue for grouting.

Solution:

- To perform an appropriate sealing, the solution is generally to use appropriate grouting material and equipment, have thorough supervision of grout properties, and experienced staff.

Vertical groundwater flow in the boreholes

- In Scandinavia with rare occasions of full borehole grouting, different forms of sealing plugs are used to shut off vertical groundwater flow in the boreholes.

Solution:

- The plugs must be placed in sections without fractures in order to be tight. To prevent failing, the boreholes must be properly documented by the driller.

Connection between an anhydrite layer and an aquifer

- One exceptional German experience is that improperly sealed boreholes have led to connection between an anhydrite layer and an aquifer. This caused severe upheaving due to swelling of gypsum.

Solution:

- If there is a risk for anhydrite getting in connection with an aquifer, the solution is to reconsider the choice of drill site. If the conditions are documented during drilling, the solution is to stop drilling and fill the borehole with appropriate swelling material such as bentonite.

Requirement of much larger than calculated amount of grout

- When drilling in mixed glacial sediments without casing it can sometimes require a much larger than calculated amount of grout due to the formation of cavities/material drop-in along the borehole.

Solution:

- The solution is to use stabilising mud while drilling.

Comments and recommendations

Most of the issues stated above are essentially prevented by using standard materials, proper installation methods and carefully performed calculations. This may not always be easy at a dirty and rainy drill site, but with some extra efforts it is definitely possible.

4.6.6. Horizontal Pipes in Clayey Soil

If the horizontal pipes are placed under or in conjunction with the free groundwater level in clayey soils there is a potential risk for frost heaving damages. This is an experience from Sweden based on a couple of examples. The cure is to limit brine temperatures to minimum – 5°C, or to drain the trenches. Another solution is to insulate the pipes.

4.6.7. Outer Damage of Horizontal Piping

There are examples of how other on-site construction work may damage horizontal pipes, either accidentally or from ignorance. This can be prevented by an appropriate documentation of the trenches on a bore field map and by using warning marker tapes on top of the pipes. To prevent damage to pipes at shallow depths by heavy trucks or machinery, vulnerable sections may be covered with a concrete layer or by steel plates.

It is recommended to use standard material and procedures for the installation of borehole heat exchangers and grouting and also to keep material at the construction site safe and protected.

Furthermore, it is recommended to consult the Subtask 2 report and the recommendations here given for performance of grouting.

4.7. Issues at the Operational Stage

After years of operation, the installation may be affected by unforeseen changes of conditions. Some examples given by the Annex experts are summarized below.

4.7.1. Modified Heating and Cooling Demand

Modification of building size, building construction (insulation) or different use may lead to an energy load situation different from that designed for. This will materialized as an undersized or oversized system with the same symptoms and the same solutions as described in ***chapter 4.5.***

Climate change may in the long run decrease the heating load and increase the cooling load, causing a thermal imbalance in the BTES plant. The solution would be to take this into consideration in the design phase by preparing for possible system alterations.

4.7.2. Retrofit of Heat Pump with Higher Efficiency

This may be an issue for countries with a long tradition of GSHP installations. The borehole field is still in place and functional but a more efficient replacement heat pump is installed. This may lead to an undersized borehole field in relation to the new heat pump. The obvious solution is to drill more boreholes to compensate for a higher COP of the heat pump or to decrease the ground load by adding supplementary heating or cooling sources. In groundwater-filled boreholes, such as in Scandinavia, increasing the depth of existing boreholes may be another solution, however it is not easily done.

4.8. Prevention of Damages and Failures

One main objective with this Annex is to work out general guidelines and recommendations for design, construction and operation of closed GSHP and BTES system applications.

The system design and the construction work should follow thoroughly the recommendation of subtask 1 and 2 and consequently most of potential damages and failures can be prevented totally or at least be significantly minimized. Nevertheless, proper education and expertise gained from practical experience are essential. The subtask 4 chapters above give recommendations how to deal with failures and list typical solutions.

Also, approval authorities have the responsibility to check for risks and to approve projects in a well-balanced manner of required restrictions and tolerable impact on the underground. Standards, like the new European

CEN Standard developed by the CEN TC 451 WG2, will document the best practices and should be accepted by all practitioners.

4.9. Environmental Assessment

In some countries, a deeper environmental assessment is required which studies the influences of construction work and later system operation on the underground but especially on groundwater, mostly with respect to temperature changes. In addition, the above-mentioned geological and hydrogeological impact should be included.

4.10. Examples of Damages and Failures

In this chapter some examples of failure episodes from different countries are given in order to underline the importance of awareness in design and construction of closed loop systems under different geological and site-specific conditions. These events demonstrate that lack of awareness and improper handling can result in severe damage with high environmental clean-up costs. It should be noted that the examples from Germany with the dramatic damage are not common and due to special geological and hydrogeological situations at the site.

Considering the given recommendations of Annex 27, combined with proper understanding of the geology and hydrogeology, these damages could have been avoided or at least minimized the impact. It is extremely important to have the required expertise and to be prepared to manage problems by having all necessary tools and materials available.

The information given is mainly based on documentation from damage investigation consultancy reports, legal documents, newspaper articles, etc. and is normally not publicly available.

4.10.1. Canada

City of Vancouver (2015)

In Vancouver City a property owner hired a foreign drilling company to drill for a GSHP system without signing a contract, which specifies requirements, details of construction and responsibilities. The driller had no experiences with the local geology and hydrogeology. The first borehole penetrated a high-pressure aquifer with artesian flow. The driller was not able to stop the flow and left the country. So did the owner of the property.

The flowrate was estimated to > 20 l/s. To handle the situation the City issued evacuation alerts to a dozen of homes in the area due to potential flooding and sinkhole development. To resolve the situation the City hired a contractor who started a monitoring program. A number of pressure relief wells were drilled and pumped to decrease the pressure. The artesian well was capped and the final seal was done almost two years after the breach. The City of Vancouver is of the view that the home owner is ultimately responsible for the cost. A sum of almost 10 Mil. $CAD has been incurred to remedy the situation.

Source: News articles and TV broadcasts

Figure 4-1: Pressure relief well, Vancouver

4.10.2.Germany

Wiesbaden (2009)

Close to the Hessian Ministry of Finance in Wiesbaden in 2009 a BHE drilling hit an artesian aquifer at a depth of 130 m resulting in a 7 m high water fountain with an artesian discharge of ca. 100 l/s occurred. Few additional water outlets were formed in the carvel aquifer with an artesian discharge of 0.5 – 0.7 l/s (dendritic artesian groundwater flow).

To solve the problem, 133 m³ concrete suspension was pumped with a cement grout pump (20 – 100 bar) into the borehole. The residual flow of approx. 0.2 l/s (with pH9) was stopped 20 days after the mitigation processes a settlement of <<2 cm was observed.

Additionally, geophysical investigations (ground radar, seismic) and ground investigations by further drillings was undertaken.

Damage: 0.5 - 1.0 Mil. Euro

Source: ***[35], [51]***

Kamen-Wasserkurl (2009)

In Kamen-Wasserkurl a borehole for a family home was to be drilled with a design depth of 95 m. The drill rig was too small for this depth. The maximum reachable length of the protective casing with this rig was only 14 m. After reaching a drilling depth of 70 m, a sinkhole was formed by sub-erosion and the drilling rig dropped into the developed sinkhole.

Due to too short protective casing, a connection of two aquifers resulted. This hydraulic short circuit between two aquifers caused a decrease of the groundwater level in the quaternary formation by 4 m. Approximately 50 m³ of sand and sandy silt were transported from the upper aquifer into the lower aquifer. A subsidence of 30 - 90 mm occurred in a sub-erosion area of approx. 240 m x 75 m.

In consequence, at four surrounding buildings, cracks in the ceilings and walls developed due to underground settlement.

For hydraulic sealing of the two aquifers, 700 t of standard grouting material was injected in the borehole and joints.

Damage: 1.0 - 10 Mil. Euro

Source: ***[29], [35]***

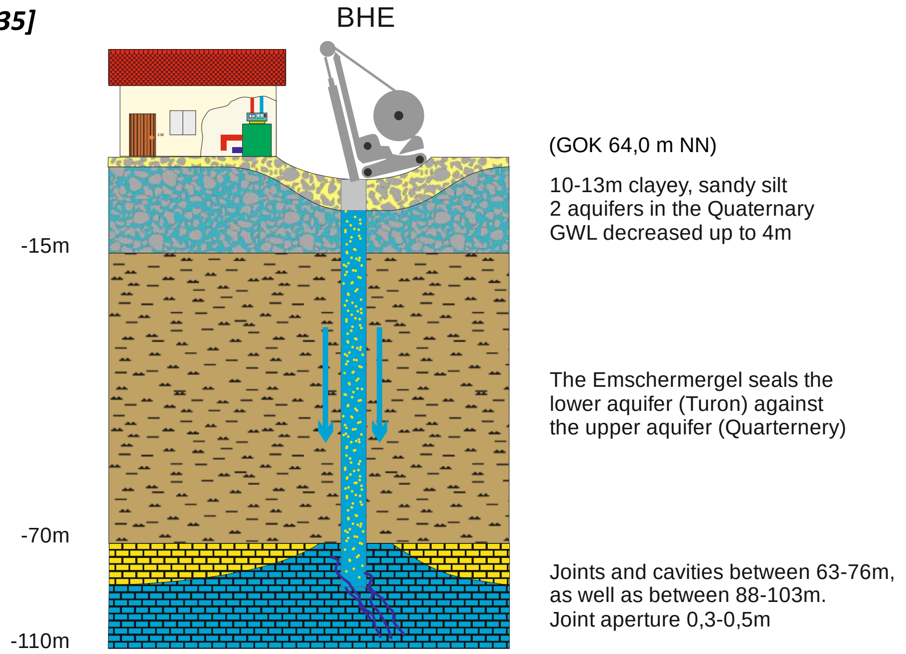

Figure 4-2: Sinkhole and geological situation in Karmen-Wasserkurl, Germany. After [29]

Rudersberg

Between 2007 and 2009, 20 BHE were drilled to a depth between 38 and 70 m. While drilling, the drilling rod stuck due to swelling processes or detritus in one borehole. From 2007 to 2013, an uplift of up to 50 cm was observed on an area of 450 m x 300 m with a vertical uplift rate of 7 mm/month with corresponding damages at buildings and infrastructure (streets, etc.).

The borehole is located in the anhydrite bearing Keuper formation and intersects three aquifers.

Due to insufficient backfilling and the use of non-sulphate-resistant grout material, ascending and descending groundwater penetrated into the anhydrite-bearing gypsum Keuper. At least atypical temperature profiles have been measured in one BHE indicating a vertical groundwater flow. Temperature measurements show also exothermic reactions (anhydrite into gypsum) at a depth between 50 - 65 m.

Reconstruction: The damaged borehole with the stuck drilling rod was re-drilled and recovered. Afterwards the borehole was sealed with clay.

Damage 1.0 - 10 Mil. Euro

Source: ***[35], [36]***

Wurmlingen

In 2002 a borehole heat exchanger was installed. In autumn 2011, the first subsidence effects were observed. The formation of a 3 m x 3 m large hole occurred. Further damages at streets, garages and buildings occurred.

At least one borehole was not sealed completely. A hydraulic short circuit was created. Artesian groundwater ran from the lower aquifer (Upper Muschelkalk) into the upper aquifer (Gipskeuper, aquiclude Lettenkeuper) resulting in an increasing of the sub erosion of gypsum (higher than under natural conditions) with corresponding formation of sinkholes.

Damage: 0.5 - 1.0 Mil. Euro

Source: ***[35]***

Schorndorf

Two boreholes with a depth of 115 m were drilled on a private property near the Kepler-School (Oct. 2008). The water well “Rainbrunnen” located a distance of 200 m to the BHE ran dry (Nov. 2008).

Groundwater flowed from the upper aquifer (Gipskeuper) into the lower aquifer (Oberer Muschelkalk). The groundwater level decreased in the range of 6 - 7 m. Consequently, a subsidence around the BHE developed. Cracks in the ceilings and walls (load-bearing elements) of the school and on eight neighbouring houses occurred.

A lack of the backfill material at a depth of a few meters under the surface was observed by re-drilling of the BHE.

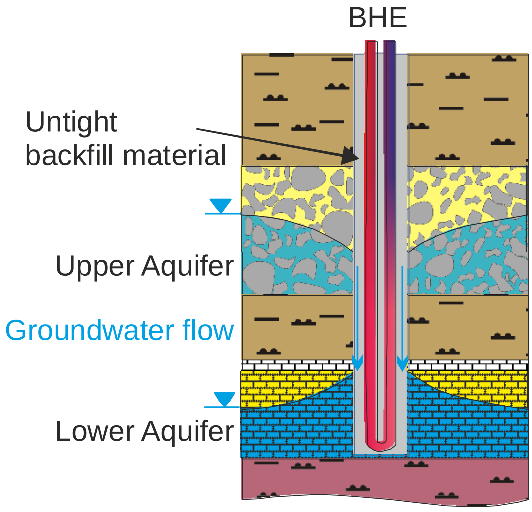

Figure 4-3: Geological situation in Schorndorf, Germany. After [34]

Reconstruction: The geological situation was investigated in detail with a groundwater monitoring system installed. No cavities were observed. The two BHE were re-drilled. A lack of the backfill material was found at a depth of a few meters. The double U-tubes were removed and the boreholes were backfilled with swelling clay to seal the two aquifers. The groundwater level recovered.

Reconstruction cost: 300,000 Euro

Damage: 1 - 10 Mil. Euro

Source: ***[35]***

Staufen im Breisgau:

In 2007, seven BHE were installed with a drilling depth of 140 m. One borehole (EWS2) collapsed at a depth between 105 - 140 m. Since the end of 2007, damages on buildings were observed, caused by uplift at the subsurface (elliptical uplift area of ca. 180 m x 280 m). The uplift process was nearly linear with maximum vertical uplift rates of 11 mm/month in the centre.

Between the borehole EWS1 and EKB1 there is a major fault (offset of formation 120 m). Swelling beds were drilled in a depth between 61.5 m – 99.5 m in EKB 2 (163 m final depth). Four aquifers were intersected (Schilfsandstein and Gipskeuper, confined groundwater, Lower Keuper and Upper Muschelkalk, artesian groundwater). From a depth of 70 m on the BHEs highly deviate from the vertical direction (up to 20 m). A hydraulic short circuit between EWS7 und EKB2 were found. The reason for the swelling of anhydrite is an upstreaming groundwater flow inside the annulus space of at least the EWS7 into the swell able anhydrite horizon of the Gipskeuper.

Temperature measurements show a dramatic difference compared to undisturbed conditions. Temperature development in B7 indicates upstreaming groundwater inside the annulus space. The temperature anomaly corresponds to the swelling horizon in EKB2 (61.5 m – 99.5 m).

Reaction of water with anhydrite => gypsum: $CaSO_4$ (Anhydrite) + $2H_2O$ → $CaSO_4 \cdot 2H_2O$ (Gypsum). Swelling pressure up to 1.7 – 4.7 MN/m^2.

The conversion of gypsum into anhydrite can cause an increase of volume up to 61 %. Because of the disable lateral strain, a distinct uplift takes place.

Damaging event: About 270 buildings are affected. Cracks in the ceilings and walls. Uplift in the historic city centre was about 60 cm. A few houses had to be demolished.

Reconstruction: Borehole EKB2 was reconstructed to a groundwater-extraction well (groundwater-lowering 132 m below surface (groundwater from the Lower Keuper- und Muschelkalk-aquifer) to minimize the GW flow into the swellable sediments.

Supplementary sealing of EWS 1-7 by injection of special sulphate resistant cement through selective perforation of the BHE-tubes. In EWS7 8,043 l of cement was injected in the underground.

Temperature measurements have shown that the reconstruction procedure was successful and the uplift could be significantly reduced.

Damage: more than 50 Mil. Euro (up to now)

Source: ***[31], [32], [33], [34], [35]***

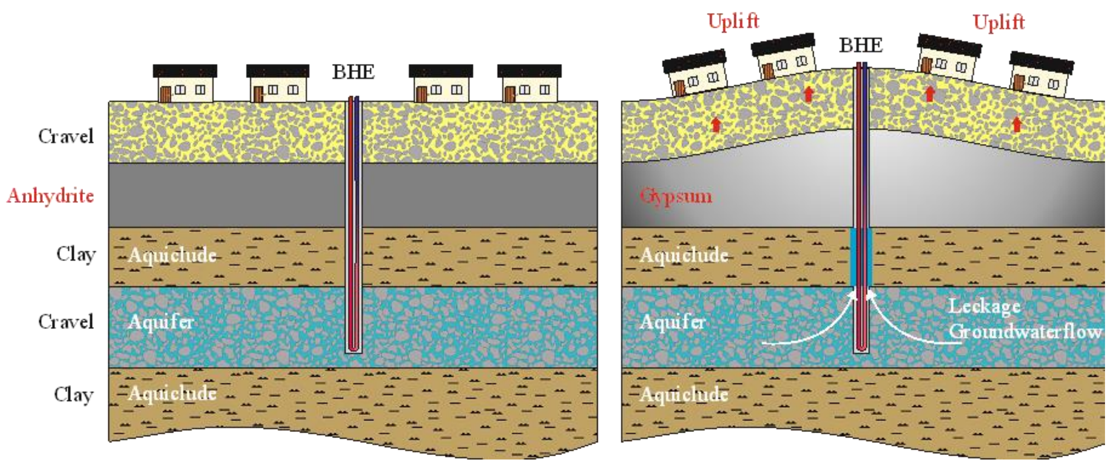

Figure 4-4: Geological situation in Staufen, Germany

Leonberg

Drilling of 4 m x 80 m deep BHE in 2011. During the drilling of the second borehole, initial cracks in ceilings and walls were observed. 24 apartment units were affected.

The lack of the backfill material caused a leakage between two aquifers. Descending groundwater potential and land subsidence due to decreasing groundwater level have occurred.

Source: ***[34], [35]***

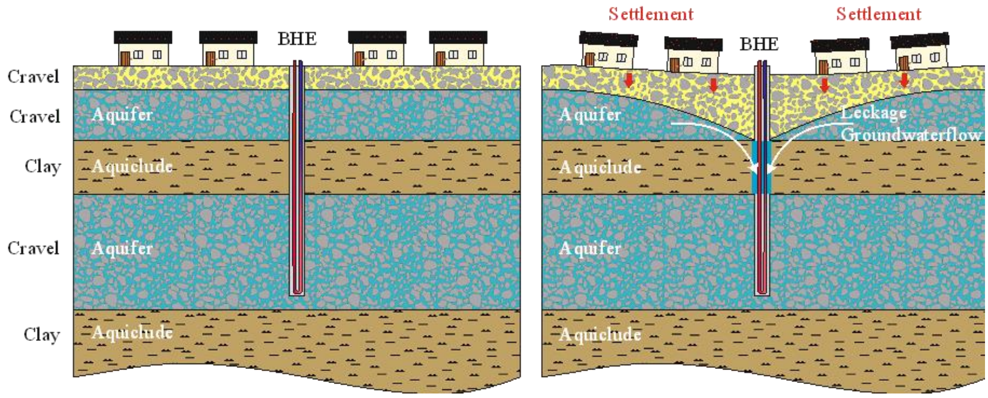

Figure 4-5: Geological situation in Leonberg, Germany

4.10.3.Sweden

Solna

Drilling of one single borehole for a GSHP to a villa in 2013. Drilling took place very close to the house. Compressed air found pathways under the house and caused a bursting uplift. A number of severe fractures on the house was created. The foundation of the villa was partly destroyed

Reconstruction cost: approx. 800,000 SEK

Sources: Damage investigation report and legal documents

Figure 4-6: Damages in basement in Solna, Sweden

Stockholm

In June 2015 drilling for a GSHP-installation with six boreholes of 300 m each in center of Stockholm started. When the fourth borehole was drilled halfway, settlement fractures on the building were observed. Drilling stopped and the driller left for the weekend. Coming back, he found his rig had dropped into a sinkhole (see pictures).

Further drilling stopped and investigations took place. A damage investigation confirmed settlements caused by the drilling. Cavities had been developed due to quicksand being transported away. Settlements were measured to be around 25 mm, enough to explain the damages. The drilling company was sued, but freed in court; lack of professionalism could not be proven.

Investigation and legal cost: 800 000 SEK

Reconstruction cost: 1 700 000 SEK (estimated)

Sources: Damage investigation report and legal documents

Figure 4-7: Accident site in Stockholm, Sweden

4.10.4.Turkey

Iller Bank, Istanbul

In the design stage for GSHP system, basement rock was defined as impermeable rock in terms of hydrogeological properties. No test drillings were made in the design phase. During the drilling, artesian groundwater was found. In three of the boreholes, it was difficult to insert U-pipes and perform grouting. After grouting a TRT-test was carried out in one of these boreholes, showing a less favourable Rb-value.

If a test-well would have been drilled in the designing stage, the number of wells would have been less and costs have been saved.

Source: ***[52]***

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Appendix 1 – Country Answers Given by the Experts for Subtask 1

Appendix 1-1 – Answers on System Concepts and Definitions

Table A1-1: How are BTES and GSHP systems defined?

Belgium	*GSHP are mainly designed to extract (and to store, but not necessarily) thermal energy from the ground ("open" and "closed" systems).* *BTES is focusing on energy storage in the ground using boreholes ("closed" loops systems)* *Both GSHP and BTES are aiming at residential and non-residential applications, for large and small projects.* *ATES is the equivalent of BTES, but with Aquifers ("open" systems). Focus on large projects.* *UTES (Underground Thermal Energy Systems) is the general name for BTES and ATES*
Canada	*BTES systems are defined and designed with the purpose to actively store thermal energy in the underground, while GSHP systems are defined and designed to extract heat (or cold) from the underground that recovers in a passive way.* *Larger heat pump systems in Canada tend to be installed in commercial projects – office towers, low-rise commercial buildings and District energy systems.* *The main market for BTES applications is commercial and institutional buildings.*
China	*There is no clear distinction between the two definitions in China. Borehole exchangers are used to extract heat (or cold), it's a part of GSHP.* *GSHP systems are used in various types of buildings, including public buildings, residential buildings, hospitals, schools, factories.* *GSHP systems are used in various types of buildings, residential and public buildings are the main market.*
Denmark	*BTES systems are defined and designed with the purpose to actively store thermal energy in the underground, while GSHP systems are defined and designed to extract heat (or cold) from the underground that recovers in a passive way.* *Larger GSHP systems are mainly applied to the residential sector.* *The main market for BTES applications is commercial and institutional buildings plus a large potential market in district heating. Until now they have preferred PTES, but new information about expected lifespan of the membranes may change that.*

Finland	*BTES systems are defined and designed with the purpose to actively store thermal energy in the underground, while GSHP systems are defined and designed to extract heat (or cold) from the underground that recovers in a passive way. BTES is designed to be a seasonal storage.* *Residential sector is still the biggest user but the largest systems have been built by commercial companies and public stakeholders.* *Large size private companies and chain store companies play an important role on the markets.*
Germany	*In the VDI 4640 guidelines the definitions are a bit more general: GSHPs use the underground as heat source or heat sink for heating and/or cooling. The BHE is one heat exchange technology among others like use of ground water wells or horizontal ground heat collector etc. BTES is one UTES system. BTES is applicable as heat storage, as cold storage or for combined heat and cold storage. The energy charged in the storage system should as far as possible be fully recovered. An important definition factor is also that the respective type of thermal energy should be deliberately introduced into the underground for use at a later date.* *Requirements met by the underground and system layout for BTES and GSHP with BHEs:* • *BTES – Energy storage: Compact and closed geometry. Minimize heat exchange at ground surface, and the ration of boundary surface area to system volume. Presence of groundwater flow is unfavorable.* • *GSHP – Direct utilization of heat/cold: Expanded and open geometry. Maximize heat exchange at ground surface, and the ration of boundary surface area to system volume. Presence of groundwater flow is favorable.* *High-temperature BTES are rare and mostly used in residential areas.* *In commercial applications BTES is mostly used as combined heat and cold storage. The transition from GSHP to BTES is gliding. There are solar district heating projects like Neckarsulm, Crailsheim and Attenkirchen using BTES as heat storage at higher temperatures. New ideas are coming up using BTES in combination of cogeneration and district heating.* *Seasonal storage of thermal energy for local district heating (for residential areas) is a typical application in Germany (which, however, up to now comprises mainly demonstration and research projects).*
Japan	*BTES systems are defined and designed with the purpose to actively store thermal energy in the underground, while GSHP systems are defined and designed to extract heat from the underground.* *Larger GSHP systems are mainly applied to the non-residential sector such as office buildings, public buildings, and commercial buildings.* *The main market for BTES application is commercial and institutional buildings.*
Korea	*BTES is not defined yet.*

	Larger systems are mainly applied to the commercial or public institutional building. Smaller systems are applied to the residential sector.
Netherlands	*The design in the Netherlands is based on a number of protocols and design documents (such as the Isso 73). The design of the system is normally (that means in houses) to extract heat in winter using the heat pump, for space heating and domestic hot water. In summer free (passive) cooling is used to provide summer comfort and regenerate the borehole store. The definition in the Netherlands is only "closed ground energy systems" and "open ground energy systems". The first covers all borehole heat exchanger systems (BHE) especially vertical ones. There is discussion about very shallow (< 10 meters) and horizontal systems and DX systems but these are generally excluded e.g. because there are no good design tools (horizontal systems) or because the physics are different (DX).* *For BTES it is mainly restricted to residential sector (single houses) and small utility (schools and small offices). However, the number of individual systems can be very large (200 – 1500). For large scale systems usually open loop (ATES) systems are implemented. Some advocate collective systems for residential sector as well, but the benefits if any are still being discussed.* *For BTES/GSHP the main market is residential. BTES in the definition of passive cooling is implemented through open ATES systems.*
Sweden	*BTES systems are defined and designed with the purpose to actively store thermal energy in the underground, while GSHP systems are defined and designed to extract heat (or cold) from the underground that recovers in a passive way.* *Larger GSHP systems are mainly applied to the residential sector.* *The main market for BTES applications is commercial and institutional buildings.*
Turkey	*GSHP systems are defined and designed to extract heat (in heating mode) or charge (inject) heat (in cooling mode) from/to the underground, such that the thermal recovery takes place primarily by yearly energy balance of system and sometimes passive way. Most of GSHP applications in Turkey work on heating in winter and cooling in summer time. Mostly extracting heat from the ground in winter is injected again in summer time. Mostly there is not energy balance between extracting and injecting, however residual or lacking heat is balanced with ground in passive way. However, there is not any control or management system most of the projects. Requirement of a monitoring and management system for GSHPs is indisputable. Larger GSHP systems are applied in the residential sector, and the in shopping centers and official buildings sector. BTES is defined as storing thermal energy (solar, residual etc.) in boreholes. The main market for BTES applications is commercial and institutional buildings.*

Appendix 1-2 – Answers on Design Approach

Table A1-2: What are the main design parameters and tools used for design?

Belgium	*In Belgium EED is by far the most popular design system for BTES.* *The main design parameters would be:* • *Ambient underground temperature (°C)* • *Ground thermal conductivity (W/m,K)* • *Thermal conductivity of the grout (W/mK)* • *Monthly heat (or cooling) load extracted (kWh)* • *Maximum extraction load (kW) over 1 month* • *Number, diameter, depth and distance between boreholes* • *Number of loops in a borehole (1 or 2)* • *Characteristics of the fluid (viscosity, heat capacity, freezing temperature, thermal conductivity,…)* • *Flow parameters (velocity) of the fluid* • *SCOP (Seasonal COP) for heating* • *Type of cooling (free or active)* • *Minimum and maximum ground temperatures for peak and long-term load* • *Some ground parameters are automatically linked to the location of the project* *In order to take into account groundwater flow and the soil profile, COMSOL Multiphysics can be used.* *For ATES MODFLOW and MT3D are commonly used for hydraulic and thermal simulations, the input parameters are:* • *Hydrogeological profile* • *Hydraulic and thermal parameters* • *Groundwater flow direction and velocity* • *Peak load* • *Annual energy (cooling/heating) demand* *Injection temperatures* *Numerical models are rarely used, other than in R/D projects. Will be used for bigger ATES-systems.*
Canada	*Main design parameters would be:* *1) undisturbed deep earth temperature;* *2) ground thermal conductivity expressed as Btu / hr – ft. °F* *3) estimated ground thermal diffusivity;* *4) 8760 hourly loads or monthly loads* *Simulation/design modeling software: Ground Loop Design (GLD) is the most commonly used software suite.* *Ground loop design software is commonly used for designing commercial projects. The use of 8760 hr. energy load models is preferred vs. monthly loads or peak loads. Residential systems are commonly sized used "rules of thumb" estimates by contractors based on similar site*

	experiences or ground source heat pump manufacturers provide ground loop sizing services to their contractors
China	*The main design parameters would be: the ambient underground temperature (℃), the ground thermal conductivity (W/m,K), the ground specific heat capacity (kJ/m³.k).TRNSYS is a commonly used design software.* *Hourly simulation of GSHP system is recommended in the National Technical Code in China. Small projects can also be estimated without simulations.*
Denmark	*The main design parameters would be: the ambient underground temperature (°C), the ground thermal conductivity (W/m,K), monthly heat (or cooling) load extracted (kWh), and the maximum average extraction load over two weeks (kW). The number, depth and distance between boreholes is then preferably defined by a simulation/design model (most often EED), or for smaller systems by experience.* *There are mostly smaller systems in Denmark, so use of "experience" is quite common. Designers of bigger systems may use TRNSYS or FeFlow.* *Numerical models are rarely used, other than for R/D projects.*
Finland	*HVAC planner designs majority of the system, even large ones. System design is mostly based on simply excel sheet calculation models provided by heat pump and / or HVAC companies. EED or other modeling is still rarely used. Minor portion of site planning is based on TRT- tests or thermogeological mapping. "Less planning, just doing – principle" is widely used in Finland.* *Numerical models are rarely used, other than for R/D projects.*
Germany	*VDI 4640-2 recommends in general simulation for GSHP but provides also tables for the small systems. For small systems (< 30 kW heating power, max. 5 BHE etc.) design according to specific values that are listed in VDI 4640 part 2 may be used.* *Larger Systems: simulation programs (e.g. EED, EWS, GEO-HAND^{light} or numerical simulation programs like FEFLOW). Numerical simulation programs are especially used if there is a significant groundwater flow at the installation site. /and more complex (larger) BHE fields.* *Design parameters:* *Heat carrier fluid temperatures at heat extraction: the heat carrier fluid temperature at borehole inlet should neither exceed 0 °C for long-term system operation (weekly average) nor -5 °C at peak load, according to new draft of VDI 4640-2. Heat carrier fluid temperatures at heat injection: the deviation between the undisturbed ground temperature and the heat carrier fluid temperature at borehole inlet should neither exceed 15 K for long-term system operation nor 20 K at peak load.* *The main design parameters listed for Sweden also hold for Germany. However instead of maximum average extraction load for two weeks, in Germany peak load (peak extraction or*

	injection rate) and the longest duration of it (ranging from a few to 24 or even 48 hours) are used.
Japan	*The main design parameters would be : the ambient underground temperature (°C), the ground thermal conductivity (W/m/K), hourly heat (or cooling) load (kW). The number and distance between boreholes is defined by a simulation/design model.* *Numerical models are rarely used, other than for R/D projects.*
Korea	*The main design parameters would be: the ambient underground temperature (°C), the ground thermal conductivity (W/m,K), monthly heat (or cooling) load extracted (kWh), and the maximum average extraction load over two weeks (kW). The number, depth and distance between boreholes is then preferably defined by a simulation/design model (most often EED), or for smaller systems by experience.* *Peak loads (heating and cooling) per hour are used. GLD is the most often used tool. 2 holes (100 m/150 m) are recommended in case of small system (10.5 kW/17.5 kW).* *Numerical models are rarely used, other than for R/D projects.*
Netherlands	*The main design parameter is the brine temperature during peak load operation and this is connected to the system SPF. This is what you design for and what you need to agree with your customer. Important aspects are also all the parameters dealing with the borehole thermal resistance (affecting performance) and pumping power. Other parameters, such as the ones mentioned, are of course important but cannot be influenced. The thermal conductivity will be less important if there is a good energy balance. Small systems need to be designed using the ISSO 73, basically a method based on tables. EED is used mostly. Design by experience is IMO not possible except for very limited cases (systems always equal, no other systems around etc).* *Numerical models are rarely used, other than for analysis of closed loop – open loop (BTES / ATES) interactions.*
Sweden	*The main design parameters would be: the ambient underground temperature (°C), the ground thermal conductivity (W/m,K), monthly heat (or cooling) load extracted (kWh), and the maximum average extraction load over two weeks (kW). The number, depth and distance between boreholes is then preferably defined by a simulation/design model (most often EED), or for smaller systems by experience.* *Numerical models are rarely used, other than for R/D projects.*
Turkey	*EED is almost a must but in Turkey this is done by experience. EED is used by some companies as our knowledge. However, how good the experience is questionable. Monthly calculations will not be accurate. The heating or cooling load varies hourly due to change of outdoor and climatic conditions. Hourly variations must be accounted for rather than monthly data. This is primarily because the heating and cooling system demand temperatures are generally*

	compensated according to outdoor temperatures. This affects the hourly COP of the heat pumps. *Main design parameters are undisturbed ground temperature, effective ground thermal conductivity (obtained by TRT test), monthly heating (or cooling) load of building. GSHP projects are designed and installed by heat pump companies, so both EED and GLDP simulation programs are used. Numerical models are used for research activities*

Table A1-3: What are common heat sources for storage (BTES)?

Belgium	*The most common sources for storage of heat would preferably be (a) waste heat from the cooling system (active or free cooling) in summer mode operation, (b) waste cold from the heat pump evaporator in winter mode operation. Also waste heat from process industry and waste burning creates significant opportunities for heat storage but is not yet widely used.* *Concepts arise to regenerate according to the unbalance (cooling-heating demand) with renewable or low energy demanding supply sources in seasonal shift (solar thermal, cooling tower, surface water, ...)*
Canada	*The most common sources for storage of heat would preferably be (a) waste heat from the cooling system in summer mode operation, (b) waste cold from the heat pump evaporator in winter mode operation; however there is also a growing application of storage of sewer waste heat.*
China	*The most common sources for storage of heat would preferably be (a) waste heat from the cooling system in summer mode operation, (b) waste cold from the heat pump evaporator in winter mode operation.*
Denmark	*Excess thermal solar energy produced during summer.*
Finland	*The most common sources for storage of heat would preferably be (a) waste heat from the cooling system in summer mode operation, (b) waste cold from the heat pump evaporator in winter mode operation. Also waste heat from process industry creates significant opportunities for heat storage.*
Germany	*The most common sources for storage of heat would preferably be (a) waste heat from the cooling system in summer mode operation, (b) waste cold from the heat pump evaporator in winter mode operation. This called combined heating and cooling. Regarding high temperature storage there is solar thermal and waste heat from cogeneration.*
Japan	*The most common sources for storage of heat would preferably be (a) waste heat from the cooling system in summer mode operation, (b) waste cold from the heat pump evaporator in winter mode operation.*
Korea	*No information*

Netherlands	*Mainly passive cooling during summer. In a number of cases solar thermal panels are used for domestic hot water and storage in the borehole system. In a few cases asphalt (road) collectors or energy-roofs are used.*
Sweden	*The most common sources for storage of heat would preferably be (a) waste heat from the cooling system in summer mode operation, (b) waste cold from the heat pump evaporator in winter mode operation.*
Turkey	*Generally air-conditioner for cooling demand in summer and natural gas for heating in summer are used. The BTES in Turkey is almost new method and GSHP is common. There isn't any BTES project*

Table A1-4: What other heat sources are applied?

Belgium	*None.*
Canada	*Other sources of heat are sometimes used for storage during the summer season, mainly for residential buildings: (a) Outdoor air by using a condenser cooler or a cooling tower, (b) waste heat from centralized ventilation systems by using an air-water heat exchanger, and (c) warm surface water from nearby lakes, streams or dams by water/water heat exchanger. Also "snow melt" or "snow prevention" systems are used, particularly in vehicle parking lots / ramps and pedestrian walkways.*
China	*Other sources of heat are also used in GSHP system, not only for residential buildings but also for other buildings, including (a) waste heat from cooling tower, (b) heat from the solar collector system*
Denmark	*Excess thermal solar energy produced during summer.*
Finland	*There has been some experience but this is not (yet) widely used technique in Finland.*
Germany	*Other sources of heat are sometimes used for storage during the summer season, mainly for residential buildings: (a) Outdoor air by using a condenser cooler or a cooling tower, (b) waste heat from centralized ventilation systems by using an air-water heat exchanger. Other sources may be tunnels, mining, solar collectors, industrial waste heat, heat and power co-generation, and refrigeration condensers.*
Japan	*There are some examples of (a) outdoor air by using a condenser cooler or a cooling tower, and (b) waste heat from centralized ventilation systems by using an air-water heat exchanger). Also, excess solar energy is applied.*
Korea	*No information*
Netherlands	*Not generally used*
Sweden	*Other sources of heat are sometimes used for storage during the summer season, mainly for residential buildings: (a) Outdoor air by using a condenser cooler or a cooling tower, (b) waste*

	heat from centralized ventilation systems by using an air-water heat exchanger, and (c) warm surface water from nearby lakes, streams or dams by water/water heat exchanger.
Turkey	*Waste hot water from balneological uses*

Table A1-5: What sources for storage of cold are applied?

Belgium	*See table 1-4.*
Canada	*Other sources for storage of cold in winter time would be (a) cold surface water, (b) snow melting and (c) outdoor air from a condenser cooler or a cooling tower.*
China	*Cold water from cooling tower is the main source for storage in winter.*
Denmark	*No other cold sources. ATES is used in connection with HVAC*
Finland	*Only few cooling systems are based on BTES (and pilot system for ATES) but large size cooling storages are not found in Finland. This is due to reason that the need for cooling is minimal compared to that of heating.*
Germany	*Other sources for storage of cold in winter time would be (a) cold surface water, (b) snow melting and (c) outdoor air from a condenser cooler or a cooling tower. Moreover ice storage systems ("container solutions") in underground and gas expansion process in industry may be used as a cold storage source.*
Japan	*Other sources for storage of cold in winter time would be outdoor air from a condenser cooler or a cooling tower.*
Korea	*No information*
Netherlands	*The cold is generated during heating of the building in winter.*
Sweden	*Other sources for storage of cold in winter time would be (a) cold surface water, (b) snow melting and (c) outdoor air from a condenser cooler or a cooling tower.*
Turkey	*Especially in the south and coasts of country seawater, in some places river water and underground water are cold sources for GSHP systems.*

Table A1-6: What are the heat and cold load coverages assumed in BTES and GSHP design?

Belgium	*The design of BTES systems as well as GSHP systems would usually not cover the maximum heat load of the building but often 100 % of the maximum cold load. Commonly the systems are designed to cover 60-80% of the heat load. This evolves however with the increasing efforts to reduce the heating demand of buildings. For residential applications however, the systems will usually be designed for 100% heat load.*

Canada	*The design of a BTES system as well as GSHP system would typically cover 60-80 % of the maximum heat load of the building producing 80-95 % of heat demand, with the exception that some installations are "greenwash" – the system may only cover 10–20% of peak and 40–60% of annual load.*
China	*The Country is divided into five climate zones, namely: cold regions, cold regions, hot summer and cold winter areas, hot summer and warm winter areas, moderate areas. GSHP system is used in all zones, it covers different load according to different demand.*
Denmark	*Limited available data, but the design of a BTES system as well as GSHP system may cover 60-80 % of the maximum heat load of the building producing 80-95 % of heat demand*
Finland	*60-80% of maximum heating power covers 90-98% of total heating energy consumption. Cooling load can be covered 100% by BTES in most cases in Finland. The <u>average</u> design is approximately 85% of maximum heat load in <20 kW projects and 70-75% in >20 kW projects (unpublished questionnaire data Majuri 2014)*
Germany	*The design of a BTES system as well as GSHP system would typically cover 60-80 % of the maximum heat load of the building producing 80-95 % of heat demand; Cooling load can vary a lot, depending on the building type and its construction.* *For (smaller) residential buildings, the energy requirements for heating and hot water are usually covered 100 %.*
Japan	*The concept is usually the same. But the design of load capacity that the GSHP system covers is depending on the region. Also, the borehole total length, which includes length and number, is sometimes determined before the design because the installation cost of borehole is more expensive. In this case, the energy load for the GSHP system is determined according to the total length.*
Korea	*No information*
Netherlands	*In residential systems the heat pump delivers usually 100% of the load. For cooling also, but it is not a problem if the total cooling demand is not met. In utility the heat pump system can provide usually around 60%-80% of the thermal load.*
Sweden	*The design of a BTES system as well as GSHP system would typically cover 60-80 % of the maximum heat load of the building producing 80-95 % of heat demand, while the system would cover 100 % of the cold load and cold production.*
Turkey	*Covers 70-90 % of the maximum heat load and 90 % of the cold load* *The peak to base load ratio largely varies. Therefore every case is special. Giving rule of thumb type numbers might be erroneous.* *There is no project related BTES system. For GSHP system 30% cooling and heating 16% demand of building is meet in Atasehir Building GSHP system. Because The system installed in*

	very limited area, just 24 borehole were installed and it's capacity 1/9 of building heat and cooling demand.

Table A1-7: Which auxiliary heating sources are used at peak load?

Belgium	*In non-residential applications, usually via natural gas or oil furnace. For residential ones, usually via electrical boilers for sanitary hot water.*
Canada	*Natural gas boilers are very common, some district steam systems (NatGas based) and electric boilers. Also electric baseboard heating is very common in Quebec and Manitoba as both Provinces have abundant Hydro – electric resources.*
China	*The peak load of a hybrid system of GSHP and other energy is supplied by (a) district heating, (b) oil or natural gas burner, (c) an electric boiler, or (d) coal boiler.*
Denmark	*Electricity for smaller systems.*
Finland	*The peak load for heating is most commonly supplied by (1) an electric boiler and (2) oil burner. Biofuel burners, district heating and natural gas burners are also used.*
Germany	*The peak load for heating is typically supplied by oil or natural gas burner, or an electric heater.* *In the German VDI 4640, the following definitions of bivalent operation is given:* • **Bivalent-alternative operation**: The HP covers up to an ambient temperature (e.g. 0°C) or another criterion the full load. Then the other energy covers the full load. • **Bivalent-parallel operation**: The HP covers up to an ambient temperature (e.g. 0°C) or another criterion the full load. Then the HP and the other energy together cover the full load. Both are operated in parallel. • **Bivalent-part-parallel operation:** The HP covers up to an ambient temperature (e.g. 0°C) or another criterion the full load. Then the HP and the other energy together cover the full load. Both are operated in parallel. When the HP reaches its limitations of use (e.g. minimum ambient temperature, maximum supply temperature) the second energy covers the full load.
Japan	*The peak load is supplied by (a) air source heat pump system, (b) oil or gas burner.*
Korea	*No information*
Netherlands	*In residential by the heat pump itself. In utility usually, gas-fired boilers are used. If district heating is available GSHP systems or BTES systems will not be used.*
Sweden	*The peak load for heating is typically supplied by (a) district heating, (b) oil or natural gas burner, or (c) an electric boiler.*
Turkey	*Commonly Natural Gas boilers and rarely coal.*

Table A1-8: Which auxiliary cooling sources are used at peak load?

Belgium	*Normally the peak load for cooling is covered by running the heat pump as a chiller (active cooling). The excess heat is disposed by using condenser coolers or cooling towers.*
Canada	*Electrically driven chillers and window "shaker" units in residential applications.*
China	*Free cooling from BTES is different because of the different climate zone,*
Denmark	*BTES are not normally used for cooling. But ATES are.*
Finland	*With heat pump or with heat exchangers.*
Germany	*Depends on the specific application and case; no general statement is possible for Germany.*
Japan	*In Japan, the peak load is supplied by (a) ASHP system, (b) water cooled chiller with cooling tower, (c) absorption chiller with cooling tower.*
Korea	*No information*
Netherlands	*For residential the cooling load (comfort cooling) is completely done with passive cooling. If the cooling requirement is not met (very warm summer) that that is not an issue. In other situations, the cooling will be augmented by chillers.*
Sweden	*Free cooling from a BTES application would typically cover 30-50 % of the maximum load and 50-75 % of the cold demand over a year. Peak load for cooling is produced with heat pump running as chiller.*
Turkey	*Split air-conditioners or chillers. Air-conditioner cover almost 90% for the cooling load.*

Table A1-9 What is a typical distance between two independent boreholes?

Belgium	*No specific legislation at this stage about the distance between boreholes, but a typical minimum distance between boreholes would be 5 to 7 m since mutual influence of the boreholes would then be reduced given the ground composition in Belgium.*
Canada	*For two independent boreholes 15 to 20 feet (4.5 m to 6.0 m) is a required distance, however, the designer/engineer may specify a greater or lesser distance (center-to-center) dependent on geology or building load demands or unbalance of loads.* *The space between the boreholes in multi-borehole systems normally varies between 5-10 m. The space and configuration are mainly dependent on the thermal properties of the underground, available surface space and thermal balance between heat and cold extraction/injection. Drake Landing in Alberta is an example of this.*

China	*According to the national technical code of China, the distance between two independent boreholes in GSHP systems is 3 m-6 m.* *The space between the boreholes in multi-borehole systems normally varies between 5-10 m. The space and configuration are mainly dependent on the thermal properties of the underground, available surface space and thermal balance between heat and cold extraction/injection.*
Denmark	*Legislation says 20 meters between two independent boreholes. But checks are normally not made by the authorities.* *Due to our generally lower lambda-values we work with 2.5-3 meters between boreholes in multi-borehole systems.*
Finland	*Typical normative distance in Finland is 15-20 metres between two independent boreholes. Municipalities have applied 7.5 to 10 meter "safe zones" regarding property borders.* *The space between the boreholes in multi-boreholes systems normally varies between 5-10 m. The space and configuration are mainly dependent on the thermal properties of the underground, available surface space and thermal balance between heat and cold extraction/injection. However the system design is not based on site specific research in most cases. Larger fields (space between boreholes over 10 meters) can "act" like BTES but they are not specially designed for that.*
Germany	*In general the BHE distance in GSHP systems is a matter of design with constraints resulting from the size of the lot, the geology and other design parameters. In Germany the VDI 4640-1 guideline gives only a recommendation for BHE-systems on neighboring properties:* *In order to avoid adverse effects VDI 4640-1 recommends a minimum distance of 10 m between BHEs on neighboring properties (for residential areas with smaller residential buildings). Exceptions are possible if appropriate mutually coordinated planning and agreements between the neighbors exist.* *Additionally there may be requirements from the local authorities that are responsible for approval.* *There are different regulations in the 16 federal states of Germany. The obligations/recommendations vary from 3 m to 5 m distance that has to be kept to boundaries. This leads to a minimum distance of two independent boreholes of 6 to 10 m. In some German states there are no obligations concerning the distance of independent boreholes.* *In VDI 4640-3 a typical borehole spacing range of 2 to 5 m is given for distinct BTES.* *Borehole distance of High-temperature BTES: Neckarsulm (2.5 m), high-temperature BTES Crailsheim (3 m).*
Japan	*The distance between two independent boreholes in GSHP system is not stipulated.*

	The space between the boreholes in multi-borehole systems normally varies between 5-10 m. The space and configuration are mainly dependent on the thermal properties of the underground, available surface space and thermal balance between heat and cold extraction/injection.
Korea	*There are no regulations related to the distance between two independent boreholes.*
Netherlands	*In the Netherlands you are required by law to calculate the possible negative interactions between neighboring systems. Analysis has shown that a “safe distance” does not exist, as this depends on the number of systems which may be large and because all effects (even small ones) need to be added (superposition). The influence area – defined as the temperature where 0.1 K temperature decrease is possible in a “worst case” scenario – is at least 60 meters and the search radius (because there may be systems further away as well) is 120 meters. Only if there are not more than 2 systems within this search radius can a fixed distance be used (“worst case distance”), this ranges between 15 and 25 meters depending on the soil thermal conductivity. Moreover, this is all only permissible if there is no significant effect of ground water flow (the allowed effect depends on the amount of ground water flow, the amount of the BHE affected along the vertical and the energy balance of the system). A minimum distance, to avoid the chance of drilling a heat exchanger into a neighbouring one, is at least 5 meters (may be shorter for short heat exchangers).* *The space between the boreholes in multi-borehole systems normally varies between 5-10 m. The space and configuration are mainly dependent on the thermal properties of the underground, available surface space and thermal balance between heat and cold extraction/injection.*
Sweden	*The distance between two independent boreholes in GSHP systems is stipulated to be >20 m.* *The space between the boreholes in multi-borehole systems normally varies between 5-15 m. The space and configuration are mainly dependent on the thermal properties of the underground, available surface space and thermal balance between heat and cold extraction/injection.*
Turkey	*The distance between 2 boreholes is important however, the limitation of land for this purpose can be effect to reduce these distance between the boreholes.* *BHE’s are 6 meter chosen according VDI guidelines.* *This must be a matter of modeling rather than just giving a rule of thumb number. A comprehensive mathematical and/or numerical model that may be customized to every country is a must* *The condition and the limit of the land affects this distance.* *There is no BTES system implemented in Turkey. So system design procedure and configuration are not known yet.*

Table A1-10: How deep is a typical borehole? Are deviated boreholes used?

Belgium	*This will depend upon the considered Region. In most parts of Flanders, permits will not be required for drilling up to 150 m (depth criterion).*
Canada	*Deeper boreholes are becoming the 'norm' in Canada. Concerning angled boreholes, there is real concern with respect to boreholes physically terminating outside property lines – ownership issues come into play. Also, adjacent properties that employ angled boreholes can interfere with one another or be destroyed.*
China	*GSHP usually used as a part of the hybrid system in urban areas where space is limited. Drilling depth is usually 80 to 120 meters, not deeper due to cost and other factors. Deviated boreholes are not reported in China.*
Denmark	*A system called "Sunwell" is being used. The boreholes are placed in a circle (about 2 m diameter) and are angled about 20 deg. from vertical. The systems are primarily used as BTES. We are right now in the planning phase of installing test BHEs using horizontal directional drilling at 4 different depth intervals (between 6 and 43 meter bsl).*
Finland	*600 meters is the maximum depth at the moment. Deviated boreholes are common but there has been major problems (freezing of boreholes, work safety issues) when even four boreholes have been drilled from one spot.*
Germany	*Depending on the geological and hydrogeological situations. Drilling depth may be restricted to prevent risks, artesian aquifers, for the protection of deeper groundwater layers, e. g. drinking water purposes and generally problematic layers, e.g. gypsum/anhydrite, karstic formations and gas bearing layers.* *At the moment in Germany there is maybe a small trend to a little bit deeper BHE's (density of BHE in urban areas is not so high in Germany like e. g. in Sweden).* *Generally boreholes for BHE have mostly a depth between 50 m to 99 m. Increasing drilling depths restrictions (imposed by the authorities) lead in some regions to more shallow drilling depths.* *Very deep boreholes as well as inclined – or even almost horizontal – boreholes are discussed and in some cases tested in urban areas with limited space, but there's yet no significant market penetration in Germany by such systems.* *Regulations in some federal states of Germany like "boreholes are only allowed to the depth of the first aquifer. It is not allowed to penetrate the confining layer to the second aquifer…" are a serious barrier for deep boreholes.*
Japan	*The borehole depth is almost always less than 150 m. Three is no tendency to drill deeper boreholes. If the borehole total length is limited, the capacity of GSHP unit is determined according to the length.*
Korea	*Deep boreholes (typically 200 m) are used in urban area.*

Netherlands	*In the Netherlands the soils are unconsolidated and therefore drilling depth is limited by the depth you are able to drill, install the heat exchanger and backfill in one day. It is not possible to leave the borehole open. In general depths will vary between 80 and 200 meters. Deviated boreholes are in my experience almost never used.*
Sweden	*In urban areas with limited or restricted space to place boreholes, there is a tendency to drill deeper and deeper boreholes, as well as use deviated (angled) boreholes, in order to have enough space between the holes.*
Turkey	*Energy and exergy analysis must be carried out to determine the optimum borehole depth for an accurate LCA.* *Especially in urban areas, there is a tendency to drill deeper boreholes. However, most of the boreholes using now are 150 m.*

Table A1-11 How does the underground temperature vary at different locations and depth?

Belgium	*Usually average ground temperature between 10°C and 12°C. For large projects there will be a systematic TRT test to assess the ground temperature.*
Canada	*Ground temperatures in Canada vary between 6°C and 12°C.*
China	*Due to large land area, there is no detailed soil temperature survey. According to our engineering experience, the temperature at 100 m depth change may be between 10°C and 20°C.*
Denmark	*Variations are smaller in Denmark for obvious reasons, but generally between + 10 and +11^{o}C.*
Finland	*Between +3,5°C in the north and +9°C in the south.*
Germany	*Annual mean ground surface temperature is in most cases around +1 K higher than annual mean ambient air temperature. The latter varies from 7.4 to 11.1°C in the different climate regions that are officially defined for Germany (DIN V 18599-10) and are used for German Test Reference Years (TRY). Temperature in 100 m depth is than appr. 2 to 3 K warmer than annual mean ground surface temperatures. Deviations, i.e. higher temperatures, may occur in dense urban areas, where underground temperature has been affected for a long time by civilization (buildings, sealed surfaces, underground structures and heat sources, release of heat into the ground).*
Japan	*The temperature at 100 m depth is varying less than +2^{o}C except for the areas in where there are the hot springs.*
Korea	*The temperature at about 150 m depth is varying between 14-16^{o}C. It shows 12-13^{o}C in the high altitude and high latitude area but 17-18^{o}C in the low altitude and southern coastal area.*
Netherlands	*Between +8 and +14 ^{o}C depending on the setting (city or countryside). In general, the importance of this parameter is underestimated a lot.*

Sweden	*The temperature at 100 m depth is varying between +4°C in the north and +11°C in the southern part of the country. This does drastically affect the design of GSHP systems.*
Turkey	*Because of heat flux and geotectonic situation, undisturbed ground temperature can vary depend of are, it is measured as 14,5°C in not intensive residential area in Ankara. Istanbul's undisturbed ground temperature was measured as 17,6°C due to intensive residential area. The average ground temperature of Turkey almost +14°C. In West Anatolia region at 100 m depth the ground temperature is higher than +20°C.*

Table A1-12 What types of antifreeze are used?

Belgium	*Regional matter. In Flanders only Monopropylene glycol (MPG). Typical concentration 25% to 35%.*
Canada	*Ethanol, methanol & propylene glycol.*
China	*Ethylene glycol is commonly used for freezing protection.*
Denmark	*IPA (IsoPropanolAlkohol) and glycol, about 30 %.*
Finland	*Fluid of 28% ethanol is used.*
Germany	*Mainly different kinds of ethylene glycol ((1,2-Etandiol). Concentration of the solution used as working fluid 20-30 % => -8 to -17 °C depending on the specific product).* *If operating temperatures can be guaranteed to be always above the freezing point, water is preferred as working fluid. In the other cases, which are in majority, ethylene glycol is very common in Germany.*
Japan	*In the moderate climate region, only water that does not include anti-freezer is sometimes used.*
Korea	*No information*
Netherlands	*Monopropylene glycol or monoethylene glycol both 10 % - 30 %. There is a lot of discussion about leakage, the Dutch health/environmental authority (RIVM) has released a study showing that especially additives are dangerous but the pure product not. Therefore the recommendation is to use pure product and mix this with clean water and not use pre-mixed fluids.*
Sweden	*A mixture of water and bioethanol is used for freezing protection of the heat carrier, normally with 27 % ethanol.*
Turkey	*A mixture of water and mono-ethylene glycol is normally used for freezing protection of the heat carrier. In field applications generally it is taking as 1/3 ethylene glycol and 2/3 water.*

Table A1-13: What are typical working fluid temperatures in a BTES loop?

Belgium	*Winter regime design temperature usually 0°C to 5°C.* *Summer regime design temperature max 16°C (25°C maximum by legislation to go back to the ground).*
Canada	*-2–0°C (28–32°F) for residential and 0–1°C (32–34°F) for commercial (Winter) - cooling 18–21°C (65–70°F) for residential and 29–32°C (85-90°F) for commercial (in Summer).*
China	*A typical working temperature of the brine loop (heat carrier) in a BTES system connected to a heat pump would be +4^{o}C as lowest (normally in February) and +32/+33^{o}C as highest (normally in August).*
Denmark	*No sufficient data to state a typical temperature*
Finland	*A typical working temperature of the brine loop (heat carrier) in a BTES system connected to a heat pump would be -3/-4^{o}C as lowest (normally in February) and +14/+16^{o}C as highest (normally in August).*
Germany	*For GSHP systems that are used for heating and cooling, the minimum heat carrier fluid temperature (return temperature from the heat pump to the BHE system) is -3 °C. The maximum return temperature in case of cooling should not exceed 15 K above the undisturbed ground temperature (~25 – 30 °C). The temperatures of high-temperature BTES are significantly higher (e.g. 40 – 80 °C).*
Japan	*A typical working temperature of the brine loop would be 0/-5^{o}C as lowest and +30/+35^{o}C as highest.*
Korea	*No information*
Netherlands	*In winter the flow/return temperature is generally -2 to +2 (dT 4K) . Some providers design based on water as working fluid, the lowest temperature is then around 5 °C (+5 - +8 °C). In summer temperatures will be comparable to Sweden.*
Sweden	*A typical working temperature of the brine loop (heat carrier) in a BTES system connected to a heat pump would be -3/-4^{o}C as lowest (normally in February) and +14/+16^{o}C as highest (normally in August).*
Turkey	*Winter -5^{o}C,0 ^{0}C (Heating), 30-40 ^{0}C (Cooling) summer.*

Table A1-14: Is freezing of boreholes common and are there precautions taken to prevent damages?

Belgium	*Ok to go under 0°C, but the legislation always requires frost resistant grout.*
Canada	*Most jurisdictions in Canada require grout filled boreholes to avoid cross-contamination of aquifers and infiltration of surface water.*

China	*The temperature of the heat carrier is typically above 0℃. The National technical code recommend the operating temperature above 4 ℃.*
Denmark	*Groundwater-filled boreholes are not allowed. All boreholes must be grouted/sealed off in order to protect aquifers.*
Finland	*Examples of freezing boreholes exist.*
Germany	*Temperatures of -5 °C for a longer period are at least in some states of Germany not allowed. E.g. Baden-Württemberg allows a minimum temperature of -3 °C at the exit of the evaporator. It is generally not permitted to freeze the borehole permanently or over a larger range.* *In Germany groundwater filled boreholes are not common. VDI 4640-2 describes the procedural and material requirements of the backfilling.* *Damage of backfilling by freezing the grouting material when operated under too low temperatures is of some concern in Germany, and some damages have been reported.*
Japan	*Boreholes are usually filled with sand. Therefore, there are several case where the moisture in the sand was frozen but it was hardly observed that the boreholes were damaged by the freezing.*
Korea	*Circulation temperature is in between 0-5°C and antifreeze is used. Freezing is not common.*
Netherlands	*It is not allowed to freeze boreholes. Since 2013 you need to limit the flow temperature to the borehole to -3 oC (taking the thermal resistance of the fluid into account then there is no freezing in the borehole).*
Sweden	*With groundwater filled boreholes, it has been shown that running the heat carrier with an average temperature below -5°C during a longer period of time will cause the groundwater in the borehole to start freezing and may in worst case cause damages.*
Turkey	*No conditions for freezing, hence no experience. In some applications, the system is shut down itself when the borehole temperature decreases below a certain temperature. However, in some long-time used boreholes average borehole temperature has been seen to decrease significantly because of improper yearly heating and cooling balance. This is understood from the increased consumption in the additional heating system or frequent stops of the heat pump. The solution depends on the situation, but mostly involves adding more boreholes*

Appendix 1-3 – Answers on Pre-feasibility Studies

Table A1-15: What is the scope of the pre-feasibility study?

Belgium	*In the scope of the European Energy Directive for Buildings an evaluation of alternative energy systems is a requirement for buildings larger than 1000 m2 (regional matter in Belgium). Geothermal systems are one of the alternatives to be evaluated.*

Canada	*A pre-feasibility report will commonly be a desktop study where the BTES or GSHP options are compared to other forms of heating and cooling, by example district heating/cooling..*
China	*A pre-feasibility report will commonly be a desktop study where the BTES or GSHP options are compared to other forms of heating and cooling, by example district heating/cooling.*
Denmark	*If district heating is available, it will typically be mandatory to use it.*
Finland	*A pre-feasibility report will commonly be a desktop study where the BTES or GSHP options are compared to other forms of heating and cooling, by example district heating/cooling. In some cases geological field trip is organized and the bedrock samples are taken and analysed*
Germany	*A pre-feasibility report will commonly be a desktop study where the BTES or GSHP options are compared to other forms of heating and cooling, by example district heating/cooling.*
Japan	*A pre-feasibility report will commonly be a desktop study where the BTES or GSHP options are compared to other forms of heating and cooling, by example district heating/cooling.*
Korea	*A pre-feasibility report will commonly be a desktop study where the BTES or GSHP options are compared to other forms of heating and cooling, by example district heating/cooling.*
Netherlands	*Not really needed – GSHP is always possible and gives big advantages in reaching the energy performance goals. When district heating is available usually it is mandatory to use it.*
Sweden	*A pre-feasibility report will commonly be a desktop study where the BTES or GSHP options are compared to other forms of heating and cooling, by example district heating/cooling.*
Turkey	*In general, according to energy efficiency for building regulation, a pre-feasibility report has to be prepared and compared with the option of fuel-oil and boiler system.* *In pre-feasibility stage, some parameters are not included such as topography, geological maps, geological data base. Pre-feasibility work includes a comparison between GSHP and fuel-oil usage in terms of economy.*

Table A1-16: What is the lay-out and content of a feasibility study?

Belgium	*Regional matter in Belgium. Flanders and Brussels: several maps (geological and legal information) have been combined in a web tool that can be used for pre-design and economical calculations, see http://tool.smartgeotherm.be/geo/alg*
Canada	*The main sources of information in a pre-feasibility are given by situation, topographic and geological maps, and geological data basis. Based on energy consumption over a year, load and temperature demands, a system is principally pre-designed and investment and operational costs are roughly calculated and compared to other forms of energy supply.*
China	*The main sources of information in a pre-feasibility are given by situation, topographic and geological maps, and geological data basis. Based on energy consumption over a year, load*

	and temperature demands, a system is principally pre-designed and investment and operational costs are roughly calculated and compared to other forms of energy supply.
Denmark	*If a designer is involved, this would be the same procedure. However GSHP installations are often sold by drillers or HP installers. None of these have sufficient knowledge in all the necessary fields of expertise.*
Finland	*The main sources of information in a pre-feasibility are given by situation, topographic and geological maps, and geological data basis. Based on energy consumption over a year, load and temperature demands, a system is principally pre-designed and investment and operational costs are roughly calculated and compared to other forms of energy supply.*
Germany	*Very often the online heat extractions maps of geological surveys are used.*
Japan	*The main sources of information in a pre-feasibility are given by situation, topographic and geological maps, and geological data basis. Based on energy consumption over a year, load and temperature demands, a system is principally pre-designed and investment and operational costs are roughly calculated and compared to other forms of energy supply.*
Korea	*The main sources of information in a pre-feasibility are given by situation, topographic and geological maps, and geological data basis. Based on energy consumption over a year, load and temperature demands, a system is principally pre-designed and investment and operational costs are roughly calculated and compared to other forms of energy supply.*
Netherlands	*Not applicable. GSHP is always possible and gives big advantages in reaching the energy performance goals. When district heating is available usually it is mandatory to use it.*
Sweden	*The main sources of information in a pre-feasibility are given by situation, topographic and geological maps, and geological data basis. Based on energy consumption over a year, load and temperature demands, a system is principally pre-designed and investment and operational costs are roughly calculated and compared to other forms of energy supply.*
Turkey	*Hourly sum of energy consumption based on cooling and heating degree days must be the basis rather than a lump sum for annual consumption* *It should include:* *-Heating and cooling load of building in monthly* *-calculation specific calculation heat extraction rate of rocks according literature values and borehole number and lengths,* *-Calculation cost of drilling, excavation, number of manifold and number of heat pumps* *-Comparison of fuel oil or natural gas prices versus year.* *- GSHP system is considered feasible if the pay-back period is between 4 and 10 years in Turkey.* *Standards and definitions regarding GSHP or BTES performance and economics related to the demand side type, load (energy, exergy profiles) must be separately developed in addition to*

	standard test conditions. Like GSHP performance standard for residences, industry (break down of industry), commercial buildings etc for different climatic conditions.

Table A1-17: Are geological and hydrogeological maps of your country available?

Belgium	*Regional matter. Flanders: drill logs and geological as well as geo-hydrological maps are freely available. (https://www.dov.vlaanderen.be). There is an equivalent system in Wallonia.*
Canada	*Geological maps are available as well as water well borehole logs, which can assist in estimating ground conductivity.*
China	*Geological maps are not available for all the country, the survey is only applied in some provinces.*
Denmark	*Geological maps are available all over the country*
Finland	*Available all over the country 1:20 000 around larger cities and 1:100 000 rural areas (Geological Survey of Finland).*
Germany	*Geological and hydrogeological maps are available more or less detailed all over the country. www.geotis.de*
Japan	*No information*
Korea	*Geological maps are available all over the country*
Netherlands	*Drill logs and geological maps as well as geohydrological maps are freely available. (Dinoloket)*
Sweden	*Geological maps are available all over the country (Swedish Geological Survey) most often in the scale 1:50 000.*
Turkey	*Available geological, active faults, geophysics, landslide, mineral, intrusive rocks, maps in the scale 1:500.000 also these are shown overlapped google earth in (http://yerbilimleri.mta.gov.tr/anasayfa.aspx) website. Other maps which is 1:25.000 and 1:50.000 scale are sold by MTA*

Table A1-18: Is there a centralized geological data base in your country?

Belgium	*Regional matter. Flanders: Drill logs and geological maps as well as geo-hydrological maps are freely available. Idem for data from existing wells.*
Canada	*Geological and Hydrogeological information is available, however, existing geothermal borehole information is virtually non-existent.*
China	*No established centralized borehole database.*

Denmark	*Available all over the country (Danish Geological Survey). Information of existing boreholes and geological and hydrogeological features can be found at the homepage.*
Finland	*No nationwide database regarding boreholes exists. Bigger cities and some municipalities have their own borehole databases. From 5/2011 it has been compulsory to get a permit for drilling a borehole. Boreholes drilled before 5/2011 are mainly not in any database. Hydrogeological and geological features can be found form public database.*
Germany	*Different in the 16 states in Germany. No unique system. Information of existing boreholes and geological and hydrogeological features can be found at any state (geological survey), but the quality and details of information is different in the states. In Germany very often heat extractions estimations (W/m) of the geological surveys are online available.*
Japan	*No information*
Korea	*TRT is mandatory and the public data (KIGAM or KIER) are also used sometimes.* • *KIGAM(Korea Institute of Geoscience and Mineral Resources; http://kgris.kigam.re.kr)* • *KIER(Korea Institute of Energy Research; http://kredc.kier.re.kr)*
Netherlands	*Drill logs and geological maps as well as geohydrological maps are freely available.*
Sweden	*Available all over the country (Swedish Geological Survey). Information of existing boreholes and geological and hydrogeological features can be found at the homepage of SGU*
Turkey	*(MTA –General Directorate of Mineral Research and Exploration web site). Now there is a project that will include all types of Wells around Turkey to put on web site.*

Table A1-19: Is there a centralized hydrogeological data base in your country?

Belgium	*Regional matter. Flanders: Drill logs and geological maps as well as geo-hydrological maps are freely available, as well as piezometer data and the licensed flow rate of groundwater extractions.*
Canada	*Not available for geothermal boreholes. Water well logs are generally available across the country.*
China	*Hydrogeological data is available for some provinces. There is no database of existing BTES.*
Denmark	*GEUS and the Regions of DK have good maps. GW levels can also be found in the borehole-database.*
Finland	*Database available all over the country (Finnish Environmental Institute)*
Germany	*Hydrogeological maps of different scale are available (depended on state, different quality and scales). General hydrogeological data are often available (depended on state, different quality).*
Japan	*No information*

Korea	*The public data (KIGAM or KIER) are used sometimes.*
Netherlands	*Drill logs and geological maps as well as geohydrological maps are freely available.*
Sweden	*Available all over the country (Swedish Geological Survey). Information of existing boreholes and geological and hydrogeological features can be found at the homepage of SGU*
Turkey	*Hydrogeological features are used* *There is no public website with information about existing boreholes in Turkey. Hydrogeology map is available as hardcopy in 1:500.000 scale. In accordance with EU water framework directive, when "groundwater bodies" map is completed, it will be available online.*

Table A1-20: Do you consult with water and mining authorities in the scope of a pre-feasibility study?

Belgium	*Regional matter. For protected water areas, see http://tool.smartgeotherm.be/geo/alg. For existing infrastructure works see https://overheid.vlaanderen.be/producten-diensten/kabel-en-leidinginformatieportaal-klip*
Canada	*Except for tunnels in urban areas, groundwater protected areas and less common, mining areas, consultancy with water and mining authorities is not considered in this phase.*
China	*Except for tunnels in urban areas, groundwater protected areas and less common, mining areas, consultancy with water and mining authorities is not considered in this phase.*
Denmark	*Water authorities and water works will have a say in this. They have been known to veto suggested GSHPs and BTESs.*
Finland	*Considered in this phase. Some municipalities strictly denies drilling on the aquifers mapped for communal water supply (groundwater areas) and some don't. Clear instructions and practice is missing*
Germany	*No general rule (depended on situation, planning company)*
Japan	*No information*
Korea	*Except for tunnels in urban areas, groundwater protected areas and less common, mining areas, consultancy with water and mining authorities is not considered in this phase.*
Netherlands	*You will need to verify that you are not in a drilling free zone, interference zone etc. Also many different regulations may apply (rail, dikes etc.). Mining law starts at 500 meters, we keep the systems above this limit else special permits are required.*
Sweden	*Except for tunnels in urban areas, groundwater protected areas and less common, mining areas, consultancy with water and mining authorities is not considered in this phase.*
Turkey	*If groundwater will not be used, there is no need to obtain permission.*

Table A1-21: Do you consider geotechnical aspects within a pre-feasibility study?

Belgium	*Not taken into consideration for closed systems (BTES) but needs detailed evaluation for open systems (ATES).*
Canada	*Geotechnical reports are consulted where available.*
China	*There are no special requirements in national codes*
Denmark	*Not widely taken into consideration.*
Finland	*Geotechnical aspects are mainly considered in areas with clay deposits (The risk for settlement). Special attention is required in sulphate rich clay areas.*
Germany	*Anhydrite/gypsum (swelling), karstic areas (cavities), soft rocks (clays, swelling), artesian aquifers, risk of hydraulic ground failures, etc.*
Japan	*No information*
Korea	*There is no consideration of the Geotechnical aspects.*
Netherlands	*Only when drilling very near to foundation piles.*
Sweden	*Geotechnical aspects are mainly considered in areas with sedimentary clay deposits (The risk for settlement)*
Turkey	*The tectonic situation also important in addition to the landslides.* *Geotechnical studies should be implemented in design phase of building, geotechnical risks can be predicted in early stage.* *Because of Turkey located in earthquake area geotechnical assessment is very important. Geotechnical studies should be implemented in design phase of building, geotechnical risks can be predicted in early stage. But geotechnical drilling's depths varies from 10 to 50 meter, these depths couldn't show actual properties of soil. Especially, in view of energy piles with clay soils, thermomechanical effects on clay soils should be considered.*

Table A1-22: Are legal aspects with respect to property ownership considered within pre-feasibility study?

Belgium	*The installer of the system must own the property (or have an admission from the owner) for borehole installations.*
Canada	*Legal aspects vary greatly across Canada. There is no prerequisite that the user of the system must also be the owner of the system. This option allows for third – party ownership models (utilities) that absorb the system's 'first-costs' and recoup the investment via long-term energy performance contracts.*
China	*The user of the system must own the property for borehole installations.*

Denmark	*Water extraction wells can be made on leased ground in DK. I would expect the same to be the case with GSHP but I haven't heard of it. On the other hand wells for drinking water are seen as being for "the common good" of a community/town. This means the municipality can expropriate if necessary. This would not be the case with GSHP.*
Finland	*Always considered and property owners must allow drilling.*
Germany	*The installer (natural person or corporate entity) must own the property, or (in case for e.g. heat contracting) he must have a power of attorney from the owner. Only the owner of the property can apply for and obtain the permit from the water authority, since in the event of damage the owner of the property (Zustandsstörer) is always liable to the state.*
Japan	*No information*
Korea	*There is no consideration of legal aspects for the ownership. Ownership of the underground generally has been recognized by 50m.*
Netherlands	*Legal aspects are always considered. The user of the system must own the property for borehole installations. However, an option is to use other properties by borehole easements.*
Sweden	*Legal aspects are always considered. The user of the system must own the property for borehole installations. However, an option is to use other properties by borehole easements.*
Turkey	*Legal aspects are always considered. The user of the system must own the property for borehole installations. However, an option is to use other properties by borehole easements.*

Table A1-23: Are environmental issues considered within pre-feasibility study?

Belgium	*Environmental aspects are always considered with general environmental and legal aspects. Commonly environmental benefits of using BTES/GSHP are put forward.*
Canada	*Environmental impacts are always considered and environmental aspects such as GHG reduction form part of the 'business case' for employing GSHP systems for most projects.*
China	*Environmental aspects are always considered with general environmental and legal aspects. Commonly environmental benefits of using BTES/GSHP are put forward.*
Denmark	*Environmental aspects are always considered with general environmental and legal aspects. Commonly environmental benefits of using BTES/GSHP are put forward.*
Finland	*Environmental aspects are always considered with general environmental and legal aspects. Commonly environmental benefits of using BTES/GSHP are put forward. Register of contaminated land areas is available and drilling in such areas needs a special attention.*
Germany	*It has to be distinguished between environmental impacts on groundwater, soil and underground biology and the environmental benefit due to reduced CO_2-emissions. Impact to*

	the underground and groundwater has to be avoided or at least minimized and is important in the approval process. Environmental benefits are of interest for the client and society. *Contaminated areas need special attention.*
Japan	*No information*
Korea	*Environmental aspects are always considered with general environmental and legal aspects. Commonly environmental benefits of using BTES/GSHP are put forward.*
Netherlands	*Covered by general law (like soil pollution law). Currently all these laws are under review*
Sweden	*Environmental aspects are always considered with general environmental and legal aspects. Commonly environmental benefits of using BTES/GSHP are put forward.*
Turkey	*Environmental impact assessment legislations do not include BTES/GSHP systems. However, if an open GSHP is considered, a permit should be taken from General Directorate of hydraulic works and municipality authority. Except ground water usage there is not any obligation. Environmental issues just depend on ownerships initiative.*

Table A1-24: How do you get information on underground infrastructure like pipes and cables?

Belgium	*For existing infrastructure works see https://overheid.vlaanderen.be/producten-diensten/kabel-en-leidinginformatieportaal-klip*
Canada	*There are free services in Canada, however, for the majority of commercial applications the project owner will require subsurface 'locates' (with an accompanying report – paid for) to be performed for all existing infrastructure as well as subsurface contaminated soil.*
China	*You can go to the municipal administrative departments to investigate the relevant information.*
Denmark	*LER (LedningsEjerRegisteret) provides information in Denmark. The source is not free, but still mandatory to use.*
Finland	*Has to be noticed. Can be found from public registers (municipality, local electricity-, data- and district heating companies).*
Germany	*Information on underground infrastructure has to be collected from the local community, gas, electricity and telecommunication companies. Special case in Germany due to World War 2: Often warfare material release is required.*
Japan	*No information*
Korea	*Important to find out but there is no public internet service yet.*

Netherlands	*With regard to cables (power, telephone) and sewage systems. All work in the ground needs to be reported and information on the underground infrastructure reviewed. Else your insurance will not cover mishaps. Mainly on public land.*
Sweden	*Very important to find out in an early state. Can be found as a free service through internet (ledningskollen.se)*
Turkey	*It is not always possible to find such data in an accurate manner.* *There is no internet-based service for this information. Infrastructure knowledge can be obtained from municipalities. Some geophysical methods such as Ground Penetration Radar (GPR) are common for determining underground pipes and cables.*

Table A1-25: Do you consider economical aspects within a pre-feasibility study?

Belgium	*A rough estimate on investment cost, energy savings and profitability are always main items.*
Canada	*A rough estimate on investment cost, energy savings and profitability are always main items.*
China	*A rough estimate on investment cost, energy savings and profitability are always main items.*
Denmark	*Depends on the owner, but a rough estimate on investment cost, energy savings and profitability are always of main interest.*
Finland	*A rough estimate on investment cost, energy savings and profitability are always main items.*
Germany	*A rough estimate on investment cost, energy savings and profitability are always main items. The VDI 4650 describes a method to calculate the expected SPF for energy savings estimation. Herein there are strict system boundaries defined, which coincide with the sepemo system boundary III.*
Japan	*No information*
Korea	*A rough estimate on investment cost, energy savings and profitability are always main items.*
Netherlands	*There are many other reasons that economy for opting for GSHP systems: reaching EPC target in very highly insulated houses with passive cooling, comfort levels (especially summer comfort), comparison noise emissions air source heat pumps, gas-less estates being developed.*
Sweden	*A rough estimate on investment cost, energy savings and profitability are always main items.*
Turkey	*Generally, cost and ROI are the most important effect for owners to invest to those systems. A rough estimate on investment cost, energy savings and profitability are always main items.* *Furthermore, exergy rationality is also considered by some academics. In economic considerations the type and load/temperature profiles must be also considered not only from the quantity of demand but also the quality (temperature) demand profiles (hourly based)*

Appendix 1-4 – Answers on Feasibility Phase

Table A1-26: What is the scope of the feasibility study?

Belgium	*The pre-feasibility study will be developed further. However, this is generally done only for plants larger than a single household.* *Typically, one or several test-holes are drilled and documented and tested. Furthermore, detailed data (occasionally specially logged) on heat and cold load characteristic are obtained and used as basis for design, as well as temperature profiles. Environmental and legal aspects are also more thoroughly considered.*
Canada	*The pre-feasibility study is developed further, but is not necessary at this stage. One or several test-holes are drilled, documented and tested. Detailed data (occasionally specially logged) on heat and cold load characteristic are obtained and used as basis for design, as well as temperature profiles. Environmental and legal aspects are also more thoroughly considered.*
China	*The pre-feasibility study will be developed further. Typically one or several test-holes are drilled and documented and tested. Furthermore, detailed data (occasionally specially logged) on heat and cold load characteristic are obtained and used as basis for design, as well as temperature profiles. Environmental and legal aspects are also more thoroughly considered.*
Denmark	*The pre-feasibility study will be developed further. However this is generally done only for plants larger than a single household.* *Typically one or several test-holes are drilled and documented and tested. Furthermore, detailed data (occasionally specially logged) on heat and cold load characteristic are obtained and used as basis for design, as well as temperature profiles. Environmental and legal aspects are also more thoroughly considered.*
Finland	*The pre-feasibility study will be developed further. Typically one or several test-holes are drilled and documented and tested. Furthermore, detailed data (occasionally specially logged) on heat and cold load characteristic are obtained and used as basis for design, as well as temperature profiles. Environmental and legal aspects are also more thoroughly considered.* *Most often feasibility stage is neglected and moved straight to the installation phase.*
Germany	*In Germany planning services by architects and engineers are regulated (order, scope, performance, fees) by the Official Scale of Fees for Services by Architects and Engineers (HOAI, Honorarordnung für Architekten und Ingenieure). It is not called a pre-feasibility or feasibility study but so-called planning stages or performance phases. The planning stages (performance phases or working stages = Leistungsphasen =LP) are: LP1: Determination of basic conditions and feasibility study; LP2: preliminary planning; LP3: design planning; LP4: approval planning; LP5 Implementation planning; LP6: preparation for awarding for contracts; LP7: participation*

	in awarding for contracts; LP8: construction supervision; LP): project management and documentation. *Since September 2011 there is a special edition from the AHO Schriftenreihe "Planungsleistungen im Bereich der Oberflächennahen Geothermie" (planning services in the sector of shallow geothermal energy; Nr. 26); (http://preview.bundesanzeiger-verlag.de/baurecht-und-hoai/baurecht-und-hoai/themenseite-hoai/aho-schriftenreihe.html).* *In LP2: preliminary planning an economic feasibility study and a cost estimation for the executing variants is part of the performance specifications. In LP3: design (draft) planning a cost calculation is part of the performance specifications.*
Japan	*The pre-feasibility study will be developed further. Typically one or several test-holes are drilled and documented and tested. Furthermore, detailed data (occasionally specially logged) on heat and cold load characteristic are obtained and used as basis for design, as well as temperature profiles. Environmental and legal aspects are also more thoroughly considered.*
Korea	*All the GSHP design for the building are reviewed by the authority (Korea Energy Agency).*
Netherlands	*Not for most projects – design based on existing data.*
Sweden	*The pre-feasibility study will be developed further. Typically one or several test-holes are drilled and documented and tested. Furthermore, detailed data (occasionally specially logged) on heat and cold load characteristic are obtained and used as basis for design, as well as temperature profiles. Environmental and legal aspects are also more thoroughly considered.*
Turkey	*There is no specific rule for pre-feasibility study.*

Table A1-27: How do you determine the location of test drillings?

Belgium	*Location of test drillings is mainly based on geological condition, land availability for placing a borehole field, and survey of underground obstacles (water or gas pipes, electric and tele/fiber cables, etc.). Depending on the size of system (predicted number of boreholes) one or several holes are chosen.*
Canada	*Test boreholes are located, in the majority of projects, to be incorporated into the final borehole field.*
China	*One test hole is recommended if the application area of GSHP is more than 3000 m^2. More holes are demanded if the application area of GSHP is more than 5000 m^2.*
Denmark	*Location of test drillings is mainly based on geological condition, land availability for placing a borehole field, and survey of underground obstacles (water or gas pipes, electric and tele/fiber cables, etc.). Depending on the size of system (predicted number of boreholes) one or several holes are chosen.*

Finland	*Location of test drillings is mainly based on geological condition, land availability for placing a borehole field, and survey of underground obstacles (water or gas pipes, electric and tele/fiber cables, etc.). Depending on the size of system (predicted number of boreholes) one or several holes are chosen.*
Germany	*Location of test drillings is mainly based on geological condition and survey of underground obstacles (water or gas pipes, electric and tele/fiber cables, etc.). Depending on the size of system (predicted number of boreholes) one or several holes are chosen. Usually the placement of the test drilling is at a position where it can easily implemented in the BHE-field afterwards.*
Japan	*Location of test drillings is mainly based on geological condition, land availability for placing a borehole field, and survey of underground obstacles. Depending on the size of system one or several holes are chosen.*
Korea	*Location of test drillings is mainly based on geological condition, land availability for placing a borehole field, and survey of underground obstacles (water or gas pipes, electric and tele/fiber cables, etc.). Depending on the size of system (predicted number of boreholes) one or several holes are chosen.*
Netherlands	*In the past test drilling and thermal response tests relatively common for larger (50 – 200) houses. Nowadays mainly restricted to very large systems only.*
Sweden	*Location of test drillings is mainly based on geological condition, land availability for placing a borehole field, and survey of underground obstacles (water or gas pipes, electric and tele/fiber cables, etc.). Depending on the size of system (predicted number of boreholes) one or several holes are chosen.*
Turkey	*Test drilling is common. Location of test drilling is based on geological condition and shape of the application field. Test drilling should give information about all application fields. For larger projects more than one test drillings are used.*

Table A1-28: What are the permit requirements for test drilling?

Belgium	*Same legal requirements will apply for test as for effective drilling when installing BTES. Test drilling for ATES is short term permit.*
Canada	*Varies by Province. Generally, no permit is required, however, certain Provinces (Ontario) requires the drilling firm to have a special license to drill any geothermal borehole.*
China	*A test hole is needed if the application area of GSHP system is more than 5000 m^2, even on your own property.*
Denmark	*A permit issued by the municipality is mandatory for any drilling. Procedure officially takes up to six weeks. But sometimes it takes longer.*

Finland	*Permit from municipal authority is always needed for borehole drilling. Statement from a Regional Environment Centre is required if drilling will be done on the aquifers mapped for communal water supply (groundwater areas).*
Germany	*All mechanical drilling operations must be notified to the relevant Geological Survey 14 days before the start of drilling. Each federal state has its own guidelines which can impose deviant regulations concerning water law and mining law. Therefore, required permits can vary depending on the location of the building ground.*
Japan	*No permit is needed for test drilling.*
Korea	*Drilling for the GSHP needs to be informed to the local government.*
Netherlands	*You do not need a permit, but you need to inform authorities.*
Sweden	*No permit is needed for test drilling if the drilling takes place on your own property.*
Turkey	*No permit is needed for test drilling if the drilling takes place on your own property. If test drilling is not done with the purpose of obtaining groundwater, permission is not needed from any authority*

Table A1-29: Will the test drillings continue to be used afterwards?

Belgium	*Test holes are normally used as production holes later on.*
Canada	*Test holes are normally used as production holes later on.*
China	*Test holes are normally used as production holes later on.*
Denmark	*Test holes are normally used as production holes later on.*
Finland	*Test holes are normally used as production holes later on.*
Germany	*Test holes are normally used as production holes later on.*
Japan	*Test holes are normally used as production holes later on.*
Korea	*Test holes are normally used as production holes later on.*
Netherlands	*If possible test holes are used as production holes later on.*
Sweden	*Test holes are normally used as production holes later on.*
Turkey	*Test holes are normally used as production holes later on.*

Table A1-30: How deep is a test drilling compared to a production hole?

Belgium	*The depth of a test hole is normally similar to the expected production holes to be drilled later. Common depths are <100 m.*
Canada	*Depth of test holes will have a target of the final borefield – depth varies greatly across the country with an average for commercial projects of 152 m (500 feet).*
China	*The depth is dependent on geological conditions at site, the cost of BTES is also very important. The depth is commonly be around 100 m.*
Denmark	*Commonly 100 meters.*
Finland	*The depth of a test hole is normally similar to the expected production holes to be drilled later. The depth is mainly dependent on geological conditions at site and will commonly be around 200 to 300 m.*
Germany	*The depth of a test hole is normally similar to the expected production holes to be drilled later. Common depths are <100 m.*
Japan	*The depth of a test hole is normally similar to the expected production holes to be drilled later. The depth is mainly dependent on geological conditions at site and will commonly be around 50-100 m.*
Korea	*The depth of a test hole is normally similar to the expected production holes to be drilled later. Typical depth of the GSHP test borehole is 150-200 m.*
Netherlands	*Test borehole similar to expected end-depth of production system (80–200 meters).*
Sweden	*The depth of a test hole is normally similar to the expected production holes to be drilled later. The depth is mainly dependent on geological conditions at site and will commonly be around 200 m.*
Turkey	*Between 80 and 150 meter. Typically around 150 m.*

Table A1-31. How many test holes and TRT are performed?

Belgium	*No legal requirements, but will usually be done for the assessment of the economical evaluation of the project. The number of test holes will depend upon the size of the project as well as the expected complexity of the underground.*
Canada	*For larger commercial projects in which the ground heat exchanger will be installed vertically, the thermal properties of the subsurface shall be determined by performing an in-situ thermal conductivity (TC) test.* *The number of test vertical borehole heat exchangers shall be determined by the engineer or geologist based on the site geology, site plan, and system size. The following table is from*

ANSI/CSA C448 Series-16 Design and installation of ground source heat pump systems for commercial and residential buildings.

Subsurface assessment guideline based on net heat of extraction, kW or tons:

- *Up to 45 kW (13 tons): One subsurface assessment. TRT (TC Test) performed depending on Engineer and Geologist's decision*
- *>45 kW to 100 kW (13 to 828 tons): Two subsurface assessments. TRT (TC Test) performed depending on Engineer and Geologist's decision*
- *>100 kW to 300 kW (28 to 85 tons): Three subsurface assessments. One TRT (TC Test).*
- *>300 kW (> 85 tons): Four subsurface assessments + one per extra 200 kW. Two TRT (TC Test) performed + one per extra 200 kW.*
- *Each test vertical borehole heat exchanger shall be drilled to at least the depth of the planned system vertical ground heat exchanger.*
- *The in situ subsurface characteristic assessment shall describe:*
  - the subsurface stratigraphy;
  - the aquifer type and conditions (confined, unconfined, flowing, etc.) including depth; and
  - the drilling method and the penetration speed.
- *The presence of substances of known potential risk to health and safety, if encountered in the formations while drilling, shall be documented in the drill log and be communicated to the property owner This data shall be recorded during the drilling process.*
- *For tests which circulate heated water in the ground heat exchanger, the method developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) shall be used and can be found in the HVAC Applications Handbook, Geothermal Energy chapter.*
- *The test duration shall be a minimum of 36 h.*
- *The collected data shall be analyzed using the line source method or other industry-accepted method referenced in Clause 4.5.5.*
- *Acceptable power to perform the test is defined as follows:*
- *- The standard deviation of the power shall be less than or equal to 1.5% of the average power.*
- *- The maximum variation (spikes) in power shall be less than or equal to 10%.*

If the two previous conditions cannot be met, acceptable results can still be obtained if the maximum deviation of the u-bend loop temperature is less than or equal to 0.28 °C (0.5 °F) when compared to a trend line of the full data set.

- *The heat rate supplied to the u-bend shall be between 49.2 and 82 Watts per bore meter (15 and 25 Watts per bore foot).*
- *The undisturbed formation temperature shall be measured by recording the temperature of the water as it returns from the ground heat exchanger to the test equipment with a circulation test before startup of the heat injection. An alternative method is to directly measure the loop temperature at various depths with a submersible probe.*
- *A minimum delay of three to five days shall be observed between loop grouting and test startup, depending upon the formation.*
- *The following minimum in-situ formation thermal conductivity (TC) test equipment requirements shall be met:*
  - Entering/leaving water temperatures shall be measured with ±0.28 °C (±0.5 °F) combined transducer-recorder accuracy.

	- Heat input rate shall be measured with 2.0% combined transducer-recorder accuracy of reading (not full scale accuracy). *- Actual underground pipe length shall be measured to within ±1% accuracy.* *- Piping length between the test unit and the u-bend shall be equal to or less than 1.2 m (4 ft) per leg and shall be sufficiently insulated to minimize ambient heat loss.* *- All hydronic components within the test unit shall be sufficiently insulated to minimize ambient heat loss.*
China	• *Up to 10 boreholes: The test hole is not needed* • *One test hole is recommended if the application area of GSHP is more than 3000 ㎡.* • *One or more test holes are demanded if the application area of GSHP is more than 5000 ㎡.*
Denmark	*One test borehole and a TRT is needed.* *So far no borehole fields larger than 40 boreholes have been drilled in Denmark.*
Finland	• *Approximately 1/3 of the sites one test hole is drilled and followed by one TRT.* • *1 to 3 test holes are most often drilled and followed by one to three TRT.*
Germany	*No regulation in Germany on this issue, but from a number of approximately 10 boreholes or more, a TRT on one, and in rare cases on more than one, borehole will be recommended.*
Japan	• *Up to 10 boreholes: A test hole is sometimes drilled* • *10-30 boreholes: One test hole is drilled, often followed by a TRT.* • *30-120 boreholes: More than one test hole is drilled and documented. Commonly followed by at least one TRT.* • *>120 boreholes: No such large GSHP system and BTES systems have yet been installed.*
Korea	*Usually one test hole is performed. Underground condition of the inside of the radius 500m is considered as a same status. When the capacity of the GSHP is not exceed 175kW using the default value of the thermal conductivity (2.0 W/(mK)), the test hole and TRT can be omitted.*
Netherlands	*As the number of boreholes for a single system will be small (1 – 2) but the total number of systems may be large (100 – 1500) it is more complex. Often within a large project there are several different suppliers each doing a small number and not willing to spend money on a test. Only when government decides to mark an area as "interference zone" may test boreholes be funded by government.*
Sweden	*As a common practice, but not regulated, the number of test holes in Sweden is related to the expected size of the borehole field:* • *Up to 10 boreholes: Normally no test holes are performed. The underground geological, thermal and hydrogeological conditions are based on pre-feasibility data.* • *10-30 boreholes: One test hole is drilled and documented, often followed by a TRT.* • *30-120 boreholes: At least two test holes are drilled and documented, occasionally three. Commonly followed by at least one TRT, occasionally two.* • *>120 boreholes: At least two test holes are drilled and documented, most commonly three or more, followed by at least two TRTs.*

Turkey	*Depends on the land area, demand of the heating and cooling load, and the geological situation. If there is a highly fractured rock and artificial filling there can be two boreholes. Actually, there is no local requirements for TRTs. Generally, for small scale projects TRT is not applied. But, generally for larger projects main contractor of the project wants from subcontractor to apply TRT(s).*

Table A1-32 How is the stratigraphy documented?

Belgium	*Drillers log and samples.*
Canada	*By drillers log, occasionally by sampling.*
China	*Usually by sampling.*
Denmark	*Drillers log and samples.*
Finland	*Not commonly used in Finland. Occasionally by drillers log.*
Germany	*By drillers log, occasionally by sampling.*
Japan	*By drillers log, occasionally by sampling.*
Korea	*There is no need to know the stratigraphy in case of the closed system.*
Netherlands	*Sampling and drillers log.*
Sweden	*By drillers log, occasionally by sampling.*
Turkey	*By drillers log, occasionally by sampling.*

Table A1-33: How are permeable zones documented?

Belgium	*Depends on region. For Flanders estimations concerning permeability of different aquifers (or at least ranges) are online available.*
Canada	*Documented by drilling firm or independent spoils engineer.*
China	*It depends on the experience of the driller.*
Denmark	*Typically identified by lithology. In fractured limestone, loss of circulation or perhaps artesian water.*
Finland	*Noted occasionally. Depends from the driller experience. No packer or other water test is done on the field.*
Germany	*If possible (depending on the drilling method) it is documented by the driller.*
Japan	*No information*

Korea	*It depends on the experience of the driller.*
Netherlands	*Not applicable, NL is with the exception of South Limburg sedimentary.*
Sweden	*As air-lift measurement at hammer-drilling with compressed air, occasionally loss of circulation if drilled by water or mud.*
Turkey	*As air-lift measurement at hammer-drilling with compressed air, occasionally loss of circulation if drilled by water or mud. Measuring samples.*

Table A1-34: How do you measure the groundwater level?

Belgium	*Estimated prediction can be made, based on online information. Groundwater level in confined aquifers can be estimated with use of measurements in existing boreholes in the surroundings. In unconfined aquifers, soil classification (water contents,…), surface water level, infiltration capacity,… can give additional information.*
Canada	*Documented by drilling firm or independent spoils engineer.*
China	*The depth of groundwater level varies greatly in different regions in China, it will be documented during drilling procedure by the drilling firm.*
Denmark	*Not that easy in a rotary mud drilling without a well screen.*
Finland	*Typically measured but not always. Begins to be a common habit.*
Germany	*It is often required by the authorities, but is practically (depending on the drilling method and the geological conditions) not possible in most cases.*
Japan	*No information*
Korea	*The groundwater level is typically about 9~12m below the ground. It is not measured daily.*
Netherlands	*Measured during drilling – each hole is finished in one day.*
Sweden	*Measured before start of drilling each morning.*
Turkey	*Measured before start of drilling each morning.*

Table A1-35. How are drilling problems documented?

Belgium	*Normally noted in drilling report but not always. Depends on the experience of the driller.*
Canada	*Documented by drilling firm or independent spoils engineer.*
China	*Fracture zones, unstable hole, swelling clay, large yield of water, etc. Levels are noted in drillers log.*

Denmark	*Will be (should be) a part of the drillers log/the consultants supervision/enquiry at the drilling site.*
Finland	*Normally noted in drilling report but not always. Depends on the experience of the driller.*
Germany	*Will be (should be) a part of the drillers log/the consultants supervision/enquiry at the drilling site.*
Japan	*No information*
Korea	*Most of the borehole is completed by grouting. The hole of too much groundwater needs to be closed.*
Netherlands	*Very soft ground (certain clays), coarse gravels (loss of drilling fluid) and artesian water.*
Sweden	*Fracture zones, unstable hole, swelling clay, large yield of water, etc. Levels are noted in drillers log.*
Turkey	*Fracture zones, unstable hole, swelling clay, large yield of water, etc. Levels are noted in drillers log.*

Table A1-36: Are drilling parameters documented?

Belgium	*No information*
Canada	*Documented by drilling firm or independent spoils engineer.*
China	*It is occasionally recorded by the drilling firm and is not required to be provided to the owner*
Denmark	*Typically not noted.*
Finland	*Not noted in drilling reports.*
Germany	*Occasionally recorded by the driller.*
Japan	*No information*
Korea	*There is no need to record the drilling parameters in case of the closed system.*
Netherlands	*Only measured in scientific projects*
Sweden	*Only measured in scientific projects (ROP as a function of WOB, Torque, etc).*
Turkey	*Only in scientific projects*

Table A1-37: Are there commercially available TRT services at your country?

Belgium	*Supplied by 4-5 companies*

Canada	*5-7 companies perform this service.*
China	*The equipment is supplied by 5-6 companies; also some college or research institutes have developed their own test equipment.*
Denmark	*One company in Denmark with their own equipment. 2-3 drilling companies have contact with German companies that act as TRT subcontractors.*
Finland	*Supplied by 3 companies and the Geological Survey (2 measurement rigs) and the Vasa Applied University.*
Germany	*There are a number of more or less experienced companies available in Germany offering TRT and also a few who offer an Enhanced Geothermal Response Test (EGRT).* *VDI 4640-5 "Thermal Response Test" based on the outcome of IEA ECES Annex 21 gives rules on the equipment and how to perform a TRT.*
Japan	*Supplied by 3-4 companies in Japan.*
Korea	*TRT equipment is supplied by 5~6 companies.*
Netherlands	*Sourced from e.g. Germany or from 1-2 Dutch companies.*
Sweden	*Supplied by 3-4 companies. One or several TRT: s is performed after drilling and insertion of borehole heat exchanger. There is a manual for performance worked out by the Swedish Geothermal Association.*
Turkey	*Two suppliers - Cukurova University and Istanbul Technical University (ITU)*

Table A1-38: How long does a TRT take?

Belgium	*>48 hours*
Canada	*>36 hours*
China	*>48 hours*
Denmark	*>48 hours*
Finland	*Commonly 50-70 hours. In special cases more.*
Germany	*VDI 4640-5 recommends the time of convergence of the thermal conductivity*
Japan	*Commonly 50-70 hours also in Japan.*
Korea	*In Korea, the duration of the test is the minimum 48 hours.*
Netherlands	*50 – 100 hours*

Sweden	*Commonly 50-70 hours. In special cases more.*
Turkey	*At least 48 hours*

Table A1-39: Which TRT evaluation method is used?

Belgium	*Line source method is used*
Canada	*Typically evaluation is performed based on the Line source method, with or without parameter estimation*
China	*Typically evaluation is performed based on the Line source method, with or without parameter estimation*
Denmark	*Line source is used*
Finland	*Typically evaluation is performed based on the Line source method, with or without parameter estimation*
Germany	*Typically evaluation is performed based on the Line source method, with or without numerical parameter estimation. Draft of German guideline on TRT is available (VDI 4640-5).*
Japan	*Typically evaluation is performed based on the Line source*
Korea	*Line source method is used for estimation.*
Netherlands	*LSA and models with parameter estimation (multi-pulse tests for groundwater flow) Evaluation of accuracy is done using error analysis method.*
Sweden	*Typically evaluation is performed based on the Line source method, with or without parameter estimation*
Turkey	*Line source method, effective thermal conductivity and thermal resistivity of the borehole. Also cylindrical source method is used in ITU for wider diameter boreholes.*

Table A1-40: Are geophysical methods in site investigations used?

Belgium	*Not in normal practice*
Canada	*Very little site investigations using VLF or radar are performed - only if specified by the engineer or project owner.*
China	*Geophysical methods in site investigations are no used.*
Denmark	*None as standard. But we utilize the existing and comprehensive geophysical (SkyTem, MEP, etc.) databases hosted by GEUS in our feasibility studies.*

Finland	*Radar is rarely used. Deviation can be measured by some drilling companies if needed. DTS is used for continuous temperature measurements by the Geological Survey in several sites.*
Germany	*Geophysical methods in site investigations are recommended in complex geological situations but used rarely.*
Japan	*No information*
Korea	*Geophysical methods are not used for GSHP investigation.*
Netherlands	*Not in normal practice.*
Sweden	*Geophysical methods in site investigations are seldom used. However, occasionally VLF (very low frequency radio waves) is used to detect vertical water holding fracture zones in Archean rocks, and radar for mapping the soil depth. Furthermore, the deviation of boreholes is sometimes measured, especially in urban areas (often as a term for permit).*
Turkey	*Using of geophysical methods is common, GPR, electrical resistivity, deviation borehole.*

Table A1-41: How is the risk for impact on groundwater quality handled in your country?

Belgium	*There are clearly designated drilling free zones (forbidden or only drilling with special permit) usually these areas are for drinking water production. Specific regulations for drilling on polluted sites. In Flanders, all BTES must be sealed from bottom to top with impermeable and frost resistant grout. For ATES, aquitards must be sealed.*
Canada	*Each Province has different water regulations and these results in inconsistent groundwater protection across the country.*
China	*Consideration of such issues is still low. Different factors are usually taken into account depending on the site situation.*
Denmark	*Groundwater is the main concern in relation to risk of leakage and temperature changes. All boreholes must be sealed with grout containing Bentonite. The municipality can require a risk assessment and a monitoring program.*
Finland	*The environmental concern is mainly related to protection of groundwater. Some municipalities reject drilling in groundwater areas. Legal practice is developing. Recently, the Supreme Court made a decision which allowed drilling energy wells into groundwater area border. In that case authorities from the municipal and Regional Environment Center had denied drilling application based on possible risk to groundwater. The land owner and drilling company complained and finally won the case.*
Germany	*Groundwater protection is covered by drilling depth limitation, enforcement of water as a heat carrier fluid (combined with an appropriate design concerning freezing). Grouting is for almost all BHEs in Germany required. There are clearly designated drilling free zones (forbidden or*

	only drilling with special permit). Usually these areas are for drinking water production. There are specific regulations for drilling on polluted sites. *Groundwater protection is covered by the water protection areas of drinking water production facilities (which are divided into at least three protected zones) In the water protection zone 1 and 2 drillings are usually not allowed. The water protection zone 3 is sometimes additionally divided into A and B. In some states BHEs are forbidden even in zone 3, in some states BHE are allowed in zone 3 (ore only in zone 3 B) with drinking water as working fluid.* *In the different federal states there could be different kind of special requirements to protect the groundwater, e.g. drilling only in one aquifer layer, or special requirements for drilling diameter.* *Every local water authority in Germany could have their own special roles for the groundwater protection.*
Japan	*No information*
Korea	*Groundwater protection measures (borehole cover and drain) are needed during the drilling.*
Netherlands	*There are clearly designated drilling free zones (only drilling with special permit) usually these areas are for drinking water production. The zone is based on 25 / 50 years infiltration zones.*
Sweden	*The environmental concern is mainly related to protection of groundwater. In water protected areas a permit is given only if it can be shown that the boreholes will not hazard the groundwater quality. If there is a risk, grouting or other forms of borehole sealing will be a term for the permit.*
Turkey	*Protect from the pollution* *There are no rules for closed systems in GSHP, but for open GSHP systems, permission is needed from General Directorate of State Hydraulic Works in Turkey.*

Table A1-42: How is the potential of physical damage assessed?

Belgium	*For closed loop systems there is no concern about this. All boreholes are backfilled. Sometimes local settling occurs due to improper backfilling but that can be fixed fairly easily. Foundations are through piles on deeper sand formations, so superficial settling does not pose a risk for the structure.*
Canada	*Soils engineers are responsible for determining the suitability of buildings for a particular project site. Geotechnical (small boreholes) are used to ascertain the types of subsurface soils / rocks and the ability to support the building design (weight).*
China	*Risk for settling of nearby buildings by consolidation of finely grained sediments, mainly clay. Such settling can be caused by (a) freezing of clay outside the casing, (b) drainage of*

	groundwater in the soil into the rock trough badly sealed casing, and (c) creation of cavities during drilling that later lead to collapsed surface.
Denmark	*There is a minimum distance to buildings and sewers that need to be kept. Leakage between aquifers should be handled by sealing the borehole.*
Finland	*Risk for settling of nearby buildings by consolidation of finely grained sediments, mainly clay. Such settling can be caused by (a) freezing of clay outside the casing, (b) drainage of groundwater in the soil into the rock trough badly sealed casing, and (c) creation of cavities during drilling that later lead to collapsed surface.*
Germany	*Connection of different groundwater layers via leaking boreholes with different pressure level. In some geological and hydrogeological settings swelling and settlements can occur, e. g. connection of an anhydrite/gypsum layer and an aquifer may result in water leaking into the anhydrite and swelling of gypsum. Subrosion of fine grained sediments (silt and sand) can be happen.*
Japan	*No information*
Korea	*Most of the bedrock of Korea is granite. So the risk for settling is not common.*
Netherlands	*For closed loop systems there is no concern about this. All boreholes are backfilled. Sometimes local settling occurs due to improper backfilling but that can be fixed fairly easily. Foundations are through piles on deeper sand formations, so superficial settling does not pose a risk for the structure.*
Sweden	*Risk for settling of nearby buildings by consolidation of finely grained sediments, mainly clay. Such settling can be caused by (a) freezing of clay outside the casing, (b) drainage of groundwater in the soil into the rock trough badly sealed casing, and (c) creation of cavities during drilling that later lead to collapsed surface.*
Turkey	*Risk for settling of nearby buildings by consolidation of finely grained sediments, mainly clay. Such settling can be caused by (a) freezing of clay outside the casing, (b) drainage of groundwater in the soil into the rock trough badly sealed casing, and (c) creation of cavities during drilling that later lead to collapsed surface.*

Table A1-43: How is the predesign procedure of the system?

Belgium	*Based on the results from test drillings, evaluated thermal parameters (from TRT) and energy load profile, the borehole system is designed by using EED. A borehole field (occasionally more than one) is placed and borehole configuration, borehole depths, deviation of boreholes (if restricted surface area) established.*
Canada	*GAIA Ground Loop Design (GLD) is used for the majority of commercial applications employing the parameters cited above.*

China	*Based on the results from test drillings, evaluated thermal parameters (from TRT) and energy load profile, the borehole system is designed by using TRNSYS, EED, GLHEPRO or other software developed by university.*
Denmark	*Based on the results from test drillings, evaluated thermal parameters (from TRT) and energy load profile, the borehole system is designed by using EED or other software tools. A borehole field (occasionally more than one) is placed and borehole configuration, borehole depths, deviation of boreholes (if restricted surface area) established.*
Finland	*Based on the results from test drillings, evaluated thermal parameters (from TRT) and energy load profile, the borehole system is designed by using mainly EED or other tools, such as GEO-HAND^{light}. A borehole field (occasionally more than one) is placed and borehole configuration, borehole depths, deviation of boreholes (if restricted surface area) established.*
Germany	*Based on the results from test drillings, evaluated thermal parameters (from TRT) and energy load profile, the borehole system is designed by using EED or other software tools. A borehole field (occasionally more than one) is placed and borehole configuration, borehole depths, deviation of boreholes (if restricted surface area) established.* *Small systems are often designed via given design tables (VDI 4640-2).*
Japan	*The design procedure is usually almost the same in Japan. Based on the results from test drillings, evaluated thermal parameters (from TRT) and energy load profile, the borehole system that is mainly borehole length and number is designed. However, the borehole length and number are sometimes determined before the design because of the expensive cost of installing borehole. In this case, the energy load for the GSHP system is determined.*
Korea	*Borehole system is designed by using GLD. The deviation of boreholes is not considered in Korea.*
Netherlands	*Usually an inventory of all input data is made and a design is made with EED. In spite of training and certification the quality of the design process is usually low. For instance, many think an EED output is the design, no design document detailing how the different input parameters were obtained / calculated and what design considerations have been made is provided. No sensitivity analysis (spacing of boreholes, peak load duration for instance) is done.*
Sweden	*Based on the results from test drillings, evaluated thermal parameters (from TRT) and energy load profile, the borehole system is designed by using EED. A borehole field (occasionally more than one) is placed and borehole configuration, borehole depths, deviation of boreholes (if restricted surface area) established.*
Turkey	*Based on the results from test drillings, evaluated thermal parameters (from TRT) and energy load profile, the borehole system is designed by using EED or GLD. A borehole field (occasionally more than one) is placed and borehole configuration, borehole depths, deviation of boreholes (if restricted surface area) established.*

Table A1-44: How are the investment costs calculated?

Belgium	*Normally based by experience from other similar and newly constructed plants.*
Canada	*Normally based by experience from other similar and newly constructed plants.*
China	*Normally based by experience from other similar and newly constructed plants.*
Denmark	*Typically based on a calculation of the actual case (due to lack of similar cases)*
Finland	*Normally based by experience from other similar and newly constructed plants.*
Germany	*Normally based by experience from other similar and newly constructed plants.*
Japan	*Normally based by experience from other similar and newly constructed plants.*
Korea	*Normally based by experience from other similar and newly constructed plants.*
Netherlands	*Normally based by experience from other similar and newly constructed plants.*
Sweden	*Normally based by experience from other similar and newly constructed plants.*
Turkey	*Normally based by experience from other similar and newly constructed plants.*

Table A1-45: How are the operational costs calculated?

Belgium	*As a function of expected Seasonal Performance Factor (SPF) using the current energy price for electricity. The predicted electricity price model is also used to estimate the costs for future.*
Canada	*As a function of expected Seasonal Performance Factor (SPF) using the current energy price for electricity.*
China	*COP of GSHP system is typically used as the parameters for operational cost calculation.*
Denmark	*As a function of expected Seasonal Performance Factor (SPF) using the current energy price for electricity. SPF is typically overrated.*
Finland	*As a function of expected Seasonal Performance Factor (SPF) using the current energy price for electricity. The predicted electricity price model is also used to estimate the costs for future.*
Germany	*As a function of expected Seasonal Performance Factor (SPF) using the current energy price for electricity.*
Japan	*The energy price for electricity is divided into basic cost and unit cost. Therefore, the unit cost is firstly calculated by multiplying the electric power consumption by the current energy price for electricity. Then the total operational cost is calculated by adding basic cost to unit cost.*
Korea	*As a function of expected Seasonal Performance Factor (SPF) using the current energy price for electricity.*

Netherlands	*As a function of expected Seasonal Performance Factor (SPF) using the current energy price for electricity.*
Sweden	*As a function of expected Seasonal Performance Factor (SPF) using the current energy price for electricity.*
Turkey	*Price of Natural Gas and electricity. COP is considered, but there is a progress of using SPF according to new guideline.* *Operational cost of the system is calculated based on previous SPF data and using current electricity prices.*

Table A1-46: How are the maintenance costs calculated?

Belgium	*Estimated to practically zero for the borehole system.*
Canada	*Estimated to practically zero for the borehole system. However, most economic models take into consideration replacement of heat pump equipment as compared to boiler/chillers.*
China	*Estimated to practically zero for the borehole system.*
Denmark	*Estimated to practically zero for the borehole system. The lifespan of heat pumps is typically set to 15 years.*
Finland	*Estimated to be close to zero. Cleaning of mud filters or making some adjustments does not cost much.*
Germany	*Estimated to practically zero for the borehole system (not for the heat pump). According to the requirements in the water law permission* ***it may be that****:* *a) a site acceptance test before startup operation by an expert is required* *b) a site acceptance test every 5 years by an expert is required* *c) the recording of data and the conveyance of data to the water or mining authority is required* *It also makes sense to check the volume flow in any BHE regulary and / or to check the quality of the heat transfer medium.*
Japan	*Estimated to practically zero for the borehole system.*
Korea	*Estimated to practically zero for the borehole system.*
Netherlands	*Estimated to practically zero for the borehole system.*
Sweden	*Estimated to practically zero for the borehole system.*
Turkey	*Estimated to practically zero for the borehole system.*

Table A1-47: How are energy savings compared to existing or other compatible systems calculated?

Belgium	*Calculated from the expected SPF of thermal energy production. Then compared to one or several other systems producing the same amount of thermal energy. The difference is defined as energy savings.*
Canada	*Calculated from the expected SPF of thermal energy production. Then compared to one or several other systems producing the same amount of thermal energy. The difference is defined as energy savings.*
China	*Calculated from the expected COP of thermal energy production. Then compared to one or several other systems producing the same amount of thermal energy. The difference is defined as energy savings.*
Denmark	*Not a standard as such. Some will want this calculated because economy is the driving factor. Others choose GSHP primarily out of "idealistic" reasons.*
Finland	*Calculated from the expected SPF of thermal energy production. Then compared to one or several other systems producing the same amount of thermal energy. The difference is defined as energy savings.* *Normally 3 to 4 % yearly increase is added for electricity and district heating cost.*
Germany	*Calculated from the expected SPF and compared with other systems which can cover the demand.*
Japan	*Calculated from the expected SPF of thermal energy production. Then compared to one or several other systems producing the same amount of thermal energy. The difference is defined as energy savings.*
Korea	*Calculated from the expected SPF of thermal energy production. Then compared to one or several other systems producing the same amount of thermal energy. The difference is defined as energy savings.*
Netherlands	*In the Netherlands there is a report (updated regularly) "uniform yardstick for calculating energy use…" which gives key values for comparison (e.g. performance factors for gas fired boilers, performance electricity production etc).*
Sweden	*Calculated from the expected SPF of thermal energy production. Then compared to one or several other systems producing the same amount of thermal energy. The difference is defined as energy savings.*
Turkey	*COP and comparison between natural gas and electricity usage is in common in Turkey.* *In Turkey, energy saving is calculated based on comparison between cost of conventional natural gas heating + air conditioning system and cost of GSHP system.*

Table A1-48: How is the Profitability as straight pay-back time calculated?

Belgium	*Investment cost divided by the value of energy savings/year. Occasionally, also presented as a return rate of investment (%).*
Canada	*Investment cost divided by the value of energy savings/year. Occasionally, also presented as a return rate of investment (%) However, avoided costs (e.g. the elimination of a cooling tower and associated water usage / chemicals) are considered and an ROI payback is always included.*
China	*Investment cost divided by the value of energy savings/year. Occasionally, also presented as a return rate of investment (%).*
Denmark	*Only used for bigger systems.*
Finland	*Investment cost divided by the value of energy savings/year. Occasionally, also presented as a return rate of investment (%). Most often the repayment time is used.*
Germany	*Investment cost divided by the value of energy savings/year. Occasionally, also presented as a return rate of investment (%).*
Japan	*No information*
Korea	*Investment cost divided by the value of energy savings/year. Occasionally, also presented as a return rate of investment (%).*
Netherlands	*Investment cost divided by the value of energy savings/year. Occasionally, also presented as a return rate of investment (%).*
Sweden	*Investment cost divided by the value of energy savings/year. Occasionally, also presented as a return rate of investment (%).*
Turkey	*Investment cost divided by the value of energy savings/year. Occasionally, also presented as a return rate of investment (%).*

Table A1-49: Is the concept of Life Cycle Cost taken into account?

Belgium	*Commonly used for a period of 20 years (technical lifetime of mechanical units) with a rest value for the borehole system that has at least 50 years lifetime.*
Canada	*20–25 years for replacement of running equipment and 50+ years for the borehole system.*
China	*15–20 years for replacement of running equipment and 50 years for the borehole system.*
Denmark	*No praxis for life cycle cost in Denmark*
Finland	*Normally a 20-25 years period is used.*
Germany	*Occasionally done but mainly for bigger systems.*

	For the calculation (LP3) of the life cycle cost analyses, usually the HVAC-planner is responsible (with data and support from the BHE-field-planner).
Japan	*Commonly used for a period of 30 years (technical lifetime of mechanical units) with a rest value for the borehole system that has at least 60 years lifetime.*
Korea	*System lifetime is considered as 20 years and borehole lifetime is considered as more than 50 years.*
Netherlands	*Not normally calculated*
Sweden	*Commonly used for a period of 20 years (technical lifetime of mechanical units) with a rest value for the borehole system that has at least 40 years lifetime.*
Turkey	*There is no rule for boreholes, but for mechanical units it is the same*

Appendix 1-5 – Answers on Detailed Design

Table A1-50: Which are the common forms of contract for plant realization?*

Belgium	*No information*
Canada	*In Canada there are two basic methods for the construction of GSHP systems (plants).* 1. *The Design/Build option which is similar to option "A" above* 2. *The Bid/Specification option which is similar to option "B" above*
China	*Both A and B are used. B is more commonly used.*
Denmark	*Bothe A and B are used. A is typically used for small systems, and B for large systems.*
Finland	*For small sites, normally turnkey model (A) is used.* *Larger size HVAC planner / consult prepare the detailed design phase for customer (B).*
Germany	*Both, A and B are used.* *Contracts based on the tenders (VOB + HOAI).*
Japan	*No information*
Korea	*Call for tenders for design and construction are usually separated.*
Netherlands	*The decision to use a GSHP system is usually made without pre design. A general contractor (installer, driller or other company providing the complete solution) will produce a design & quote for the system.*
Sweden	*Both A and B are used. Turnkey projects (A) dominates*
Turkey	*A and B type are both common in Turkey. Call for tenders is most common*

A and B are defined under section "Contractual options" in **chapter 1.7.1*

Table A1-51: How is a turnkey call for tenders be executed in your country and how common is it?

Belgium	*No information*
Canada	*This is the “Design/Build” option in Canada. The contractor is responsible to understand the building loads and must work with the other construction disciplines (e.g. concrete formers, electrical, plumbing contractors etc.) to execute the project. They are responsible for initial performance and functionality of the system. This is the least frequent option in Canada but is gaining acceptance.*
China	*The contractors have a responsibility for the whole process, including the design, construction. Also the system operation if the owner needed.*
Denmark	*A turnkey contract would typically describe function and performance. The contractor will have a relatively large degree of autonomy in getting the desired result.*
Finland	*A turnkey contract would typically describe the drilling, equipment, installation and necessarily HPAC work. In small size the contractor will have a relatively large degree of autonomy in getting the desired result.*
Germany	*The contractor has the responsibility for the design and construction in case of turnkey project.*
Japan	*No information*
Korea	*Turnkey call option is used for the big project especially. The contractors have a responsibility for the design, construction and performance in case of turnkey call.*
Netherlands	*For BTES this is not common at all.*
Sweden	*The contract normally has two separate set of documents, Administrative Regulations and a Technical Frame Description. In the latter one the technical terms and specification are given on which the final design of the system must be executed. These documents are sent out to potential contractors with call for tenders. In Sweden this option, with the functional responsibility of the system is resting upon the contractor, is the most frequent one.*
Turkey	*Turnkey call with the functional responsibility of the system is resting upon the contractor, is most frequently used but it depends on the company.*

Table A1-52: Does the client have the option to review and make comments on the design?

Belgium	*No information*
Canada	*The client has the option to review and make comments on the design before it is stamped as construction documents.*

China	*The client has the option to review and make comments on the design before it is stamped as construction documents.*
Denmark	*It's common practice/mandatory in all professional cases. However, a lot of house owners may not be aware of this. They are not professionals in this context.*
Finland	*The client has the option to review and make comments on the design before it is stamped as construction documents.*
Germany	*The client, or his/her consultant, has the option to review and make comments on the design.* *In bigger projects (not at residential buildings/detached houses) it is always an ongoing process from LP1 (see HOAI and AHO) to the end with jour fix every week or month where the client and his representatives (architect, HVAC, Geologist, BHE-planner and so on) take part and discuss the planning and construction progress, the results, problems, solutions, variants, overlaps with other trades, follow up chart…*
Japan	*No information*
Korea	*In Korea, supervision system is mandatory for the big system. Usually supervisor monitors the design and construction process of the system.*
Netherlands	*As GSHP/BTES systems in the Netherlands are small installations this is not usual. For the cases where a big system (or ATES) system is installed this is the case, although usually it is a consultant acting on the clients behalf.*
Sweden	*The client has the option to review and make comments on the design before it is stamped as construction documents. This is a way for the client to have a quality control of the design.*
Turkey	*The client has the option to review and make comments on the design before it is stamped as construction documents.*

Table A1-53: How is a performance contract be handled in your country, and how common is it?

Belgium	*No information*
Canada	*This is the Bid/Specification option in Canada and is the norm for most construction projects. The client, through their agents (General Contractor (GC) or Construction Manager (CM)) releases the specifications for the project to:* *a) The public; or* *b) A select group of contractors invited to bid* *The bidding contractor reviews all project specifications for their area of work and submits a price bid to the GC or CM. Generally, the lowest price from the contractor is awarded the work.*
China	*Performance contract is the common method in China, maybe accounting for 80% of the GSHP system design.*

Denmark	*Performance contract is less common than turnkey.*
Finland	*Performance contracts are more widely used than turnkey contracts. The responsibilities between client and constructer are specified in prevalent contract terms which are normally used. The contract terms and models for legal contracts are publically available.*
Germany	*The design is normally performed and specified by a consultant company. As a tool for design the consultant might use other modelling tools than EED, for example DST (Duct Storage Model). In the modelling procedure a number of parameters are considered.*
Japan	*No information*
Korea	*In Korea, the responsibility of the performance is in all the design company, responsible supervision company and construction company. Engineering companies have several tools for GSHP design.*
Netherlands	*Does not really exist – to do a design you need certification. Design by end user or client is not possible (only very few cases).*
Sweden	*This option is similar to the procedure of a turnkey project. The main difference is that the client is responsible for the function of the system, since he designed it himself. The contractor is only constructing the plant according to the design. In Sweden this option is much less frequent than the turnkey option. The design is normally performed and specified by a consultant company.*
Turkey	*Performance contract is much less frequent than the turnkey option.* For larger systems contracts and design performance are presented to General Contractor. Handling of contracts and design performance is in the responsibility of General Contractor

Table A1-54: How is the load profile modeled?

Belgium	*Monthly base load modeling is common although site-specific hourly base modeling is increasing and used especially in greater projects.*
Canada	*Superior system modeling employs 8760 hourly loads for heating and cooling. Monthly loads are also used.*
China	*Normally daily loads. Maximum loads for heating and cooling. Total annual load for heating and cooling.*
Denmark	*Normally monthly energy loads, and annual and monthly maximum loads for heating and cooling including corresponding durations in hours.*
Finland	*Monthly base load modeling is common although site specific hourly base modeling is increasing and used especially in industrial sites.*
Germany	*Normally monthly loads. Maximum loads for heating and cooling.*

	The HVAC-planner usually don't understand what kind of data the BHE-planner needs, especially for the software EED. The terms "peak load" and "base load" are not defined and are used in different ways. The HVAC-planner calculates according to his guidelines with a big safety margin. It is a hard (or sometimes impossible) way to find a good compromise for a heating and cooling data basis which fits to both, the HVAC- and the BHE-planner. *The input mask of the software specifies form and level of detail of the load profile.*
Japan	*Normally monthly loads. Maximum loads and integrated load for heating and cooling. Sometimes hourly loads.*
Korea	*Normally monthly loads. Maximum loads for heating and cooling.*
Netherlands	*Usually only total heating / cooling and DHW is available. Translation to monthly values by "known" or assumed ratios of load by month.*
Sweden	*Normally monthly loads. Maximum loads for heating and cooling.*
Turkey	*Normally monthly loads. Maximum loads for heating and cooling. Normally year. Maximum loads are same.*

Table A1-55: How is the temperature demand modeled?

Belgium	*Outdoor air temperatures in conjunction occupancy and building use (hours of operation) are used.*
Canada	*Outdoor air temperatures in conjunction occupancy and building use (hours of operation) are used.*
China	*Normally related to outdoor temperature variations.*
Denmark	*Degree days.*
Finland	*Normally related to outdoor temperature variations. Finland is divided into four climatic zones according to outdoor temperatures. The heating systems are designed according to temperature demands of these zones.*
Germany	*Normally related to outdoor temperature variations.*
Japan	*Normally related to outdoor temperature variations.*
Korea	*Normally related to outdoor temperature variations.*
Netherlands	*Usually fixed, low temperature heating 35°C.*
Sweden	*Normally related to outdoor temperature variations.*

Turkey	*Normally related to outdoor temperature variations. In addition, it depends of heating system in the building. For ground floor heating system possible minimum temperature is used however for radiator heating systems higher temperatures are used.*

Table A1-56: How is the heat load coverage of BTES or GSHP systems estimated?

Belgium	*Varies, but often 60-80% of maximum heat load for non-residential building. For residential buildings: 100%*
Canada	*Varies, but often 60-80% of maximum heat load.*
China	*There is a large variety in load coverage because the climatic zones are different, maybe cover 100% heat load in some regions.*
Denmark	*Varies, but often 60-80 % of maximum heat load.*
Finland	*Varies, but often 60-90 % of maximum heat load.*
Germany	*All small systems have a load coverage of 100 %. For large systems there is the option of bivalent systems with a second one typically for peak load coverage.*
Japan	*Varies.*
Korea	*In Korea, GSHP system usually covers 30~50 % of maximum heat load.*
Netherlands	*100% of heat load.*
Sweden	*Varies, but often 60-80 % of maximum heat load.*
Turkey	*90% Heat load. For one school project in Ankara (Ankusem school) the heat load coverage 100%. Some projects use both primary and auxiliary heating system, in that case, heat load coverage of GSHP depends on that it is primary or auxiliary system. Namely, it depends on projects.*

Table A1-57: How is the cooling load coverage of BTES systems split between free cooling and heat pump operation?

Belgium	Most systems are designed to cover all cooling demand.
Canada	*Unknown at this time.*
China	*There is a large difference because the climatic zone is different. There is no clear statistical data until now.*
Denmark	*Normally ATES is used for cooling, all of it as free cooling.*
Finland	*Cooling s provided often by heat exchangers and hence BTES can provide 100% of cooling demand.*

Germany	*Depending on the project size, but a significant part of maximum load as free cooling and the rest covered by the heat pump or, if cooling load is too high compared to heating load, by air-cooled chillers.*
Japan	*Varies.*
Korea	*All of the cooling is covered by the heat pump. There is no free cooling in Korea.*
Netherlands	*Free cooling only (see remarks made earlier)*
Sweden	*Normally 30-50 % of maximum load as free cooling and the rest covered by the heat pump. Occasionally all cooling is supplied by the heat pump with waste condenser heat seasonally stored in the BTES system.*
Turkey	*Mostly depends on projects.*

Table A1-58: How is the number, depth and configuration of boreholes set?

Belgium	*Studied and optimized with the model.*
Canada	*Studied and optimized with the model.*
China	*Studied and optimized with the model.*
Denmark	*For bigger plants.*
Finland	*Studied and optimized with the model.*
Germany	*Studied and optimized with the model.*
Japan	*Studied and optimized with the model.*
Korea	*Studied and optimized with the model.*
Netherlands	*In the best practice case that should be done, in practice however it is not documented.*
Sweden	*Studied and optimized with the model.*
Turkey	*Studied and optimized with the model. Sometimes (R/D projects), in project phase generally literature data are used. There are some ongoing studies about borehole field modeling*

Table A1-59 What influence does the groundwater level have?

Belgium	*Boreholes have always to be grouted (legislation). The thermal conductivity of the ground is affected by the groundwater level and determined by the TRT.*
Canada	*Has an impact but is not well defined in Canada.*

China	*There is no specific definition or description in China.*
Denmark	*The boreholes are grouted, but the groundwater will be taken into consideration in the modeling (if done in FeFlow – only big projects or research).*
Finland	*Defines the active borehole length (if not grouted holes).*
Germany	*Boreholes have always to be mostly grouted (legislation). The thermal conductivity of the ground is affected by the groundwater level.*
Japan	*Defines the active borehole length.*
Korea	*Borehole length is not affected by ground water level because the grouting is mandatory.*
Netherlands	*Groundwater level is always high (exception south Limburg) and therefore not an issue.*
Sweden	*Defines the active borehole length (if not grouted holes).*
Turkey	*Groundwater level at 70-100 m depth. In closed GSHP system, grouted boreholes are common.*

Table A1-60: What influence does the groundwater level have?

Belgium	*May affect storage system performance in a negative way, but dissipative borehole systems in a positive way. This will be taken into account when supposes a flow > 5m/year.*
Canada	*May affect storage system performance in a negative way, but dissipative borehole systems in a positive way. Not modeled, just considered in the design*
China	*It has positive influence on GSHP, but not modelled in normal design. The enhancement of heat transfer capacity is treated as an extra benefit.*
Denmark	*May affect storage system performance in a negative way, but dissipative borehole systems in a positive way. Not modeled, just considered in the design*
Finland	*May affect storage system performance in a negative way, but dissipative borehole systems in a positive way. The effect is not modeled, just estimated.*
Germany	*May affect storage system performance in a negative way, but dissipative borehole systems normally in a positive way. Generally not modeled, just considered in the design, unless for very large projects or critical cases.* *May effect the system performance of BHE in a positive way (recovery of heat).*
Japan	*May affect any storage system performance in a negative way, but dissipative borehole systems in a positive way. The ground temperature calculation influenced by groundwater flow had been modeled and has been installed simulation tool.*
Korea	*The influence of groundwater flow is not considered in the design.*

Netherlands	*Depends on magnitude of flow and length of BHE affected. Also the effect depends on the energy balance: positive in unbalanced situations, neutral or negative in storage situation. Note that in large fields the downstream BHE may be positively/negatively affected depending on distance. Also note that interference with open ATES systems may be an issue.*
Sweden	*May affect storage system performance in a negative way, but dissipative borehole systems in a positive way. Not modeled, just considered in the design.*
Turkey	*For GSHP systems, ground water amount and flow is considered, but not modeled. For GSHP it has positive effect, however for BTES system, it can affect the design negatively, in terms of general application in Turkey, hydrogeological modeling studies do not used, but it should be done (BTES).*

Table A1-61: What are the most common types of BHE?

Belgium	*Single U-pipe and double-U-type are common.*
Canada	*Single U – bends are the standard for vertical systems.*
China	*Single U-pipe and double-U-type almost share equal proportions. Coaxial BHE is rarely used.*
Denmark	*Single U.*
Finland	*Most often single U-pipe is used. Furrowed and clean pipes are used. Coaxial or double pipes are rarely used. The effect of different pipe types to system´s thermal conductivity and resistance is tested by the Geological Survey.*
Germany	*Mainly double U-pipe, in some cases coaxial BHE, single U-pipe BHE are very rarely used. Coaxial BHE are often used in cases when the drilling depth is considerably restricted. In the last years especially coaxial BHE with very large diameters (ca. 140 mm) have become popular in such cases. Due to their high water volume content per meter they are often called "storage BHE".*
Japan	*Single U-pipe or double U-pipe are common*
Korea	*Single U-pipe is dominant in GSHP.*
Netherlands	*Generally the same – single U most common but concentric HX used with some regularity.*
Sweden	*Single U-pipe dominates (cheapest option). Double U-pipe quite common in systems with restricted free cooling temperature limit (more costly, but also more effective). Occasionally coaxial BHE is used, so far mainly for R/D projects.*
Turkey	*Single U and double U pipe*

Table A1-62: What material for BHE pipes and joints is used?

Belgium	*Plastic pipes, PE100. Joints welded with special electro-joints for connection to the surface pipe system. U-bent at bottom of borehole specially welded by manufacture.*
Canada	*HDPE in PE4710 resin compound – similar to PE 100. Connections are socket, butt or electro-fusion welded. U – bend at the bottom of the borehole is generally an injected molded, factory attached piece.*
China	*PE100, PE80 and PB are recommended pipe materials. PVC should not be used. Joints welded with special electro-joints for connection to the surface pipe system. U-bent at bottom of borehole specially welded by manufacturer.*
Denmark	*Plastic pipes, PE100 (replaced PE80 in later years). Joints welded with special electro-joints for connection to the surface pipe system. U-bent at bottom of borehole specially welded by manufacturer.*
Finland	*Plastic pipes, PE100 (replaced PE80 in later years). Joints welded with special electro-joints for connection to the surface pipe system. U-bent at bottom of borehole specially welded by manufacturer.*
Germany	*VDI 4640-2 gives recommendations according to the application GSHP or BTES (HT-BTES): PE100 and PE100-RC for GSHP; PE100-RT, PEX and PB for BTES – occasionally they are also used for GSHP. 2-U-BHE: plastic pipes PE100 or PE100-RC (**r**esistant to **c**rack) is most common. PE100-RC is a material of a high quality non cross-linked PE which has a high resistance against slow crack propagation. Also resistance against notching effects and point loading is higher. The improved mechanical stability allows installation without sand bed. In special applications with high temperatures like in BTES PE-RT cross-linked PE (PE-X), PB or PP is used. For these materials operation temperatures up to 70 °C and peak temperatures up to 95 °C are possible. In recent years PE-Xa with a roughened surface have been developed to improve the contact between the pipe material and the grouting and thus to reduce the system permeability. U-bent at bottom of borehole is specially welded by manufacturers. Coaxial BHE with large diameter are welded at the drilling site.*
Japan	*Plastic pipes, PE100. Joints welded with special electro-joints for connection to the surface pipe system. U-bent at bottom of borehole specially welded by manufacturer.*
Korea	*Socket welding is used for small diameter and fusion welding is used for big diameter.*
Netherlands	*PE100 SDR 11 for heat exchangers, SDR 17 for horizontal. The pressure class is related to depth and described in the protocols. Sometimes PEX or Polybutane are used. U-bend welded by manufacturer, length marking required.*
Sweden	*Plastic pipes, PE100 (replaced PE80 in later years). Joints welded with special electro-joints for connection to the surface pipe system. U-bent at bottom of borehole specially welded by manufacturer.*

Turkey	*Plastic pipes, PE100 (replaced PE80 in later years). Joints welded with special electro-joints for connection to the surface pipe system. U-bent at bottom of borehole specially welded by manufacturer.*

Table A1-63: What diameter and thickness is most commonly used?

Belgium	*DN 32 and DN40 SDR11*
Canada	*SDR – 11 and SDR – 13.5*
China	*DN25 and DN32 are commonly choice. The pressure rating of the pipe is PN10, PN12.5 or PN16 according to the demand.*
Denmark	*Most commonly DN40/2.0 SDR 17 (PN10) for single U-pipes and DN32/2.0 SDR17 (PN16) for double U-pipes.*
Finland	*Most commonly for single U-pipes DN40/2.4 SDR 17(PN10) and DN32/2.0 SDR17 (PN10) for double U-pipes.*
Germany	*Most common for double U-pipes: DN32/2,9 SDR 11 (PN 16)*
Japan	*The diameter is commonly approximately 26 mm or approximately 32 mm. The thickness is approximately 2.5 mm.*
Korea	*Most of them are single U-tube and PE100/SDR11.*
Netherlands	*DN32 – DN40, SDR 11 for vertical pipes up to 200 meters depth. Thickness quoted for Sweden would be completely unacceptable as HX cannot be changed. The thickness required is related to resistance against damage.*
Sweden	*Most commonly DN40/2.0 SDR 17 (PN8) for single U-pipes and DN32/2.0 SDR17 (PN10) for double U-pipes. In later years DN 45 and DN50 have become an option for very deep boreholes (250-400 m)*
Turkey	*Most commonly DN40/2.0 SDR 17 (PN8) for single U-pipes and DN32/2.0 SDR17 (PN10) for double U-pipes. Most commonly DN40/3.7 SDR11 (PN16) for single U-pipes and DN32/2.9 SDR11 (PN16) for double U-pipes.*

Table A1-64: What quality criteria for BHE are stated?

Belgium	*Bursting pressure, collapsing pressure, extension coefficient and change of strength with increased temperature.*
Canada	*The higher the temperature, the lower the bursting pressure, the lower the maximum operating pressure.*

China	*Hydrostatic strength, collapsing pressure, extension coefficient and change of strength with increased temperature.*
Denmark	*Reference to a specific type of plastic. None of the other criteria are specifically mentioned. Statement from legislation § 14 part 2: "PE100RC, SDR11 and shall be accepted according to standard EN 13244 or EN 12201." You can deviate from this by proving that the alternative has the same properties.*
Finland	*Bursting pressure, collapsing pressure, extension coefficient and change of strength with increased temperature.*
Germany	*VDI 4640-2 gives recommendations/requirements. Bursting pressure, collapsing pressure, change of strength with increased temperature, contact between grouting material and pipe material (-> system permeability).*
Japan	*No information*
Korea	*Quality criteria of Korea are similar to ASTM.*
Netherlands	*Bursting pressure, collapsing pressure, extension coefficient and change of strength with increased temperature. Tested by manufacturer.*
Sweden	*Bursting pressure, collapsing pressure, extension coefficient and change of strength with increased temperature.*
Turkey	*Bursting pressure, collapsing pressure, extension coefficient and change of strength with increased temperature.*

Table A1-65: How are the material properties certified?

Belgium	*Certified by the manufacturer regarding bursting pressure, collapsing pressure, extension coefficient and change of strength with increased temperature.*
Canada	*Dictated by Standards bodies – CSA/ANSI/ASTM and complied with by manufacturers.*
China	*Certified by the manufacturer.*
Denmark	*Reference to a specific type of plastic. None of the other criteria are specifically mentioned. Statement from legislation § 14 part 2: "PE100RC, SDR11 and shall be accepted according to standard EN 13244 or EN 12201." You can deviate from this by proving that the alternative has the same properties.*
Finland	*Certified by the manufacturer regarding bursting pressure, collapsing pressure, extension coefficient and change of strength with increased temperature.*
Germany	*VDI 4640-2 gives recommendations/requirements.*
Japan	*No information*

Korea	*KS (Korea Standard) certified materials are used.*
Netherlands	*Tested by the manufacturer regarding bursting pressure, collapsing pressure, extension coefficient and change of strength with increased temperature.*
Sweden	*Certified by the manufacturer regarding bursting pressure, collapsing pressure, extension coefficient and change of strength with increased temperature.*
Turkey	*Certified by the manufacturer regarding bursting pressure, collapsing pressure, extension coefficient and change of strength with increased temperature.*

Table A1-66: How are BHE manufactured?

Belgium	*Manufacturing in larger workshops, in production lines with material mixing, melting, pressure molding, water basin cooling and finally winding. Before delivery, pressure testing with air is done.*
Canada	*Manufacturing in larger workshops, in production lines with material mixing, melting, pressure molding, water basin cooling and finally winding. Before delivery, pressure testing with air is done.*
China	*The pipes and joints are manufactured in larger workshops, in production lines with material mixing, melting, pressure molding, water basin cooling and finally winding. There are a lot of manufacturers, 5-8 large suppliers. The pressure testing of pipes with air is applied before delivery. The pressure testing of the BHE is carried out on the spot when the connection work is completed.*
Denmark	*2-3 large, reliable suppliers in DK. Also import from Germany.*
Finland	*Two Swedish companies have manufacturing in Finland. Similar testing methods are used. Before delivery, pressure testing with air is done.*
Germany	*6-7 manufacturers. VDI 4640-2 gives requirements for testing, packing, transport and documentation. Due the construction especially the large diameter coaxial BHEs cannot be rolled. They are delivered to the construction site as prefabricated rods and have to be welded during installation into the borehole.*
Japan	*No information*
Korea	*Manufacturing process is based on KS (Korea Standard) certification.*
Netherlands	*General suppliers are used (Haka Gerodur, Rehau, Muovitech, Stuwa). For horizontal pipes also Pipelife or Wavin.*
Sweden	*Manufacturing in larger Swedish workshops, in production lines with material mixing, melting, pressure molding, water basin cooling and finally winding. There are 3-4 large suppliers. Before delivery, pressure testing with air is done.*

Turkey	*Manufacturing in larger workshops, in production lines with material mixing, melting, pressure molding, water basin cooling and finally winding. Before delivery, pressure testing with air is done.*

Table A1-67: What welding method and procedure are used to connect the BHE to the surface pipe system?

Belgium	*The BHE connected to surface pipe system by specially designed 90 degree electro-joints according to specifications from the joint manufacturer. Special tools are used and joining pipes must be perfectly cleaned and certain weather conditions avoided.*
Canada	*Socket, butt and electro-fusion are acceptable methods in Canada.*
China	*The BHE connected to surface pipe system by specially designed 90 degree electro-joints according to specifications from the joint manufacturer. Special tools are used and joining pipes must be perfectly cleaned and certain weather conditions avoided.*
Denmark	*Electro welding fittings used according to specs. Other joints may be used if they have the same properties. Joints at the surface must be accessible for inspection.*
Finland	*The BHE connected to surface pipe system by specially designed 90 degree electro-joints according to specifications from the joint manufacturer. Special tools are used and joining pipes must be perfectly cleaned and certain weather conditions avoided.*
Germany	*VDI 4640-2 gives recommendations/requirements.*
Japan	*No information*
Korea	*The BHE connected to surface pipe system by specially designed 90 degree electro-joints according to specifications from the joint manufacturer. Special tools are used and joining pipes must be perfectly cleaned and certain weather conditions avoided.*
Netherlands	*Electro-joint fusion, butt fusion not advised. Use of mechanical couplings underground prohibited.*
Sweden	*The BHE connected to surface pipe system by specially designed 90 degree electro-joints according to specifications from the joint manufacturer. Special tools are used and joining pipes must be perfectly cleaned and certain weather conditions avoided.*
Turkey	*The BHE connected to surface pipe system by specially designed 90 degree electro-joints according to specifications from the joint manufacturer. Special tools are used and joining pipes must be perfectly cleaned and certain weather conditions avoided.*

Table A1-68. How is the use of spacers handled?

Belgium	*There is a discussion on the effectiveness of spacers. Normally spacers are not used. Sometimes it is demanded.*

Canada	*Spacers are a subject of debate in Canada.*
China	*In the National Technical Code it is recommended to set spacers at 2-4 meters intervals .*
Denmark	*Spacers are recommended, but not widely used.*
Finland	*Spacers are hardly used. The main reason to use spacers is more to avoid BHE's coiling up in installing phase, rather than for thermal reasons.*
Germany	*They are often required by the authorities, but can usually only be installed with major complications. They can cause major problems when grouting and should therefore not be used. In practice they make no sense and make only problems during insertion the pipes in the borehole. The positive effect they should have on preventing / reducing thermal bridges is only given on the paper. Therefore, you would need a spacer at least every meter and this would produce much more serious problems for the grouting of the borehole.*
Japan	*No information*
Korea	*Spacers are typically not used*
Netherlands	*Normally spacers are not used.*
Sweden	*With groundwater filled boreholes, spacers make no significant difference on the borehole resistance. Therefore not normally used.*
Turkey	*Spacers are typically used. For small projects, spacers are not used, but for larger projects generally spacers are used as specification list ordered.*

Table A1-69: How is the use of different manifolds (headers) handled?

Belgium	*A variety of prefabricated out-door field manifolds has been developed and is commonly used. Big systems are designs on site. For smaller systems, the manifolds are placed indoors*
Canada	*Generally, on-site headers are constructed – prefabricated units are available but are not widely used. Indoor headers are rare.*
China	*A variety of underground field manifolds have been developed by the BHE manufacturers. These are normally designed for 10-20 boreholes and prefabricated. Less common is special designs that are constructed on-site. Occasionally the manifolds are placed indoor in the energy central.*
Denmark	*Some bought ready-made. Others are constructed on site. Often placed in a well-pit outdoors.*
Finland	*A variety of underground field manifolds have been developed by the BHE manufacturers. These are normally designed for 10-20 boreholes and prefabricated. Less common is special designs that are constructed on-site. Occasionally the manifolds are placed indoor in the energy central.*

Germany	*Prefabricated manifolds are available for very small up to very large systems and used. Occasionally the manifolds are placed indoor in the energy central, but then you have to take care on the condensation water.* *Manifolds are built of plastic and concrete and the manifold covers are available in any load classes (Belastungsklassen).* *Manifolds are available in any sizes. The number of connected BHEs depends on the BHE-planner and hopefully he considered the hydraulic pressure loss in the connecting pipes.*
Japan	*No information*
Korea	*Usually 10 boreholes are combined and they are connected to the header as a reverse-return.*
Netherlands	*A variety of underground field manifolds have been developed by the BHE manufacturers. These are normally designed for 10-20 boreholes and prefabricated. Less common is special designs that are constructed on-site. Occasionally the manifolds are placed indoor in the energy central.*
Sweden	*A variety of underground field manifolds have been developed by the BHE manufacturers. These are normally designed for 10-20 boreholes and prefabricated. Less common is special designs that are constructed on-site. Occasionally the manifolds are placed indoor in the energy central.*
Turkey	*A variety of underground field manifolds have been developed by the BHE manufacturers. These are normally designed for 10-20 boreholes and prefabricated. Less common is special designs that are constructed on-site. Occasionally the manifolds are placed indoor in the energy central. Generally for manifolds manufacturers designs are used, sometimes special designs are also used.*

Table A1-70: How are boreholes and manifolds typically connected?

Belgium	*Except for very shallow systems the boreholes and field manifolds are connected in parallel in order to minimize the flow resistance in the system.*
Canada	*Most commonly all the boreholes and field manifolds are connected in parallel. The main reason is to minimize the flow resistance in the system.*
China	*Most commonly all the boreholes and field manifolds are connected in parallel. The main reason is to minimize the flow resistance in the system.*
Denmark	*Most often parallel. But a combination of serial and parallel can be seen if the boreholes are relatively short.*
Finland	*Most commonly all the boreholes and field manifolds are connected in parallel. The main reason is to minimize the flow resistance in the system.*

Germany	*Usually the flow and return of each double-U-pipe is connected with a Y-section, so that from each BHE two pipes are laid horizontally to the manifold. The horizontal pipes have to be bigger than the BHE-pipes to limit the hydraulic pressure loss. Typically, a 40(x3.7) pipe is used for the horizontal connection with 32(x2.9)-type BHE. Better would be a 50(x4.6) pipe. The horizontal pipes are laid in utility trenches with a slope of one degree to the BHE. A warning tape must be placed a few centimeters (10 – 20 cm) over the pipes. The bedding material in the surrounding of the pipes must not have sharp edges.*
Japan	*No information*
Korea	*Most commonly all the boreholes and field manifolds are connected in parallel. The main reason is to minimize the flow resistance in the system.*
Netherlands	*Smaller systems directly connected to heat pump manifold, larger systems often with Tichelmann to reduce horizontal pipe runs. Very large systems with header pits in BHE field and large diameter flow and return pipes to technical plantroom.*
Sweden	*Most commonly all the boreholes and field manifolds are connected in parallel. The main reason is to minimize the flow resistance in the system.*
Turkey	*Most commonly all the boreholes and field manifolds are connected in parallel. The main reason is to minimize the flow resistance in the system.*

Table A1-71: What concepts of flow control are used in borehole systems?

Belgium	*To be further investigated*
Canada	*Many systems have VFDs for the ground – loop circulation pumps. Balancing valves are generally placed on the return (to the loop-field) side of the building distribution manifold.*
China	*The circulation pump has frequency control. Typically several boreholes share a flow meter and valve.*
Denmark	*Commonly the circulation pump has a frequency control allowing the flow rate through the system to be adapted to the energy demand from system. Secondary, each connection to boreholes has a simple flow meter and a valve for adjustment of flow. In practice these are adjusted only once, but the valve can be used to shut down single boreholes if required.*
Finland	*Commonly the circulation pump has a frequency control allowing the flow rate through the system to be adapted to the energy demand from system. Secondary, each connection to boreholes has a simple flow meter and a valve for adjustment of flow. In practice these are adjusted only once, but the valve can be used to shut down single boreholes if required.*
Germany	*Flow adjustment in boreholes is basically conducted by valves (typically used valve: taco-setter). In GSHP systems the flow is typically determined by the heat pump requirements. Larger plants and BTES may be operated with variable speed pumps.*

Japan	*No information*
Korea	*Pumps with metering and step control are typically used.*
Netherlands	*Smaller systems no flow control, newer and larger systems with flow control. In cascading systems or inverter driven compressors flow regulated as function of load.*
Sweden	*Commonly the circulation pump has a frequency control allowing the flow rate through the system to be adapted to the energy demand from system. Secondary, each connection to boreholes has a simple flow meter and a valve for adjustment of flow. In practice these are adjusted only once, but the valve can be used to shut down single boreholes if required.*
Turkey	*Flow control valves are located in manifold (sometimes on heat pump ground flow line). Not at each connection point.*

Table A1-72: What grouting materials and procedures are used?

Belgium	Grouting/backfilling always required. The permeability has to be proven > 10^{-8} m/s and frost resistant. (legislation in Flanders) Sand etc. is forbidden.
Canada	*Borehole grouting is virtually mandatory in all jurisdiction of Canada. Different grout conductivity products are available.*
China	*The National Technical Code requires grouting, but there is no grouting guidance.*
Denmark	*Always grouting. German or Danish manufacture.*
Finland	*Grouting is only used in special cases. Testing with some bentonite grouts has been done by the Geological Survey (results unpublished).*
Germany	*Grouting is for almost all boreholes in Germany required. In former years so-called "construction-site mixtures" have been used. These mixtures are produced on-site by mixing the single components (cement, bentonite, sand, water). This procedure made a quality control very complicated.* *On-site produced grouting mixtures are due to quality problems not allowed any more by the VDI 4640-2.* *The grouting materials used today are mostly produced by specialized manufacturers. These mixtures only have to be mixed at the drilling site with a defined amount of water.* *In general, there are three main groups of grouting materials:* • *Standard grouting material with a heat conductivity of 0.8 – 1.0 W/m/K* • *Thermally enhanced grouting materials with quartz sand (heat conductivity of around 2 W/m/K); these materials have the highest suspension densities (1.80 – 1.95 kg/l; the lowest density of the other materials is around 1.45 kg/l)* • *Thermally enhanced grouting materials with graphite or other additives (heat conductivity of around 2 W/m/K)*

	Beneath there are also special materials (e.g. clay/bentonite pellets), that are rarely used. *In the last years magnetite doped grouting materials came up and are mostly used in Baden-Württemberg. In this state of Germany the grouting suspension level in the borehole has to be documented during the whole grouting process. Therefore miniaturized magnetic susceptibility sensors can be used within the BHE pipes. This obligation for documentation came up as a reaction to different damage events that occurred in Baden-Württemberg due to insufficient borehole grouting.* *The grouting process is described in VDI 4640 part 2.* *The examination of the grouting quality with regard to hydraulic permeability, cavities within the grouting, durability under the influence of freeze-thaw-processes or aggressive groundwater is subject of recent research projects.*
Japan	*Sand is commonly used.*
Korea	*Grouting is mandatory*
Netherlands	*Grouting/backfilling always required. Usually pea gravel (using drill cuttings not allowed), clay layers (aquitards) need to be sealed with swelling clay.*
Sweden	*Only in special cases, grouting is used in Sweden. However, there is a tendency for increased use caused by permits terms, see above. There is no standard or even practice for how to grout the boreholes. There is a discussion going on how to grout deep boreholes in hard rock types. So far thermal grout manufactured in Germany or Denmark is used, lately also a thermal grout fabricated in Sweden. There are also other systems available, not using grout for groundwater protection, such as plugs that separate different water holding fractures in the rock, or a hydrostatic controlled capsule along the entire borehole length.*
Turkey	*Only in special cases, grouting is used. Grouting is prepared with specific mixing rate of bentonite + water +silica sand on site.*

Table A1-73: What pipe material is the horizontal pipe system most commonly made of?

Belgium	*Most commonly PE100*
Canada	*PE 3408 / 3608 or PE 4710*
China	*Both PE100 and PE80*
Denmark	*PE80*
Finland	*Most commonly PE100*

Germany	*Depending on the application (GSHP or HT-BTES) temperature requirements have to be met also by the horizontal pipe system => PE100 und PE100-RC for low temperatures PE100-RT, PEX und PB for HT applications.*
Japan	*Most commonly PE100*
Korea	*Most commonly PE100*
Netherlands	*PE100 SDR 17.*
Sweden	*Most commonly PE100 and thermal resistance plastics such as PP for HT-BTES*
Turkey	*Most commonly PE100*

Table A1-74: What dimension and strength are typical for the horizontal pipe system?

Belgium	*DN 32/40*
Canada	*SDR 11 – SDR 13.5 – SDR 17*
China	*Most commonly DN32 or DN40 (PN10).*
Denmark	*No information*
Finland	*Most commonly DN40/2.4, SDR 17 (PN10). Occasionally DN50/3.0 SDR17 (PN10), to decrease the fluid resistance losses.*
Germany	*According to the hydraulic layout the pipe dimensions have to be selected to gain a reasonable pressure drop.*
Japan	*The diameter is commonly approximately 20 mm or approximately 26 mm. The thickness is approximately 2.5 mm.*
Korea	*PE 100/SDR 11 is used.*
Netherlands	*DN32/40 up to DN110.*
Sweden	*Most commonly DN40/2.4, SDR 17 (PN10). Occasionally DN50/3.0 SDR17 (PN10), to decrease the fluid resistance losses.*
Turkey	*Most commonly DN40/2.4, SDR 17 (PN10). Occasionally DN50/3.0 SDR17 (PN10), to decrease the fluid resistance losses.*

Table A1-75: How is the insulation of the horizontal pipe system handled?

Belgium	*Only parts that are exposed to air or placed at shallow depth (<0.80m).*
Canada	*Only parts that are exposed to air or placed at shallow depth.*

China	*Only parts that are exposed to air or placed at shallow depth.*
Denmark	*Horizontal pipes close to foundations or sewer pipes (1.5 or 1 meter respectively) must be insulated.*
Finland	*Only parts that are close to foundations, exposed to air or placed at shallow depth.*
Germany	*Only parts that are exposed to air or placed at very shallow depth.*
Japan	*No information*
Korea	*Only parts that are exposed to air or placed at shallow depth.*
Netherlands	*Only parts that are exposed to air or placed at shallow depth. Usually no insulation on outdoor pipes installed.*
Sweden	*Only parts that are exposed to air or placed at shallow depth.*
Turkey	*Only parts that are exposed to air or placed at shallow depth.*

Table A1-76: At what depth is the horizontal pipe system placed?

Belgium	*Commonly 0.8-1.2 m (ground frost depth considered).*
Canada	*Shallowest is 4 feet (1.2 m) most common 6 – 8 feet (1.8 m – 2.4 m)*
China	*0.4 m below the ground frost depth and no less than 0.8 m.*
Denmark	*Commonly 0.8-1.2 m (ground frost depth considered).*
Finland	*Commonly 1.0 to 1.5 m due the ground frost depth in winter time.*
Germany	*Commonly 0.8-1.2 m (ground frost depth considered).*
Japan	*No information*
Korea	*Ground frost depth must be considered.*
Netherlands	*Commonly 0.8-1.2 m (ground frost depth considered)..*
Sweden	*Commonly 0.8-1.2 m (ground frost depth considered). Pipes should be placed with 20 cm spacing.*
Turkey	*Commonly 0.8-1.2 m (ground frost depth considered).*

Table A1-77: What material is used as bottom bed for the horizontal pipe system?

Belgium	*Commonly a sand bed. Must be free of stones with sharp edges.*

Canada	*Native soil is accepted so long as there are no stones/sharp edges.*
China	*Commonly a sand bed. Must be free of stones with sharp edges.*
Denmark	*Commonly a sand bed. Must be free of stones with sharp edges.*
Finland	*Commonly clay overlay with a thin man made sand bed.*
Germany	*Commonly a sand bed. Must be free of stones with sharp edges.*
Japan	*No information*
Korea	*Commonly a sand bed. Must be free of stones with sharp edges.*
Netherlands	*Commonly a sand bed. Must be free of stones with sharp edges.*
Sweden	*Commonly a sand bed. Must be free of stones with sharp edges.*
Turkey	*Commonly a sand bed sometimes tiny soils. Must be free of stones with sharp edges.*

Table A1-78: How does the backfilling of pipe trenches work?

Belgium	*Commonly a layer of sand*
Canada	*Not used in Canada*
China	*Commonly a layer of sand. The filling ends with soil material from digging the shaft.*
Denmark	*Commonly a layer of sand and on top of that a permeable geotextile. The filling ends with soil material from digging the shaft.*
Finland	*Occasionally styrofoam insulation and thin sand bed. Final filling with soil material from the pit.*
Germany	*Commonly a layer of sand. The filling ends with soil material from digging the shaft. A warning tape is placed above the pipes in the trench.*
Japan	*No information*
Korea	*Commonly a layer of sand and on top of that a permeable geotextile. The filling ends with soil material from digging the shaft.*
Netherlands	*Commonly a layer of sand and on top of that a permeable geotextile. The filling ends with soil material from digging the shaft.*
Sweden	*Commonly a layer of sand and on top of that a permeable geotextile. The filling ends with soil material from digging the shaft. A red/white warning tape is placed at the top of the trench.*
Turkey	*Sand and clay*

Table A1-79 What heat transfer fluids are used?

Belgium	*Only Monopropylene glycol is accepted (legislation in Flanders). Typical concentration 25% to 35%. Pure water is used by some suppliers, but only rarely.*
Canada	*Ethanol (denatured – undrinkable) is used as well as methanol (methanol is slowly being phased out) and propylene glycol. The percentage concentration is usually specified by the engineer.* *Pure water is occasionally used in systems with storage of heat only, providing above freezing temperatures is assured.*
China	*Pure water is the most commonly used heat carrier. Ethylene glycol is a common antifreeze component added to water, the content of ethylene glycol is 25%-30%.*
Denmark	*Commonly bioethanol as antifreeze component to water. The content of ethanol shall be less than 27% (flammable at higher concentration). In later years there is a tendency to cut down the percentage to 10-20%. The ethanol used has two slightly toxic additives, n-Butanol (45 gr/m^3) and Isopropanol (350 gr/m^3). These additives make the ethanol undrinkable.* *Pure water is occasionally used in systems with storage of heat only, providing above freezing temperatures is assured.*
Finland	*Normally 28% ethanol fluid is used. 60 % or 90% ethanol can be bought (permit is needed) and mixed with water on site.* *Pure water is not commonly used in Finland (only one pilot scale BTES system in western Finland uses water).*
Germany	*Water/antifreeze mixture with a freezing point at 5 K below minimum design temperature (typically -14 C) is used. Most commonly used are ethylene glycol or propylene glycol water mixtures.* *Pure water may be used for systems that are always operated at temperatures above 0 °C, e. g. in groundwater protection zones, some BTES applications etc.*
Japan	*In the moderate climate region, pure water not including anti-freezer is sometimes used.*
Korea	*Water-ethyl alcohol or water-propylene glycol mixtures are used as ground loop brine. The freezing temperature must be below -6°C. Antifreeze must be used.*
Netherlands	*Monopropylene or monoethylene glycol mixed with water by 10–30%. Additives not allowed (although not yet prohibited by law).* *Pure water is occasionally used by some suppliers.*
Sweden	*Commonly bioethanol as antifreeze component to water. The content of ethanol shall be less than 27% (flammable at higher concentration). In later years there is a tendency to cut down*

	the percentage to 10-20%. The ethanol used has two slightly toxic additives, n-Butanol (45 gr/m³) and Isopropanol (350 gr/m³). These additives make the ethanol undrinkable. *Pure water is occasionally used in systems with storage of heat only, providing above freezing temperatures is assured.*
Turkey	*Ethanol-water mixture (sometimes monoetylene glcohol) is used as well as pure water, which is common.*

Table A1-80: Is it mandatory to perform environmental risk analyses?

Belgium	*For BTES risk assessments are no part of the permit procedures. For large ATES systems a risk assessment is mandatory.*
Canada	*Very little emphasis is given to risk analysis unless dictated by a governmental agency in particular situations.*
China	*The main subject is then to show the risks for groundwater contamination by leakage of heat carrier fluid or surface water.*
Denmark	*Thermal and leakage risk towards the groundwater. Hydraulic flow between aquifers is generally considered being blocked by grout.*
Finland	*Mostly recognized in the permit application stage. However, public databases are not commonly used in risk evaluation and hence the evaluation is not done properly. Normally same basic sentences are used when applying for the permit and site specific risk evaluation has not been done. Environmental risks are undervalued by applier and overvalued by authorities. This is due to lack of realistic information available and/or attitudes (both clients and authorities) related to environmental issues.*
Germany	*Risk assessment is not required in most cases. Critical areas and environmental risks are considered in the approval procedure by the authorities.* *Usually not mandatory. During the approval procedure for a BHE-field it can happen, that the water or the mining authority requests some statements to environmental or geotechnical or hydrogeological risks. A classic environment impact assessment (UVP) is not mandatory.*
Japan	*No information*
Korea	*Environmental risks are not considered for GSHP.*
Netherlands	*Not done on a project basis, general studies have been performed with regard to positive and negative impacts of BTES/GSHP systems.*
Sweden	*Environmental risk analyses are commonly made in the feasibility stage after test drilling. The main subject is then to show the risks for groundwater contamination by leakage of the heat carrier fluid. Another risk is that the boreholes penetrate several permeable zones (fracture systems in hard rocks) and cause an uplift of deep brackish water to fracture system with fresh*

	water. A third risk considered is drainage of groundwater in clayey soil layers with a risk for settling
Turkey	*Environmental risk analyses are commonly made without a legislation in the feasibility stage. The main subject is to show the risks for groundwater contamination by leakage of heat carrier fluid. They can penetrate several aquifer zones in sedimentary area (gypsum) and cause a mixture deep different quality water with fresh water. A third risk considered is drainage of groundwater in clayey soil layers with a risk for settling.*

Table A1-81: Is it mandatory to perform technical and economic risk analyses?

Belgium	*No information*
Canada	*Risk analysis varies greatly by contracting document – there is no consistency.*
China	*Technical and economic risks are considered in the feasibility stage, but it is rarely shown in the design contract.*
Denmark	*Seen in the form of a "what if it doesn't work" backup solution.*
Finland	*Considered in the feasibility stage by using risk scenarios of different kinds. Risk analysis is normally also asked for in the contracting documents.*
Germany	*Risk analysis is generally not done, only if required by the client.*
Japan	*No information*
Korea	*Risk analysis is not normally asked for in the contracting documents.*
Netherlands	*Risk analysis is not done.*
Sweden	*Considered in the feasibility stage by using risk scenarios of different kinds. Risk analysis is normally also asked for in the contracting documents.*
Turkey	*Risk analysis is not common. If done it is considered in the feasibility stage by using risk scenarios of different kinds. Risk analysis may be asked for in the contracting documents.*

Appendix 1-6 – Answers on Approval Procedures

Table A1-82: How does the approval procedure work?

Belgium	*For most boreholes systems (<150m) no permits are required. But the drilling activity must be reported to the environmental government and a drilling log most be sent by the drilling company.*
Canada	*There is no national uniform approval procedure. In many instances, projects will specify that the ANSI/CSA C448 Series-16 Design and installation of ground source heat pump systems for*

	commercial and residential buildings Standard must be complied with. However, the majority of geothermal systems are installed "under the radar".
China	*The approval procedures are different in different provinces. It is usually necessary to apply to the local authorities according to the location of the project.*
Denmark	*Application/notification is sent to the local environmental authority and the project is reviewed with respect to local environmental regulations. Information about property owner, placement of boreholes, borehole configuration and neighbors' view on the installation shall be attached to the application as well as size and type of heat pump, volume and type of cooling medium. Drilling company and heat pump installer must be certified. The authority evaluates the project from an environmental point of view only.* *Approval is commonly given with certain terms that the applicant must follow, e.g. drilling water must be handled according to local regulations, and the sealing of casing towards the rock shall be done according to norms stated in Brøndborerbekendtgørelsen.* *If there is risk for contamination of groundwater the authority can either reject the application or give terms to avoid the risk.*
Finland	*The applications are sent to Building Control Authority (BCA, municipality level). If the site is situated on the groundwater area BCA will require an opinion from Regional Environment Centre (ELY) who will check environmental risks and can, for example, ask more specific environmental research. The BCA will make a final decision. ELY center or any other person can appeal the decision. The handling time for permit varies from days (no risk areas) to months (areas which needs risk evaluation). The GSHP and/or BTES systems are advised to install according to guide Energy Well (2012) provided by the Finnish Environment Institute.*
Germany	*In Germany planning services by architects and engineers are regulated (order, scope, performance, fees) by the Official Scale of Fees for Services by Architects and Engineers (HOAI, Honorarordnung für Architekten und Ingenieure). The planning stages (performance phases or working stages = Leistungsphasen =LP) are: LP1: Determination of basic conditions and feasibility study; LP2: preliminary planning; LP3: design planning; LP4: approval planning; LP5 Implementation planning; LP6: preparation for awarding for contracts; LP7: participation in awarding for contracts; LP8: construction supervision; LP): project management and documentation.* *Since September 2011 there is a special edition from the AHO Schriftenreihe "Planungsleistungen im Bereich der Oberflächennahen Geothermie" (planning services in the sector of shallow geothermal energy; Nr. 26); (http://preview.bundesanzeiger-verlag.de/baurecht-und-hoai/baurecht-und-hoai/themenseite-hoai/aho-schriftenreihe.html).* *Approval procedure is done in LP4.* *Most water authorities offer pre-printed forms (especially for residential buildings) for the permit application on their websites to download. The approval procedure and the required data is explained in detail in the guidelines of the states.*

Japan	*No information*
Korea	*Drilling activity must be reported to the local government. In the case of a public mandatory and subsidy program, system design document including TRT must be reviewed by the authority (Korea Energy Agency).*
Netherlands	*For small systems (<70 kW underground capacity) there is only a requirement to register the system.* *For larger systems (>70 kW underground capacity) a permit is needed but the permit can only be granted or not granted (few cases). Only in an "interference region" it is possible to regulate the systems and put specific requirements in the permit.*
Sweden	*An application/notification is sent to the local environmental authority (community level). Here the project is reviewed with respect to local environmental regulations. The application format can be found on line. Information on property owner, placement of boreholes, borehole configuration and Nabors view on the installation shall be attached to the application as well as size and type of heat pump, volume and type of cooling medium. Furthermore, name of drilling company and heat pump installer. These must be certified. The authority evaluates the project from an environmental point of view only.* *If no risks, the project is normally approved within six weeks. However, the approval is commonly given with certain terms that the applicant must follow. An example is that drilling water must be handled according to local regulations and that the sealing of casing towards the rock shall be done according to norms stated in Normbrunn 14.* *If there is risk for contamination of groundwater the authority can either deny the application, or subscribe terms to avoid that risk. Grouting of boreholes is a good example of such terms.*
Turkey	*Information about property owner, placement of boreholes, borehole configuration and neighbors' view on the installation shall be attached to the application as well as size and type of heat pump, volume and type of cooling medium.* *In the case of an open GSHP system where ground water is used, permission from The General Directorate of State Hydraulic Works (DSI) is required. If the project is a closed system, there is no need for permission - ownership is sufficient.* *Recently, there is a preparation stage for heat law consisting heat pump, therefore in next term rules can be changed.*

Appendix 1-7 – Answers on Call for Tenders

Table A1-83: What are the main forms of contracts for construction of borehole systems?

Belgium	*No information*

Canada	*Energy Performance contracts are becoming popular. These contracts entail a third–party who designs, builds, owns and operates the system and charges a set price for energy (btu/kW/tons/square footage etc.) for the life of the contract – e.g. 15, 20, 25, 30 years.*
China	*Contractor and customer contract, and agreed time limit for warranty.*
Denmark	*Uncertain praxis. Turnkey for smaller plants. No information on praxis for larger plants.*
Finland	*Common contract terms are normally used. The terms are publicly available.*
Germany	*Depends on kind of project and customer. Often turnkey for smaller plants.*
Japan	*No information*
Korea	*Main form of contracts is the general contract (design and construction are separated).*
Netherlands	*Not applicable for BTES systems*
Sweden	*Mainly Turnkey or Performance contracts based on General Regulations for Constructions (ABT06 and AB04). Occasionally there are other forms, such as partnering contracts.*
Turkey	*The bid is performed according "Public Tender Law"4734 No. The bid covers whole building project. If the tender is related project stage of building, it covers architecture, mechanical system and electricity system. GSHP system is a part of whole mechanical system of building. Tender document covers two main issues. These are "technical specification" and "administrative specification". The Public Tender Law has defined three main contract a) turnkey contract b) unit price contract c) combined contract. According the project which consists of complicated works, combined contract can be implemented.*

Table A1-84: How is the quality and skill of contractors ensured?

Belgium	*Certification of drillers and installers is required.*
Canada	*Most contractors are IGSHPA certified and drilling firms have a provincial "water well license". Reference project and CVs are provided in many instances but are not prerequisites.*
China	*In the specification, the tenderers must deliver documents showing Quality Control certification as well as Environmental Control certification. They are also asked for organization scheme including CV:s on key personnel and name a number of reference projects to show their skill.*
Denmark	*No control of quality or skill of contractors.*
Finland	*Some call for tenders include reference list and personnel CV. Finland has driller's interest group Poratek. Poratek educates new drillers and has certain quality documents (e.g. uniform drilling report) that all members should use. The Finnish heat pump association, SULPU, organizes education for heat pump installers. However there are several companies that are*

	not members of Poratek. Only a few companies have quality certifications for environment, work quality and/or health and safety for their operation.
Germany	*DVGW W120-2 certification of drillers is required, but only if the builder / planer or the water authority request it.* *There is no quality control or certification for the BHE-planner.*
Japan	*No information*
Korea	*Every company that wants to participate in the government program needs to get the quality assessment for each year. It includes the organization scheme, reference project and post management plan*
Netherlands	*All contractors must have certification for GSHP systems. Training is part of the certification.*
Sweden	*In the specification, the tenderers must deliver documents showing Quality Control certification as well as Environmental Control certification. They are also asked for organization scheme including CV:s on key personnel and name a number of reference projects to show their skill.*
Turkey	*Client and contractor must follow "Public Tender Law". Quality and skills depend on contract between contractor and Client.*

Table A1-85: How is responsibility for damages caused by borehole systems handled?

Belgium	*No information*
Canada	*Responsibility issues are tried in a court of law. Engineers are required to carry E & O (errors and omissions) insurance (typically $5million) to pay claims were liability on the engineer is determined.*
China	*For turnkey projects the contractor will be held responsible. The time limits may be 3-5 years.*
Denmark	*Praxis is not yet established in Denmark. There have so far not been any such court trials.*
Finland	*Responsibilities are included in contract terms. Responsibility is normally limited to 10 years. Contractor responsibility for damages for third party may be limited to cover only the sum which has been charged from customer.*
Germany	*First the owner of the property is responsible in the event of damage (Zustandsstörer). He is always liable to the state (cf. table 22). Only he can obtain the permit from the water authority. Whether he can make a third-party (driller, planner) responsible for the damage and the costs afterwards, is a question of private law.*
Japan	*No information*
Korea	*The responsibility is normally limited to 3 years.*

Netherlands	*The installer typically provides a guarantee, but this is not specified.*
Sweden	*For damages, linked to the functional design and construction of the plant, the contractor will be held responsible if it is a turnkey project. This responsibility is normally limited to 5 years.* *For a performance contract, responsibility for functional design is put on the client. Yet, the contractor can be held responsible for damages caused by bad performance in construction.*
Turkey	*2 years warranty. Responsibility and damage responsibility are stated in the contract.*

Appendix 2 – Country Answers Given by the Experts for Subtask 2

Appendix 2-1 – Answers on Legislation

The table gives an overview of any national “official” documents related to construction/installation of BHEs. The legal framework is listed in a prioritized order of succession for each country.

Table A2-1: Existing legislation, official guidelines, standards etc.

Belgium	*Due to the federal structure of Belgium regional regulations will apply Flanders VMM/YDG* • *Notification (no permit) for closed systems up to 150 m, except in specific zones (can be consulted by a webtool)* • *Authorization required for other cases, including open systems* *Special rules will apply within drinking water protection areas* *(See also Technical guideline n°259: design and construction of shallow borehole systems with U-shaped exchangers (BBRI, Belgian Building Research Institute)* *Wallonia (Jacques, Aymé)* *Brussels (ref. IBGE/BIM event on 2017-02-02)*
Denmark	*1) Consolidated Act on Environmental Protection (Concerns among other things general ground water protection and therefore also applies to construction of BHEs)* *2) Statutory Instrument on Construction and Discontinuance of Borings and Wells (BHEs are not directly mentioned but per the classification as A boreholes the same regulations apply)* *3) Statutory Instrument on Drillers Training (Document completed before BHEs became widely used in DK. They are therefore not directly mentioned. However, boreholes with BHEs are defined as class A boreholes, and class A boreholes are covered in the training program)* *4) Statutory Instrument on Ground Source Heating. (Primarily concerns horizontal systems. Plastic quality and distance requirements for BHEs are mentioned)* *5) Guidelines on Construction of On-shore Boreholes. (Gives practical examples on compliant construction of water wells)* *The municipality gives the permit for a given borehole and have the rights and obligations to set the specific demands. They may be stricter and more detailed than stated in the statutes. The demands set by the municipalities are often found to vary from one municipality to another.*
European Union	*Directive 2006/118/EC of The European Parliament and of The Council of 12 December 2006 on the protection of groundwater against pollution and deterioration*
Finland	*1) Water act and environmental act are controlling the BHE installation (Concerns among other things general soil and ground water protection and therefore also applies to construction of BHEs). Also legislation related to land use may affect BHE installation.* *2) Guide “Energy Well” (2012) regarding shallow systems provided by the Finnish Environment Institute is widely used and referenced. (outdated?)* *3) Voluntary and unofficial drillers certificate of qualification exists. Initiative by the well drillers organization* *4) Official heat pump certification of qualification exists.* *The application for BHE installation (all size) is sent to Building Control Authority (BCA, municipality level). If the site is situated on the groundwater area. BCA will require an opinion*

	from Regional Environment Centre (ELY) who will check environmental risks and can, for example, ask more specific environmental research. The BCA will make a final decision. ELY center or any other person can appeal the decision. Some drilling companies design and supply ground source heat pump systems.
Germany	*Due to the federal structure of Germany several national laws and regulations exist which are complemented by federal (Bundesländer) laws. The legislation is not very detailed, but BHEs are mentioned in some of the documents.* *1) WHG Water Resources Law (WHG)* *2) Water Law of the federal states (WG)* *3) Federal Mining Act (BBergG) >100m* *4) Drinking Water Ordinance (TrinkwV)* *5) Ordinance on installations handling materials hazardous to water(VAwS)* *6) Administrative regulations for the localization of water protection area* *7) Guidelines of the federal states (as well as LQS EWS (BW))* *8) Technical guidelines (VDI, DIN, DVGW)* *9) Rules of action for medicinal spring protective area of LAWA (Bund/Länder-Arbeitsgemeinschaft Wasser)* *Boreholes between 0 - 99 m must be notified at the local water authority.* *Boreholes deeper 100 m need a permit of the mining authority (BBergG).* *If the BHE isn't on the plot where the heat/cold is used a permission of the mining authority is necessary.* *Drillers have to be certified according to DVGW W120-2.* *In addition to the technical guidelines and standards (VDI, DIN, DVGW – which have equal importance) there are guidelines in each Federal State which define specific requirements for this State.* *The local authority may define site specific requirement like restriction of the depth et al. or refuse drilling at all because of e.g. contamination in the underground.*
Japan	*1. Ministry of Environment* *Guideline for use of shallow geothermal energy (ground heat source), (only in Japanese)* *https://www.env.go.jp/press/files/jp/108674.pdf* *https://www.env.go.jp/press/files/jp/108673.pdf* *2. Ministry of Land and Transportation* *Guideline for installation of shallow geothermal energy system (ground heat source) for public buildings and facilities, (only in Japanese)* *http://www.mlit.go.jp/common/001016159.pdf* *3. By NPO Geo-Heat Promotion Association of Japan* *Manual for installation of GSHP* *http://www.geohpaj.org/* *http://www.geohpaj.org/wp/wp-content/uploads/cm_manual_hoko201609.pdf* *4. By NPO Geo-Heat Promotion Association of Japan* *installation of GSHP* *Underground thermal system construction management engineer qualification system* *First class: Three years and more filed work, or two years and more after taking second class qualification after taking GSHP construction management course operated by GHPAJ in these three years*

	Second class; One year and more field work, or after taking GSHP construction management course operated by GHPAJ
Netherlands	*1) In the Netherlands there are laws for shallow geothermal (ATES and BTES) that are integrated in the general "Water Law"(ATES/open systems) and in the "Activiteitenbesluit" and "Besluit lozingen buiten inrichtingen" (BTES/closed systems). The closed loop systems are divided in large and small and have different, but quite similar, legislation. In addition, for deep geothermal, there is the Mining Law (> 500 meters depth).* *2) A number of limitations are clearly put in the law, e.g. minimum and maximum allowed temperatures, thermal pollution not allowed, method to decommission systems etc.* *3) Quality is mainly assured by protocols and certification. The law states that everyone working on geothermal systems needs to be certified. This can be checked in a public register.* *4) Main protocols are:* *- Protocol Mechanical Drilling (Protocol SIKB 2101 and BRL SIKB 2100, https://www.sikb.nl/richtlijnen/brl-2100)* *- Protocol design, realization and management of the subsurface part of shallow geothermal energy systems (Protocol SIKB 11001, BRL SIKB 11000, https://www.sikb.nl/bodembeheer/richtlijnen/brl-11000)* *- Protocol design, realization and management of the aboveground part of shallow geothermal energy systems (BRL KvINL 6000-21)* *- http://kvinl.nl/consumenten/voorpagina/nieuws/bericht/news/detail/News/nieuwe-regeling-in-ontwikkelingbrl6000-21-ontwerpen-installeren-en-beheren-van-wko-energiecentrale* *The protocols are regularly updated. The rules concerning ATES/BETS are mainly found in the protocols.* *5) Open systems need a permit (by application), granted only by the regional authority. The permit may have many specific requirements which may differ by region. Once the permit is given there is no further requirements.* *6) Small BTES systems (< 70 kW ground capacity) need only register.* *7) Larger BTES systems need a permit, but it is a permit without additional requirements.* *8) For all systems it needs to be verified that there is no negative interaction between adjacent systems.* *9) For BTES municipality is the authority.* *10) Zones of "interference" can be defined by authorities. All systems require a permit and special requirements can be set for all systems. These are detailed in a "Shallow geothermal energy plan"* *11) Many additional laws may apply: near railroads, near major waterworks, archology, soil-pollution. Also there may be permits required for dumping the drilling spoils and drilling fluid.*
Sweden	*1. The Swedish Environmental Code (Miljöbalken, MB) that in general terms regulates the legislative demands for any type of construction that involves installation in the water in the ground.* *2. The Environmental and Health Code (Miljö- och hälsoskyddslagen, SFS:1998:899) specifically states that any GSHP system with boreholes or wells, regardless size, must be announced to the Local Environmental Authority (LEA) prior to installation. The LEA may deny installation for environmental or health reasons or state certain terms in*

	the permit. Typical terms are that the driller must be certified and that the drilling shall be executed according to Normbrunn-14 (see further down) 3. *The Swedish Work Environment Authority's (Arbetsmiljöverket) Statute Book (AFS) contains a number of provisions with AFS designations. AFS 2006:4 regulates the use of work equipment, such as for drilling.* 4. *The Swedish Environmental Protection Agency (Naturvårdsverket) has issued regulations for water protection areas (NFS 2003:16), based on the Environmental Code (MB, chapter 7). Special requirements are given by the regional environmental authority for installations in water protection areas. In the inner and secondary zones BTES and GSHPs are forbidden, in the tertiary zone BTES and GSHPs may be allowed, but special requirements on grouting etc. may be required.* 5. *Consumers right (Konsumenttjänstlagen 1985:716) regulates the rights of private persons buying services from a company, such as a GSHP installation.* 6. *Common Regulations AB04 and ABT06 (Allmänna Bestämmelser, Svensk Byggtjänst, 2004/2006) set general contractual rules for construction and installations. In these plans for quality control and environmental control are required.* 7. *The Normbrunn-16 is a guideline for water protection covering design and installation of water wells and energy boreholes and wells.* 8. *Since 1976 all professional well drillers are required by law (SFS 1975:424, SFS 1985:245) to register all wells drilled to the Swedish Geological Survey (SGU). SGU keeps the open access Well Database where all registered wells are listed.*
Turkey	*There is no law or regulations related to shallow ground source heating boreholes. For preventing ground water contamination, Turkey has the "Ground Water Law" for protection of aquifers (no. 162). In case of aiming for exploiting of ground water from water well, one should obtain a permit from General Directorate of State Hydraulic Works (DSI). For drilling as a borehole heat exchanger, a permit should be obtained from the legal owner of the related land.*

Appendix 2-2 – Answers on Site Preparation

Table A2-2. Site preparation – site facilities

Belgium	*Site preparation includes survey of underground infrastructure and verification that there is no possible interaction with existing systems.* *Soil pollution situation needs to be assessed. Normally that is the responsibility of the main contractor and the information needs to be present on-site. In practice it is often the driller that needs to ensure that the site is clean and safe to work.* *Typically a request for water and electricity on site, but this is not mandatory. Drillers normally have gear to handle the situation.* *Driller must have a recognition in Flanders.*
Denmark	*Typically a request for water and electricity on site, but this is not mandatory. Drillers normally have gear to handle the situation. Fence required by law, but seldom put up.* *The drillers must have their certificate (Danish or equal) present on the site. The drilling permit from the municipality must also be present.*
Finland	*Typically a request for water and electricity on site, but this is not mandatory. Drillers normally have gear to handle the situation. Fence required by H&S legislation, but seldom put up in small projects.* *The drilling permit from the municipality must be present.*
Germany	*According DVGW W120 regarding "Zertifizierung von Bohrfirmen nach W 120 Qualifikationsverfahren für Unternehmen im Brunnenbau und Geothermie". However, only general requirements are made there.*

Japan	*General preparation:* • *Water is prepared by driller in water tanks* • *Electricity is generally provided by their own onsite engine generators.* • *Fences are not required by law, but site is often surround by a soundproof sheet to avoid construction noise to the ambient.* • *Steel container for sediment cuttings during circulation of mud water from well to drilling machine*
Netherlands	*Site preparation includes survey of underground infrastructure, verification that there is no negative interaction with existing systems. Soil pollution situation needs to be assessed. Normally that is the responsibility of the main contractor and the information needs to be present on-site. In practice it is often the driller that needs to ensure that the site is clean and safe to work.* *Often permits need to be arranged for dumping of drilling spoils and water.* *Normally water is requested on site, often the driller needs to organize this. For larger sites sometimes a small well is drilled first. The supply of water is increasingly becoming a problem.*
Sweden	*If drilling is done on customers own property no drilling permit is needed other than the permit from the LEA.* *If water and electricity is needed for the drilling, it is commonly provided by the customer.* *Potential underground obstacles (pipes for water, gas, electric cables and, fiber cables, etc.) must be surveyed before placing the boreholes.* *Permit for disposal of "drilling water" in the storm water system is in some community's requirement.* *For safety reasons the working area is commonly marked by lines or by a temporary fence.*
Turkey	*However heating/cooling project is evaluated together mechanical project and it must also be approved from the municipality.* *Electricity, water and supplying backhoe for digging mud pit is performed by the employer, otherwise these costs are reflected into expenditures per meter. The certificate is required for only oil, mining, water and geothermal (hot water) drillers. Drilling certificate is given by Special "The Course Private Experts Heavy Construction equipment and Drillers" approved by The Ministry of Education in Turkey. Also Geological Chamber of Turkey gives the certificate of Drillers in the frame of agreement with Ministry of Education. The drilling permit from municipality or land owner must be present.* *Because Drilling works is defined as "Very Dangerous Work class" in terms of Occupational health and safety dangerous classification, drillers should take precautions like covering with fence.* *Health and Safety Plan is always required regardless of the size of the system. No requirement for any certificate for the drillers (This is only required for Water Well Drilling). No requirement for any permit from the municipality for drilling.*

Table A2-3: Site preparation – Localization of underground obstacles

Belgium	*The driller is responsible for checking the underground installations in relation to the proposed drilling site in public areas. On a private site, it is up to the site owner. Excavation is an option. If excavation and soil removal (ex site) is necessary, it is mandatory to check if the site may be contaminated. If there is a risk, samples must be taken and analyzed. If contaminated, the soil must be handled and removed in accordance with legislation. (The same applies to drill cuttings and drilling mud but is normally only followed if it is pumped to a container).*
Denmark	*The driller is responsible for checking the underground installations in relation to the proposed drilling site in public areas. On a private site, it is up to the site owner. Excavation is an option. If excavation and soil removal (ex site) is necessary, it is mandatory to check if the site may be*

	contaminated. If there is a risk, samples must be taken and analyzed. If contaminated, the soil must be handled and removed in accordance with legislation. (The same applies to drill cuttings and drilling mud but is normally only followed if it is pumped to a container).
Finland	*The responsible for checking the underground installations in relation to the proposed drilling site in public and private areas should be agreed in agreement between driller and property owner. Excavation is an option but rarely used. If excavation and soil removal is necessary, driller or property owner (according to agreement) should also check if the property is listed as a possible soil contamination site (public record exists). If there is a risk for contaminated land handling, samples must be taken and analyzed. If soil or groundwater is contaminated, it must be handled and removed in accordance with legislation.*
Germany	*According DVGW W120-2 the driller is responsible to: […] ensure that information on the absence of explosive ordnance, esixting underground supply/disposal and other pipelines and underground structures is obtained before work begins.*
Japan	• *For small project; Onsite actual geological survey is no done, but geological information of the site is checked using the electrical database of the geology and existing well data.* • *For large project; Onsite shallow geological survey in some points of the site is conducted in order to design building foundation piles by the contraction company first. But these are really shallow ones. Next, deep geological information of the site, are checked using the electrical database of the geology and existing well data. TRT must be carried out before the construction when the project will receive the subsidy from the government.* • *Localization of underground obstacles* • *Cuttings mud and mud water should be treated and wasted according to the law absolutely In Japan, we have many problems of noise and ground vibration during drilling.* • *We must pay much attention to avoid friction with neighboring.*
Netherlands	*Formally the main contractor is responsible for assessing underground infrastructure and soil contamination (check with current protocol)* *In practice however, and required by the protocols and insurance, the driller will also verify the status of the site with regard to underground infrastructure and contamination.* *The drill cuttings etc. need to comply with the "regulations on building materials", in essence this means that the material needs to be un-contaminated.*
Sweden	*The drilling method in Sweden does normally not require any excavated pit for handling water or mud. Instead cuttings and drilling water is handled by using containers.* *If there is a risk for soil contamination, samples of cuttings are taken during drilling of casing. If contamination in the soil is found, the drilling must be stopped and the findings must be reported to the LEA.*
Turkey	*if excavation and soil removal (ex site) is necessary, it is necessary to move to the place where the municipality determines. (The same applies to drill cuttings and drilling mud but is normally only followed if it is pumped to a container).*

Appendix 2-3 – Answers on Drilling methods

Table A2-4: Drilling methods – Methods and underground

Belgium	*Will depend upon the geology which in turn is different from region to region. In most of the cases, the rotary mud method will be used.* *Flanders (commonly sand/clay):* • *BTES: Direct flush rotary drilling* • *ATES: Reverse circulation drilling/Direct flush rotary drilling*

	• *All drillers need to hold a recognition.* *Wallonia* *Brussels (see Flanders)*
Denmark	*Drillers in Denmark must hold a certificate (based on 5 weeks course) to prove their capability. Installing BHEs have recently been added to the course.* *Rotary mud it the typical method, both with and without casing. DTH may be used in compact limestone/flint. Artesian water is rare and pressure is normally low. Drillers can normally handle it. Packer/concrete is rarely necessary. Outflow will be registered as loss of mud, but is not normally documented or a part of the log. If drilling with pit, the mud will normally settle and the pit simply covered with the excavated soil. If using container, mud and cuttings settle and excess water goes in sewer. The rest is removed/deposited.*
Finland	*Due to geological conditions, DTH is normally used. Artesian water is rare and pressure is normally low. Drillers can normally handle it. Outflow may be mentioned but is not normally documented for the drilling log. The bore slime is gathered to the container in urbanised area and delivered to landfill area. In rural area the drilling mud is blown to ground.*
Germany	*DTH is the typically used method. In soft rocks also rotary mud drilling is used. Sometimes artesian groundwater and gas (e.g. CO2, CH4) is a problem (partly with high pressure). Hence, packer and diverter must hold available by the drillers. In sand and gravel sometimes auger drillings is used.*
Japan	*Drillers in Japan are recommended to hold engineers and workers who are a licensed or certificated. Not must now.* *But in some cases, companies which will tender for the drilling wells or boreholes of public facilities are sometimes required to hold engineers and workers who are a licensed or certificated.* *National qualification for drillers;* *Water well Drilling Technician qualification system; First class and Second class:* *Conditions for taking an examination by Ministry of Health, Labor and Welfare* *First class: seven years or more actual field work experience is required, two years or more after taking second class qualification is required. Or totally more than seven years of actual field work experience.* *Second class: two years or more actual field work experience is required.* *Both department and practical examinations are imposed.* *License renewal procedure is needed every five years* *Examination items are below:* *A. Written test items are;* *1) Basics of water well* *2) Basics of construction and drilling* *3) Materials* *4) Pumps* *5) Pumping test* *6) Geologic column* *7) Related laws and regulations* *8) Occupational safety and health* *9) Elective subjects;* *Percussion drilling method/ Rotary drilling method.* *B. Practical skill test items are:* *1) Elective subjects;* *Percussion well drilling works/ Rotary well drilling works*

	- *Machine: Rotary vibration drive machine is now popular in Japan due to its quiet and low vibration with high drilling speed for complex particle geological conditions. Rotary percussion and down the hole hummer drilling machines are used for hard rock.* *But, a down the hole hummer is rather rare in Japan for drilling the bore hole.* *Major rotary vibration drilling machine producers and suppliers are as below;* *(1) Toa-Tone Boring Co. Ltd.,: Boring machine with a Sonic Drill head* *https://www.toa-tone.jp/index_e.html* *https://www.toa-tone.jp/manufacture_e/index.html#m01* *(2) Koken boring machine Co. Ltd. (a group company of Hitachi construction machinary company, https://www.hitachicm.com/)* *https://www.koken-boring.co.jp/e/index.htm* *(3) YBM CO. Ltd.*
Netherlands	*All drillers need to hold a certificate.* *Mainly rotary mud, direct circulation (straight flush). Inverse circulation is used for open (aquifer) systems. Dry drilling techniques such as augering are sometimes used as well. In the past shallow BHEX have been installed using cone penetration methods. Drillings are normally done without casing.* *One of the main aspects is sealing of aquitards. Salinity may affect clay swelling in parts of the Netherlands.* *In some polders artesian water is an issue and drilling is prohibited without a permit. These permits are very difficult to obtain.* *From a quality point of view drilling with a pit is not the preferred method, although it is often used for small systems.* *In general, the processing of waste water from the drilling process is becoming a problem. The law permits rejecting water on the ground, but in many cases that is not possible and the sewages system needs to be used. This is becoming increasingly difficult.*
Sweden	*Practically all boreholes are drilled with the DTH-method and compressed air. This is done in three main steps:* 1. *A steel casing is drilled through the overburden and at least two meters into stable rock. This is done by a reamer or an enlarged ring bit leaving a space between the borehole wall and the casing.* 2. *The annular space between the wall and the casing is sealed off by placing a grout in the bottom, then lift and replace the casing and finally press or hit the casing towards the bottom.* 3. *Drilling of an open hole to the target depth and finally clean the borehole by air lifting* *The driller notes the type and colure of samples taken at the outlet pipe, fractures or fracture zones, and air lifting yield of water. Also the salinity of water is measured, as well as the ground water level after finishing the borehole. These are data reported to SGU.* *Getting rid of water used in the drilling process is becoming an issue.*
Turkey	*Drillers must hold a certificate but the certificate (and the courses behind it) is concerning mining, geotechnical, oil, water and geothermal (hotwater) wells. Installing heat exchangers is NOT a part of the certificate in Turkey. Mud rotary method and using with drilling pit are widely used. The mud will normally settle and the pit simply covered with the excavated soil. The rest is removed/deposited. It is necessary to move to the place where the municipality determines.* *Container using isn't common in Turkey. DTH is used in hard rocks such as basalt, andesit, limestone etc. Artesian water is rare and pressure is normally low. Drillers can normally handle it. Packer/concrete is rarely necessary. But in western part of Turkey, some high pressure zones consisting hot water can be encountered, driller must be well-prepared against this situation.*

Table A2-5: Drilling methods – Borehole diameter and casing

Belgium	*Closed loop systems: diameter 130-160mm. Normally no casing is used, with the exception of the top 2 – 3 meters for the protection of the top layer and in unstable layers. The heat exchanger itself, mainly HDPE PE100 diameter 32mm. Open systems: Strongly depends on requested flow rate and aquifer. Common: borehole diameter 400 mm/casing-screen 200 mm.*
Denmark	*Most drillers use casing (6"; 150 mm) some prefer to drill without. The borehole will typically have a diameter of 8-10", if the drilling is done without casing – even if the driller claims it's a 160 mm borehole (up to 300 mm has been seen in difficult geology). There are no requirements.*
Finland	*Borehole diameter is normally 4", 4,5" or 5" depending the driller. Casing (same size as borehole diameter) is used for soil and upper (normally 3 to 6 m) part of bedrock. Drilling to bedrock is done without casing.*
Germany	*Depends of the federal state (sometimes also of the municipality). According to the guidelines of the federal states e.g. >120-180 mm, the diameter of the BHE-tubes + 60/80mm. For a typical double-U-pipe with DN32 (x 2.9 mm) the drilling diameter is usually 152 mm (6") to the bottom of the borehole. This is to provide the typically required 30 mm annular space for the grouting. That means if temporary casing is necessary for some meters, this has to be bigger, usually 178 mm (7").*
Japan	- *Single pipe method is applied by Sonic drill machine. generally, OD = 167.9 mm* - *Double pipe method is applied by other drilling machine for rather soft layer,* *For single U tube, casing OD=120 mm and bit OD= 127 mm is used.* *For double U tube, casing OD=133 mm and bit OD= 137 mm is used.*
Netherlands	*Normally no casing is used (borehole remains open due to overpressure), with the exception of the top 2 – 3 meters for the protection of the top layer. Borehole diameter is somewhere between 0.12 – 0.15 m.*
Sweden	*The majority of boreholes are drilled with 140 mm steel casing and with 115 mm open hole. If deeper holes are applied (approx. > 250 m) 160 mm casing and 140 mm open hole is an option. BHEs with a pipe diameter of DN 45 and DN50 seems to be moving into the market. This will influence the borehole diameter. Drilling depth is also changing. 250-350 meter deep boreholes are seen more often in recent years. Thermal short-circuiting is small when the BHE length is 300 m or less.*
Turkey	*In Turkey most drillers are not using a casing. If casing is used it typically has a diameter of 6", 6 5/8" and 8". The borehole's diameter can be a diameter of range between 81/2", 85/8", 9 7/8", 10 ½" or 121/4". Without casing the borehole will typically have a diameter of 81/2"-121/4".*

Table A2-6: Drilling methods – Safety during drilling

Belgium	*Normal health and safety rules apply. Measurements regarding borehole collapse, overflow, etc. is primarily up to the driller. He must be prepared, but it is up to him to determine what this includes.*
Denmark	*Normal health and safety rules apply. Measurements regarding borehole collapse, overflow, etc. is primarily up to the driller. He must be prepared, but it is up to him to determine what this includes.*
Finland	*According the law, health and safety coordinator has to be nominated by the municipality for the project (even single borehole drilling). Site owner has to give "description of property and working environment" document to the driller and driller has to write health and safety plan. H&S coordinator has to check and approve drillers H&S plan before work can be started. This does not apply to small sites with only one contractor.*

Germany	*DVGW W120-2 / No special rules for BHE-drillings. The same for all drillings (groundwater wells, etc.). Normal health and safety rules apply like in Denmark.*
Japan	*There are some safety manuals of the civil works and drilling works.* *Main guideline for civil works construction safety guidelines is defined by ministry of land, infrastructure and transportation of Japan.* *http://www.mlit.go.jp/tec/sekisan/sekou/pdf/221126anzensekousisin.pdf* *Also, for maintain the safety and health of construction workers strictly, Occupational Safety and Health Act is defined by ministry of Health, Labor and Welfare.* *In addition, construction safety manuals are made by specified contraction associations. For example, all Japan united association of the geological survey complied the safety manual for boring works in 2014.* *https://www.zenchiren.or.jp/geocenter/genba/boring-anzen.pdf*
Netherlands	*Normal health and safety rules apply. Depending on the site conditions it may be required to measure the fumes from the borehole.*
Sweden	*The driller must in general follow what is regulated in AFS 2006:4 in order to protect the personal as well as any third part. There are special rules for hot works (by example welding)* *Many drilling contractors are using a Safety Check List prior to drilling* *At large construction sites the drillers have a "safety education"*
Turkey	*In Turkey all drilling works is in "Very Dangerous Jobs" class. In terms of health and safety it is subject to the special rules. From the technical side, it must be carried out under the legal responsibility of an engineer. Measurements regarding borehole is primarily up to this engineer. He must be prepared, but it is up to him to determine what this includes.*

Table A2-7: Drilling methods – Borehole profile, drilling log, samples

Belgium	*Samples must be taken at least in every sediment/soil type the drill penetrates and every 5 -6 m, when changing the drill-rod. Samples must be inspected and may be removed after taking notes of the characteristics. In some cases, the samples have to be sent to the geological services. The samples have to be packed in plastic.* *Driller has to make a drilling log with localization, description of the layers and plan of borehole.*
Denmark	*Samples must be taken at least in every sediment/soil type the drill penetrates. Samples must be sent to GEUS (Danish Geological Survey). A log shoving the depth to the various layers and the GWT must be made and sent to GEUS. This log will typically also include a brief field description of the materials. The driller may include "other observations" in the log. If many boreholes are made close to each other (as in a BTES), only one log/set of samples may be taken. Observations like pressure and torque will normally not be a part of the log. GEUS will normally make a revised borehole log, including detailed sample description based on the samples. The information is then made public on the national borehole database.*
Finland	*No legislative needs for sampling or even drilling log. Drilling log normally done by drillers. No sampling etc. environmental research done during BHE installation.*
Germany	*Samples must be taken at least in every sediment/soil type the drill penetrates. Samples must be stored for xx months (e.g. Baden-Württemberg 1 month), profile according DIN 4023 and DIN EN ISO 14688-1.Documentation of water levels, caverns, fractures, etc. protocol of strongly increasing or decreasing water levels. Artesian conditions have to be immediately communicated to the authorities. Significant drilling mud losses have to be communicated to the authorities.*
Japan	*Usually, an operator takes cuttings from the circulated mud water and checks, then determines the types of the soil property. Finally, geologic column chart is made.*

	Whole core sampling and labo test of the sample are investigated for only important facilities such as dam and bridges etc.
Netherlands	*The driller needs to register the X- and Y-coordinates, the used drilling technique and drilling mud composition, the general soil description and especially depth of aquitards. If a geophysical log is done it needs to be included, if layered backfilling is done there needs to be a record, any remarks. Name of the drill master.* *There is no requirement to send the drill-logs to the geological survey.*
Sweden	*The driller try to classify the stratigraphy as his best knowledge based on cutting samples and changes in lithology. Stratigraphy is reported to the Swedish Geological Survey (SGU) by filling in a documentation format. The format also contains information level of fractures and air lift yield, salinity, and the ground water level*
Turkey	*Samples are taken in every per meter through the drill penetrates. Logs be prepared by engineer if wants the owner. Logs is not required about project approval for municipality. Logs include a brief field description of the materials and also it shows depth of groundwater level, fractured levels and diameters of borehole. There is no any requirement that samples and logs to be sent to any institution. Although each institutions such as MTA (General Directorate of Mineral Research and Exploration) and DSI have their own database, there is no borehole database in terms of common usage in Turkey. Recently some works of building up of the common database has commenced.*

Table A2-8: Drilling methods – Geophysical investigations in borehole

Belgium	*No requirement* *ATES: Sometimes done for confirming the hydrogeological profile (e.g. EM dual induction measurement)*
Denmark	*Done in boreholes for mapping purposes, deep geothermal boreholes and often in deep water wells. Not known to have taken place in shallow geothermal boreholes. Requests for logs to verify presence of grouting have been put in at several occasions (but so far a small diameter gamma-gamma has not been located)*
Finland	*No geophysical investigations related to shallow geothermal boreholes.*
Germany	*Sometimes recommended in special geological settings (Anhydrite/Gypsum, gas, oil, etc.). It could be Gamma-Ray, caliber logs, etc. depending on the given site conditions.*
Netherlands	*No requirement.*
Sweden	*In rare cases the borehole deviation is measured, but else no geophysical logs are run*
Turkey	*Geophysical investigation methods for deep geothermal boreholes and water wells is not mandatory in Turkey. It is up to technical specification in contract. Only temperature logs are mandatory for all (hot water exploiting) geothermal boreholes. Must be done in boreholes for mapping purposes, deep geothermal boreholes and often in deep water wells.*

Table A2-9: Drilling methods – Drilling influence on temperature, pressure, groundwater flow

Belgium	No measurements of temperatures in general. Pressure levels and quantification of GW-flow are only measured under artesian conditions or high pressure differences between different groundwater bearing layers. The complete grouting of the borehole should also like in DK ensure that the pressure levels and GW flow pathways are unchanged after the grouting is hardened

Denmark	Temperatures have been measured, but not as a standard. The complete grouting of the borehole should ensure that the pressure levels and GW flow pathways are unchanged after the grouting is hardened. This has not been tested in DK.
Finland	Influence occurs due to DTH drilling but not required or mapped when drilling.
Germany	No measurements of temperatures in general. Pressure levels and quantification of GW-flow are only measured under artesian conditions or high pressure differences between different groundwater bearing layers, even if the measurements may be questionable. The complete grouting of the borehole should also like in DK ensure that the pressure levels and GW flow pathways are unchanged after the grouting is hardened.
Japan	Overflow of the water during drilling borehole is the main problem in Japan. It would induce the breaking of the borehole wall. Drillers often use the water clocking material such as silicate, some polymers and sulphurated asphalt derivatives as additives depending on the situations.
Netherlands	No requirement.
Sweden	The temperature is always recorded as a part of TRT's. The initial circulation of fluid in boreholes also gives a clue on the geothermal gradient. The drilling process creates a temperature increase along the borehole length. For this reason the TRT cannot be performed until the normal borehole temperature has been reestablished. This takes normally from a few days, up to a week.
Turkey	Temperatures have been measured all geothermal and water well boreholes, but not as a standard. Temperature logs are mandatory for all (hot water exploiting) geothermal boreholes. In terms of ground heat boreholes, the complete grouting of the borehole should ensure that the pressure levels and GW flow pathways are unchanged after the grouting is hardened. Also, this has not been tested in Turkey.

Appendix 2-4 – Answers on Borehole Heat Exchanger

Table A2-10: Borehole heat exchangers – Installation

Belgium	*Typically from a reel, waterfilled and with weights.*
Denmark	*Typically from a reel, waterfilled and with weights. Initially a momentum is created, and later when buoyancy increases, the momentum is typically enough the keep the unreeling going (at least to 100 m). Use of excessive force has been seen to damage (bend) pipes.*
Finland	*Typically from a reel, 28% ethanol filled and with weights in bottom U.*
Germany	*Typically from a reel, waterfilled and with weights. Initially a momentum is created, and later when buoyancy increases, the momentum is typically enough to keep the unreeling going (at least to 100 m).* *Sometimes spacers are used or required by the water authority. But to reach an effect of a maximum of only 7% increasing the borehole thermal resistant, spacers have to be installed at least every meter. Based on this and the negative practical experiences they cause for the grouting, spacers are not recommended.*
Japan	*Usually, a tube reel for single U-tube or two reels for double U-tubes is used. They are hung up at the straight up side of the target borehole by the small crane or a reel stand.*
Netherlands	*Typically from a reel, waterfilled and with weights.*
Sweden	*Specially made reel equipment with a motor. Pressure tested and filled with water prior to insertion. Balanced by a bottom weight. Left with a slight weight and hanging somewhat above the bottom of the hole.*

Turkey	*Same (Typically from a reel, waterfilled and with weights. Initially a momentum is created, and later when buoyancy increases, the momentum is typically enough the keep the unreeling going (at least to 100 m)).*

Table A2-11: Borehole heat exchangers – Leakage test

Belgium	*It is mandatory to perform 3 tests: before mounting the borehole exchanger, after backfilling the borehole and after the installation of the whole system. The tests are performed with water according to the environmental standards.*
Denmark	*After insertion, before grouting. Water filled to an overpressure (4 bars?) and left for a couple of hours (while getting ready for grouting).*
Finland	*Pressure test is done after installation.*
Germany	*Up to now nobody knows how to do it in a really correct way without causing other / bigger problems as increasing the system permeability (pipe + backfilling).* *In practice the drillers fill the pipes with water to an overpressure and measure the pressure(-loss) with a manometer. For self-protection they do it usually before insertion in the borehole while hanging on the reel, during insertion and after grouting.*
Japan	*When the fresh-water drilling is applied for drilling, empty U-pipe is installed. In this case the air leakage test is done using pressed air up to 0.5 MPa. Usually, no change of the pressure for 24 hours is required. For the big project, pressure gauges are always attached by staring the pipe connection works to the machine to check and confirm the no leakage.* *When the mud-water drilling is applied for drilling, a water filled U-pipe is installed. In this case the water leakage test is done using pressed air up to 0.2 MPa. Usually, no change of the pressure for 24 hours is required. For the big project, pressure gauges are always attached by staring the pipe connection works to the machine to check and confirm the no leakage.*
Netherlands	*There is a protocol for leakage and strength testing that also takes into account the plasticity of the material -> increasing pressure in 2 – 3 steps up to working pressure of 2 – 3 bars. Leaks are easier found on low pressure test, not on high pressure test. Pressure drop at each stage not to exceed 0.1 bars after 1 – 2 hours.* *Strength test at at least 0.8 times the nominal pipe pressure.* *Flushing and testing on complete system (horizontal connections). Large systems may test individual loops and loop sets.* *System left pressurized & with manometer.*
Sweden	*Before and after insertion, commonly at 5 bars till stable pressure drop is reached. Repeated again for the parts of, or total system during degassing. There is yet no standard procedure in Sweden.*
Turkey	*Leakage test is performed before insertion and after.*

Table A2-12: Borehole heat exchangers – Test protocol of leakage test

Belgium	*Protocol has to safeguarded*
Denmark	*Not handed over unless stated in tender documents (typically only for larger installations)*
Finland	*No specific protocol.*
Germany	*Has to be handed out*

Japan	-
Netherlands	*See above, documentation needs to be handed over.*
Sweden	*Normally a protocol over self-controls by the contractor that is part of the documentation (only larger systems)*
Turkey	*Same (Not handed over unless stated in tender documents (typically only for larger installations))*

Table A2-13: Borehole heat exchangers – Flow test

Belgium	*Guideline n°259: deviation < 15%*
Denmark	*Done at the time of TRT or when the BHE is ready to be connected with the HP.*
Finland	*Not normally done. For larger scale systems done with TRT.*
Germany	*In practice, the flow test is done after grouting by connecting each u-pipe to the water supply and let the water flow. If water is coming out in a water jet as expected, the flow test was successful. This is also good for cleaning the pipe (flushing) so that no dirt (sand, backfilling, soil, PE-chips/cuttings etc.) is remaining. Afterwards the pipes have to be closed tightly to avoid pollution of them until the horizontal pipes are connected.*
Japan	*A flow test is not don after installation of the U-tube in Japan.*
Netherlands	*No formal rules.*
Sweden	*Depends on the contract. Sometimes a flow test to find out the pressure drop at different flow rates is required. In other cases the pressure drop is calculated.*
Turkey	*Same (Done at the time of TRT or when the BHE is ready to be connected with the HP.)*

Table A2-14: Borehole heat exchangers – Horizontal connections and pipe installation

Belgium	*Mostly electrofusion welding. Horizontal connections at minimum depth of 0.8 meters, on clean sand bed.*
Denmark	*Welding or by joints/gaskets. Joints in the horizontal part of the installation must be accessible for inspection (inspection well/manhole). Pipes must be placed in sand without stones.*
Finland	*BHE's connected to manifold(s). Welding or by joints/gaskets. Joints in the horizontal part of the installation is recommended to be accessible for inspection (inspection well/manhole). It is recommended that pipes must be placed in sand without stones.*
Germany	*Similar to DK*
Japan	*All connections of the small pipes are done by electrical fusion sockets given an identification bar code in factory. But for the bigger pipe, an automatic butt welding method is applied on-site.* *https://to-yo-kikou.com/rental/ef_hf.html*
Netherlands	*Electrofusion welding. Mechanical couplings and metal parts not allowed below ground. Horizontal connections at minimum depth of 0,8 meters, on clean sand bed.*
Sweden	*Welding of joints/gaskets must be performed by certificated plastic welder. Thermal extension of plastic pipes is not always considered, but normally coped with placing the pipes with a*

	slight sinus curve. Pipes have rest and surrounded by a layer of sand. Sharp edged particles are not allowed. Documented by photographs or pre-inspection.
Turkey	*Inspection well /manhole isn't common. But pipes must be placed in sand (sand thickness approximately 10 cm)*

Table A2-15: Borehole heat exchangers – Test protocol of flow test

Belgium	Test protocol as self-control by the contractor is part of the final documentation
Denmark	Only made if required by tender documents (typically only in bigger installations)
Finland	Only made if required by tender documents (typically only in bigger installations)
Germany	Required by VDI 4640
Japan	In many cases, after all connections have been done, pressure test is carried out at the header of the heat source side loop or at the machine room. After connecting to the heat pump units, flow test is carried out. Engineers check the proper flow rate and reasonable pressure drop of the loop including pressure. Also, distributed flow rates to each BHX at the heat source side header are regulated using the float type flow checker. When the inverter-controlled pump is used, flow rates under specific frequencies of the supply power are checked. Particularly, special attention should pay the attention at the minimum frequency whether stop of the flow will occur or not.
Netherlands	See above.
Sweden	Test protocol as self-control by the contractor is part of the final documentation (only larger systems)
Turkey	Same (Only made if required by tender documents (typically only in bigger installations))

Appendix 2-5 – Answers on Filling or Grouting Process

Table A2-16: Filling or grouting process – Grouting concept

Belgium	*All BHE boreholes must be sealed from bottom to top with a grout* *The material used to seal the borehole needs to have a low permeability and must be safe for freezing. For ATES, aquitards have to be sealed. (commonly with clay pellets).*
Denmark	*All BHE boreholes must be sealed with a grout that prevents groundwater flow in the borehole. The statutes and legislation states that any penetrated aquitards must be grouted with a "low-permeable" grout in order to seal the perforated barrier. Sandy layers may be backfilled with sand. The boreholes must also be sealed off at the top. Local authorities may (and often do) demand a complete grout filling.*
Finland	*No need for grouting due to crystalline bedrock. Grouting is used only a few times when boreholes have been drilled on the area of aquifer which is mapped for communal water supply (groundwater areas).*
Germany	*The backfill has to ensure the heat transport between the soil and the heat transfer fluid.* *It must protect the double U-tubs and seal the borehole to prevent a possible input of pollutants as well as a leakage between different aquifers.* *The backfill has to assure an impervious and permanent physical and chemical stable integration of the u-tubes to the surrounding soil after the hardening process.*

	It has turned out that the mixing process has large influence on the result. The formula for the "ideal" grout is still sought after.
Japan	*In Japan, there is no regulations and restrictions of sealing the boreholes as GHXs by using grouting. So that, drillers generally drop the course silica sand (usually No. 3 silica sand which has the particle size distribution of 3.3 mm – 0.8 mm) from the ground surface to fil the cavity of the borehole. Sometimes mortal cement mixture is poured top 5 – 10 m in the borehole after filling the course silica sand to prevent the cave-in in the ground surface of the borehole.*
Netherlands	*The only requirement is that water-separating layers (aquitards) are restored. This means that you need to know where they are beforehand, that you need to be able to note them during drilling and that you need to verify at what depth the sealing material is installed (e.g. working with a filling-pipe). The material used to seal needs to have low permeability. In practice the driller has a choice to either backfill in a layered fashion or to backfill the borehole completely with grout. Bentonite grout and (more common) pellets are used. Grout with cement is normally not used. A seal at the top (at least 0,5 m) is required in all cases. The permeability needs to be less than 10-9 m/s. Clay from the drilling itself cannot be used. There is a fairly detailed description of different aspects in the protocol.*
Sweden	*Only a fraction of the boreholes must be grouted (or sealed off one way another). This is required in areas where groundwater is used for drinking water. The grouting is a demand that will be stated in the permit. Thermal enhanced grout is commonly used if full hole grouting is required.*
Turkey	*For preventing groundwater flow in borehole, the grout is prepared on site or prefabricated mixing at specified rate in all boreholes. There is no statutes or legislation related to grouting.*

Grouting needs and grouting properties depend on geology concerning permeability and thermal conductivity.

Table A2-17: Filling or grouting process – Grouting vs. geology

Belgium	*Grouting is mandatory almost all over Flanders*
Denmark	*All BHE boreholes must be sealed with a grout that prevents groundwater flow in the borehole. The statutes and legislation states that any penetrated aquitards must be grouted with a "low-permeable" grout in order to seal the perforated barrier. Sandy layers may be backfilled with sand. The boreholes must also be sealed off at the top. Local authorities may (and often do) demand a complete grout filling.*
Finland	*See above*
Germany	*Grouting is mandatory almost all over Germany. In some areas with e.g. soils that are hydrologically seen as unproblematic (such as the first aquifer in the Upper Rhine Graben) exceptions are possible. Often this depends not only on the geology but also on the approving authority responsible for the area.*
Japan	-
Netherlands	*N.a.*
Sweden	*At least 90 % of all boreholes are drilled into crystalline rocks, most commonly granite and gneiss. The overburden is drilled by a steel casing at least 2 meters into the crystalline rock. Before drilling the open hole the casing is sealed off by grout, see above. The same method is used in areas with sedimentary rocks (commonly limestones, shale and consolidated sandstones). In rare cases the rocks contains more than one aquifer. In these*

	cases the borehole must sealed in a way that mixing of water from different aquifers is avoided.
Turkey	-

Table A2-18: Filling or grouting process – Alternative sealing

Belgium	*The permeability needs to be less than 10-8 m/s. Mostly cement-bentonite grouts and clay pellets are used*
Denmark	*The only requirements are related to the sealing properties. So far only bentonite based grouts has been used in DK. The legislation demands "impermeable materials". This means that other materials than bentonite, with the same permeability properties, may be allowed.*
Finland	-
Germany	*In almost all cases a cementous grouting slurry is used. Rarely swelling clay pellets are used for grouting in case of fissures in combination with groundwater. Thermal enhanced clay pellets and a special pumping device have been developed.* *The permeability of the backfill needs to be <= 10-10 m/s according to the VDI 4640 guideline. This value, however, is under discussion in Germany.*
Japan	-
Netherlands	*The permeability needs to be less than 10-9 m/s. Clay from the drilling itself can not be used.*
Sweden	*Alternative sealing are by different forma of sealing plugs that are attached to collector. These are used to avoid salt or brackish water to enter higher levels in the boreholes, but also to seal off potential leakage between aquifers.*
Turkey	-

Table A2-19: Filling or grouting process – Grouting method

Belgium	*It is mandatory that the backfilling pipes are pulled while filling from bottom to top.*
Denmark	*No specifications, but pumping in grouting pipe is typically applied. Some pump from the bottom during the whole process, others retract the grouting pipe during filling. Often problems with pipe-burst – particularly when pumping from the bottom.*
Finland	-
Germany	*Filling from bottom to top is common. Typically the grouting slurry has a higher density than the other fluids which may be in the borehole (water, drilling mud). Therefore the grouting replaces these fluids through the top of the borehole. The grouting procedure is finished when the density of the fluid leaving the borehole is equal to the injected one.* *Typically the grouting pipe (regular PE-pipe) is installed in the borehole together with the U-pipes and should remain in the borehole. If required due to the hydrogeology or the borehole depth, several grouting pipes of different length may be installed.* *Sometimes the backfilling pipes are pulled while filling but this is not recommended in VDI 4640. Some drillers use steel rods (verfüllgestänge) for the grouting. These have to be retracted during the grouting.*
Japan	-

Netherlands	*In practice the driller has a choice to either backfill in a layered fashion or to backfill the borehole completely with grout. Bentonite grout and (more common) pellets are used. Grout with cement is normally not used.* - *Pumping of bentonite slurry with tremie pipe below the surface of borehole filling.* - *Backfilling with larger diameter pipe, the pipe is retracted to just above level in borehole, used with gravel / bentonite pellets.*
Sweden	*For grouting casing, see above. For full hole grouting a tremie pipe is used to pump down the grout from bottom to top. For deep holes the grouting must be performed in two or even three steps. There is no manual available in Sweden.*
Turkey	*Same (No specifications, but pumping in grouting pipe is typically applied. Some pump from the bottom during the whole process, others retract the grouting pipe during filling. Often problems with pipe-burst – particularly when pumping from the bottom.)*

Table A2-20: Filling or grouting process – Grouting materials

Denmark	*Industrial mixtures are normally used. But the technical demands are only related to the properties, not the production.*
Sweden	*There are several thermal grouts on the Swedish market. However, the knowledge concerning grout properties is remarkable low.* *There quite recent examples that bentonite pellets have been used as a back fill in deep boreholes.*
Germany	*Industrial premixed grouting materials are required. These are delivered to the construction site in bags or silos. They have to be / should be mixed in an appropriate mixer with water at the required ratio and pumped into the borehole. Site mixtures (e.g. cement, bentonite and sand) are not permissible anymore. Most of the grouting materials are thermally enhanced due to additives like quartz-sand or graphite.*
Netherlands	*Industrial mixes used. Material needs to comply with rules about quality of building materials.*
Finland	-
Turkey	*Both industrial mixture and onsite preparation at specific rate are common used.*
Belgium	*Mainly industrial mixes used.*
Japan	-

Table A2-21: Filling or grouting process – Material contents

Belgium	*Mix of bentonite-cement-quartz sand, otherwise clay pellets and sand.*
Denmark	*Varies with the brand. The Danish brand are using quartz sand as thermal enhancer.*
Finland	-
Germany	*Varies with the brand. The German brands are using graphite, quartz sand or other minerals as thermal enhancer.* *Other contents are: Cement (often sulfate resistant), bentonite/clay and filling materials (grinded rock)* *In some materials additives like concrete liquefiers are used (reduces needed water content and increases flow characteristics).*

	In Baden-Württemberg automatic grouting control is mandatory. The most common method therefore (roughly 80 % or more of the boreholes) is the use of magnetic doped material in combination with susceptibility measurements (CemTrakker). Magnetite is used as doping material. *In others parts of Germany doped materials are used rarely.*
Japan	-
Netherlands	-
Sweden	*The thermal enhanced components are mainly fine grained quarts sand and/or graphite.*
Turkey	*Quartz sand is used for thermal enhancing. Varies with the brand*

Table A2-22: Filling or grouting process – Mixing

Belgium	*Mixers are frequently part of the drilling machine.*
Denmark	*Some use batch mixing but most use compulsory mixers. It is assumed, but not tested, that the compulsory mixers actually mix powder and water in the correct ratio. This has been observed not to be the case in at least one situation.*
Finland	-
Germany	*The main criterion for the mixing technology is the rotational frequency. Various mixers give very different results. In Germany colloidal mixers are frequently used. This technology assures an optimal mixing procedure. By using such batch mixers with high rotational frequency the mixing process and the pumping process are separated and sequential.* *Other technologies (continuous mixer, mixing pond) are also in use.* *Manufactures ought to recommend the most appropriate mixing method in their documentation.*
Japan	-
Netherlands	*One company (Terratech) has developed a method to backfill with pellets & install the heat exchangers to the outer diameter of the borehole to improve thermal characterstics.* *In other cases bentonite mixers are used.*
Sweden	*There are no special mixers other that the ones used for grout injection in construction of tunnels etc.*
Turkey	*Same (Some use batch mixing but most use compulsory mixers. It is assumed, but not tested, that the compulsory mixers actually mix powder and water in the correct ratio. This has been observed not to be the case in at least one situation.)*

Table A2-23: Filling or grouting process – Chemo-physical properties

Belgium	*Not checked.*
Denmark	*Generally not checked. If the data sheet claims permeability is low enough and thermal conductivity high enough, then that's it. Grout that has reacted with moisture prior to mixing has been observed.*
Finland	-

Germany	*Data sheets (kf, bending tensile strength, compressive strength, thermal conductivity, sulfate resistant's, frost-thaw behavior, etc.) of the producers, but there is no standard, thus they differ sometimes very much. On the construction site the density measurement is required and marsh-time measurement is recommended.*
Japan	-
Netherlands	*Not checked.*
Sweden	*The supplier of grouts provide information on density (at certain water content) strength and permeability after hardening. These data are claimed to be defined at laboratory tests.*
Turkey	*Not checked*

Packers or stockings can be used in these cases. The driller must be prepared.

Table A2-24: Filling or grouting process – Loss of grouting fluid

Belgium	-
Denmark	*This would normally be handled earlier as a loss of drilling fluid.*
Finland	-
Germany	*If the amount of grouting fluid used exceeds the theoretically calculated amount by a factor of 2, the grouting process has to be stopped and the local authorities have to be informed as soon as possible.* *Potential measures to solve the problem: Use a different grout with significantly high density, use sand or gravel in the zone of high fluid losses, packer, stocking etc..*
Japan	-
Netherlands	*This would normally be handled earlier as a loss of drilling fluid.*
Sweden	*No experiences available*
Turkey	*Same (This would normally be handled earlier as a loss of drilling fluid.)*

Table A2-25: Filling or grouting process – Geophysical measurements after grouting, in case of emergency

Belgium	*Sometimes TR-tests occur*
Denmark	*TRT and temperature measurements has been used (in a court case) as indicator of grouting/no grouting. Gamma-gamma would have been useful.*
Finland	-
Germany	*Classical TRT and enhanced TRT are used. Also so called "short-time TRT's are used to check the quality of grouting. Gamma-gamma is sometimes used. In research and development are ultrasonic, electromagnetic waves and fiber optic measurement systems.* *Cemtrakker may be applied during the grouting process.*

	In BW susceptibility measurements in combination with automatic grouting control are often used during the grouting process. In boreholes where an automatic grouting control with susceptibility measurement takes place additional control measurements after the grouting process are not mandatory, but recommended by the authorities. *A comparison of the accuracy and validity of different measurement methods has been done in the research project EWSplus. The results can be found in the final project report (Abschlussbericht zu dem Forschungsvorhaben EWSPLUS – Untersuchungen zur Qualitätssicherung von Erdwärmesonden – Weiterentwicklung der Erdwärmesonden-Technik, published by Solites). http://solites.de/download/literatur/2013-09-10%20EWSplus%20Abschlussbericht.pdf*
Japan	-
Netherlands	*Not normally.*
Sweden	*No experiences available*
Turkey	*TRT test is common, but temperature measurements are not common.*

Table A2-26: Filling or grouting process – Doped grouting

Belgium	*Enhanced grouts are frequently used*
Denmark	*Not known*
Finland	-
Germany	*Magnetite is used as doping material. Zirkon sand was examined but it was not very successful because the low contrast of the gamma ray log compared to the underground makes an initial measurement necessary.* *In BW doped material with magnetite is used in roughly 80 % or more of the boreholes in combination with automatic grouting control.*
Japan	-
Netherlands	*Not normally. Sometimes "enhanced" grouts may be used.*
Sweden	-
Turkey	-

Table A2-27: Filling or grouting process – Life expectancy of grout

Belgium	-
Denmark	*Forever?*
Finland	-
Germany	*Hard to say!*

Japan	-
Netherlands	*Geological*
Sweden	*No experiences available*
Turkey	-

Table A2-28: Filling or grouting process – Hardening time of grout

Belgium	*No specifications*
Denmark	*No requirements. Normally the boreholes will be made early in a project and connection to HP and completion inside the building is done last and therefore the risk of accidentally freezing the borehole within a month of its completion is quite small.*
Finland	-
Germany	*Also no general requirements. Heavily material depending (which kind of cement, age of cement, amount of cement, water to cement ratio, etc.) and depended on the mixing procedure. Likely from days to weeks. For strength measurements and so on the hardening time is 28 days. The complete hardening time is likely ~100 days (material depended).*
Japan	-
Netherlands	*Usually no hardening. If a TRT is considered, waiting time increases from one week to about 3 weeks.*
Sweden	*Have not been measured in this type of application. Standard cement takes approx. 2 days to harden underground.*
Turkey	*Same (No requirements. Normally the boreholes will be made early in a project and connection to HP and completion inside the building is done last and therefore the risk of accidentally freezing the borehole within a month of its completion is quite small.)*

Note: Pipes add to permeability. Field not fully investigated.

Table A2-29: Filling or grouting process – System hydraulic permeability

Belgium	*Mandatory < 10-8 m/s*
Denmark	*The permeability is expected to be "0" but it is not tested.*
Finland	-
Germany	*The VDI 4640 Vol. 2 gives first recommendations. This subject is still under intensive investigation. A general rule is that the system permeability should at least be in the order of magnitude as the underground permeability even after several freezing cycles.* *kf ~ 10-8 - 10-9*
Japan	-
Netherlands	*Not tested.*

Sweden	*According to the suppliers > 10-6 m/s*
Turkey	*Same (The permeability is expected to be "0" but it is not tested.)*

Appendix 2-6 – Answers on Additional Methods

Table A2-30: Additional methods – Geophysical tests

Belgium	*No standard protocol only for research purposes.*
Denmark	*Not as standard, only for research purposes.*
Finland	*Not normally done.*
Germany	*Not as standard. Sometimes measurements has to be done (magnetic response or gamma-gamma and temperature in BHE and upstream in the groundwater)*
Japan	*Very seldom. In many cases, an operator just checks the cuttings and make the geologic column.*
Netherlands	*Not as standard, only for research purposes.*
Sweden	*Functional control of the system is required to have the system approved at the final inspection (only larger systems)*
Turkey	*Geophysical test is not a standard, same as DK only can be implemented for research purposes.*

Table A2-31: Additional methods – TRT

Belgium	*Not done as standard. Typically for big installations*
Denmark	*Not done as standard. Typically for larger installations. Only one contractor in DK.*
Finland	*Not done as standard even though nowadays almost normally done for large (over 20 boreholes) installations. Typically for larger installations. Several private contractors plus GTK provides TRT service.*
Germany	*Equal to DK*
Japan	*Generally, standard heating TRT is carried out according to the basics of the IEA ECES ANNEX21 protocols. In some cases, the history matching method or Horner plot analysis method using temperature recovering data after stop heating.*
Netherlands	*Not done as standard. Typically for larger installations. More contractors. Preferred test with cooling and heating (not heating only).*
Sweden	*Normally done for larger projects (> 10 boreholes)*
Turkey	*In small projects such as having 10-12 boreholes, not as standard. For larger installation having 20 or more boreholes is common. Two contractor in Turkey, both of them in Universities.*

Table A2-32: Additional methods – Wireless probe method

Belgium	*No*
Denmark	*No*
Finland	*No. Temperature measurements have been done for research purposes from few boreholes*
Germany	*Rarely used, no standard*
Japan	*No. It is still just for scientific interesting.*
Netherlands	*N.a.*
Sweden	*No*
Turkey	*No*

Table A2-33: Additional methods – Fiber optics

Belgium	*Yes, but so far only in scientific projects*
Denmark	*No. It is being introduced for research purposes.*
Finland	*Temperature measurements have been done for research purposes from few boreholes with DTS system by GTK.*
Germany	*Rarely used, no standard*
Japan	*No. It is still just for scientific interesting.*
Netherlands	*Only for research.*
Sweden	*Yes, but so far only in scientific projects*
Turkey	*No*

Table A2-34: Additional methods – Design adjustment due to parameter change (Heating load, TRT results)

Belgium	*No, sometimes more or less boreholes according TRT test*
Denmark	*There are known cases where it would have been useful…*
Finland	*No*
Germany	*Maybe not known, but will occur.*
Japan	*In some cases, number of the BHX may change according to the TRT result. Especially, when the measured average effective thermal conductivity λe is much larger than expected due to high ground water flow, number of the BHX is redesigned and might be reduced to cut down the construction cost.*

	Contrarily, when the H/C space or H/C load expected to be increased, redesign and number of the BHEXs are increased, but according to the building owner's decision.
Netherlands	*? not known but will occur.*
Sweden	*Not only redesign, but also reconstruction of plants that fails. Only rarely*
Turkey	*No*

Appendix 2-7 – Answers on Supervision of the Construction Process

Table A2-35: Supervision of construction process

Belgium	*No real supervision, but in big projects engineering companies do the design and follow up*
Denmark	*Bigger systems will normally have a consulting engineer attached for supervision during the construction phase. For smaller systems it is very much up to the buyer/house owner.*
Finland	*Similar than in Denmark.*
Germany	*A regulation of whether and how a construction supervision hast to be done does not exist. Usually bigger constructions are supervised by an expert as independent third party, usually those who have designed the BHE-field.* *HOAI: The fee schedule for architects and engineers (Die Honorarordnung für Architekten und Ingenieure) provides a special performance stage (phase, Leistungsphase) with "scope of work" (Leistungsbild) and "schedule of fees" (Honorartabelle) for the construction supervision.* *AHO: Since 2011 there's own scope of work with schedule of fees specifically for "planning services in the field of shallow geothermal energy" within the framework of the AHO – series (committee of associations and chambers of engineers and architects for the honorary order e.V., issue 26)* *Exception Bavaria PSW: In the State of Bavaria a private expert in water management (PSW = Privater Sachverständiger der Wasserwirtschaft) is to hire at the latest for completion at the beginning of construction.*
Japan	*1) Construction supervisions are occupied in each construction layer:* *a) Whole project; Architect and engineer from architect office or consulting company.* *b) Whole construction site management; Licensed engineer from construction company* *c) HVAC including GSHP system: Licensed engineer from HVAC engineering company* *d) BHX and drilling site; Licensed or certificated engineers or operators from drillers*
Netherlands	*No formal supervision.*
Sweden	*Normally not done for turnkey projects. Faults will be noted in the protocol of the inspector, who also state when the faults shall be corrected*
Turkey	*Same (Bigger systems will normally have a consulting engineer attached for supervision during the construction phase. For smaller systems it is very much up to the buyer/house owner.)*

Appendix 2-8 – Answers on Start-Up

Table A2-36: Start-up – Functional check

Belgium	*Very much up to the supplier of the HP. No standard procedure in relation to BHE*

Denmark	*Very much up to the supplier of the HP. No standard procedure in relation to BHE. Problems with poorly mixed brine/water have been seen.*
Finland	*Very much up to the supplier of the HP. No standard procedure in relation to BHE.*
Germany	*HP: Function test HP according to manufacturer's instructions. BHE-Field + HP: Flow and leak test of the entire system (visual inspection). Adjustment of the circuit control valves with HP circulating pump on the calculated target volume flows in the individual BHE's. The basis for this should be the calculation from the hydraulic pressure loss to optimize the total system. Target should be a turbulent flow through the BHE's (to increase the heat extraction) at full load of the heat pump and a laminar flow in the connecting pipes (to reduce the hydr. pressure loss). Acceptance: After performing the function test, flow and leak test and adjustment of flow rates through the executing company, (if necessary under supervision) an acceptance date of the entire system should be made. Thereof a protocol has to be written and if necessary any faults (rework, subsequent work) have to be noticed.*
Japan	*Header of the heat source side; checked by looking and observation of the little effusion of the thermal medium from the connections In the machine room: flow rates, pressure and pressure drop, temperature of temperature differences of the thermal medium. Stability of the voltage and frequency of the supply electric power and amperage and power consumption of pumps. Strange noise of vibration of pumps Heat pump unit: Evaporating pressure and temperature, condensing pressure and temperature, discharging side temperature of the compressor, Stability of the voltage and frequency of the supply electric power and amperage and power consumption of the heat pump unit. Strange noise of vibration of the compressor.*
Netherlands	*There are some requirements with regard to flow balancing: 5% max. difference between sub-systems. There is little about actual commissioning and running the final heat pump system, this is usually the responsibility of the heat pump installer.*
Sweden	*Most large projects, constructed on turnkey projects are checked at start of operation, after 2 years and after 5 years as guaranty inspections of both functionality and performance.*
Turkey	*Functional check is performed by HP supplier, not standard procedure.*

Table A2-37: Start-up – Comissioning

Belgium	*Every 2 years for big systems and those within drinking water protection areas, every 5 years for others.*
Denmark	*Typically pressure test, not performance test. Bigger systems (with proper tender documents) will typically have 1 and 5 years guarantee inspections.*
Finland	*No formal procedure.*
Germany	*No standard inspection procedure. Depending if the tender documents require.*
Japan	*Measurement items: flow rates, pressure and pressure drop, temperature of temperature differences of the thermal medium. Stability of the voltage and frequency of the supply electric power and amperage and power consumption of the heat pump unit and pump. Check the heat balance; seasonal heat extraction amount from the ground and seasonal heat injection amount to the ground, long term changes of the return temperature from the BHX and ground temperature at the certain points in the ground.*
Netherlands	*Annual check of heat pump, check on antifreeze level and quality. Advice is to e.g. also check filters.*

Sweden	*According to the general rules in ABT06 or AB04, see under point 2.0*
Turkey	*It depends on guarantee period (in tender document) typically 2 and 5 years for bigger systems. There is no performance test. Pressure test is common in every year.*

Table A2-38: Start-up – Instruction of operator

Belgium	*No standard*
Denmark	*No standards for this.*
Finland	*No standards for this*
Germany	*Recommended by VDI 4640.*
Japan	*Daily operation; Q&A and simple treatments for the accidents of problems.* *- flow rates, pressure and pressure drop, temperature of temperature differences of the thermal medium. Stability of the voltage and frequency of the supply electric power and amperage and power consumption of the heat pump unit and pump.* *Especially, pay attention to the low limit of the supply temperature to GHX of the heat source side during heating season. In general, it is around -10 oC instantaneously to avoid the freezing in the evaporator of the heat pump unit. In addition, the high limit of the supply temperature to GHX of the heat source side during cooling season. In general, it is around 35 oC to 40 oC instantaneously.*
Netherlands	*Hand over documentation of the system, including documentation of design, efficiency calculation and assessment of interaction with adjacent systems. Hand over to client and also to authorities with system description.* *Large systems may have training of client as well.*
Sweden	*Will always be a part of documentation supplied by the contractor and will be checked by the inspector*
Turkey	*There is no standard*

Table A2-39: Start-up – Documentation

Belgium	*Normally instruction manuals of heat pump handed over.*
Denmark	*Normally handed over, but often with a structure and language that a non-expert will be unable to understand.*
Finland	*Normally instruction manuals of heat pump handed over. No detailed documentation.*
Germany	*A complete documentation of the approval and implementation planning, including all product data sheets, acceptance reports has to be handed over to the client (owner). Deviations from the implementation planning during the construction phase must be documented. The documentation of the construction has to be done according to the restrictions by the legal water permit. This documentation has to be send to the water authority and the client.* *Nature, scope and quality of the documentation varies considerably and also depend on the size of the construction project.*

Japan	*a) small system without logging function; it is recommended to record observation data on the sheet once at a month during HP operation; flow rates, pressure and pressure drop, temperature of temperature differences of the thermal medium. Voltage and frequency of the supply electric power and amperage and power consumption, thermal output and extracted/released heat of HP unit. As a performance, results of COP is also calculated. Also, conditions of noise of vibration of HP units and pumps are checked and recorded.* *b) large system with logging function; All measured data is recorded, but it is recommended to print out on the monthly summarized data sheet once at a month.* *They include flow rates, pressure and pressure drop, temperature of temperature differences of the thermal medium, voltage and frequency of the supply electric power and amperage and power consumption, thermal output and extracted/released heat of HP unit. As a performance, results of COP is also calculated. Also, conditions of noise of vibration of HP units and pumps are checked and recorded.* *- long term changes of the return temperature from the BHX and ground temperature at the certain points in the ground.*
Netherlands	*Hand over documentation of the system, including documentation of design, efficiency calculation and assessment of interaction with adjacent systems. Hand over to client and also to authorities with system description.*
Sweden	*Will be delivered in several paper files and on USB stick. Will contain description and function of the system, description and manufacturer of main components, protocols of self-controls, etc. as well as instruction for maintenance and operation.*
Turkey	*Same (Normally handed over, but often with a structure and language that a non-expert will be unable to understand.)*

Appendix 2-9 – Answers on General Questions

Table A2-40: General questions – Key performance indicators

Belgium	*Pay back, investment cost, maintenance*
Denmark	*Construction cost, performance or user friendliness?*
Finland	*Pay-back time, overall costs, performance, maintenance need.*
Germany	-
Japan	*a) Performance of BHX: Unit heat exchanging rate; [W/(m·K)]* *-meaning; heat exchanging rate per unit length of the BHX and per unit temperature difference between natural ground temperature and average heat extraction/ injecting temperature during a peak day or peak month or season.* *b) Performance of GSHP system; COP and SPF* *- Definition of COP: COP (Coefficient of performance) = [Thermal output for H/C (W)] / [Electrical power consumption of the heat pump unit (or compressor) (W)]* *- Definition of SPF (Seasonal Performance Factor) = [Seasonal total thermal output for H/C (MJ)] / [Seasonal total electrical power consumption of the heat pump unit (or compressor), circulating pumps and other additional devices (MJ)]* *c) Stability of the BHX: Annual temperature changing rate [K/year]* *- Definition;([Annual average fluid temperature of the heat source side of the current year (oC)] – [Annual average fluid temperature of the heat source side of the previous year (oC)]) / [time (year)]*

Netherlands	-
Sweden	*Quality of components is stated in tender documents. Quality of work is checked by the contractor himself and finally by the inspector.*
Turkey	*Same (Construction cost, performance or user friendliness?)*

Table A2-41: General questions – Safety margins

Belgium	-
Denmark	*Depending on the supplier.*
Finland	*Depending on the supplier.*
Germany	-
Japan	*Maintain proper performance and stable operation without failure of the ground temperature;* • *Estimated H/C loads are not so matched to the realistic H/C load due to the different usage of the room and building compared to the design condition and changes of whether condition by each year. So that, actual extracted and injected heat amounts are fluctuated each year.* • *From the optimistic point of view, because ground has huge heat capacity and water movement exist in the ground layer, above mentioned fluctuation may be absorbed for the long year.* • *However, it is fact that excessive imbalance of heat extraction from the ground and heat injection to the ground cause annual averaged temperature lowing or rising gradually.* • *If the steady state of the ground temperature is not reached, an additional control to set a limit to heat extraction or heat injection must be added in order stabilize fluid temperature during H/C operation. Otherwise, operation of GSHP will be failed.*
Netherlands	*Discussed in the training for the certification: what constitutes a robust design? Express safety margin as added temperature limit to design in view of uncertainties.*
Sweden	*Redundancy, if any, is stated in the tender documents. Applies mainly to larger systems.*
Turkey	*Same (Depending on the supplier.)*

Appendix 3 – Country Answers Given by the Experts for Subtask 3

Appendix 3-1 – Answers on Monitoring

Table A3-1: Definition of the size of GSHP system and purposes of monitoring for BHEs and GSHP systems

Size of GSHP system	Cooling and Heating Capacity			Purpose of monitoring for BHEXs and GSHP systems
Small	<	50 China 12 Denmark 20 Japan ?? Netherlands 20 Sweden 30 Turkey 30 Gernany (VDI) 50 (Gerany HP corp.)	kW	**· Energy performance of GSHP systems (C) or Energy performance (energy, ecologically, economically) (G)** **· Qualitative performance of BHEX (temperature limits not violated) (G)** **·That its works properly or Reliability sytem or Checking pressure in BHEX and functionality of GSHP (S, T, D)** **· Checking reliability of BHEXs and GSHP systems (J)**
Medium	<	50 - 528 China 12 - 35 Denmark 20 -80 Japan ??? Netherlands 20 - 80 Sweden 30 - 100 Turkey 20 - 1500 Germay	kW	**·Energy performance of GSHP systems (C, S, T, D, J)or Energy performance (energy, ecologically, economically) (G)** **· Qualitative performance of BHEX (temperature limits not violated) (G)** **·Stability of BHEXs and GSHP systems (C,)** **·That it works properly or Reliability sytem or Checking pressure in BHEX and functionality of GSHP (S, T, D)** **· Influence on ambient underground environment and groundwater (G)** **· Management and reliability of BHEXs and GSHP systems (J)**
Large	> =	528 China 35 Denmark 80 Japan ??? Netherlands 35 Germay 80 Sweden 100 Turkey 2000 Germany	kW	**· Annual management of heat in/out systems by variable operation modes (C, J)** **·Energy performance of GSHP systems (C, S, T, D, J)or Energy performance (energy, ecologically, economically) (G)** **· Qualitative performance of BHEX (temperature limits not violated) (G, J)** **·Influence of GSHP systems on the temperature of ambient underground or Thermal impacts (C, D) or Influence on ambient underground environment and groundwater (G, J)** **·That it works properly and meets intended energy performance or Checking pressure in BHEX and functionality of GSHP (S, T, D, J)**

Table A3-2: Needed level of monitoring

Level	Needed level of monitoring
I	Manual checking using low cost sensors including monitoring devices equipped in a heat pump unit (C, J) Sensors built into the GSHP unit, manual reading (D) Eletric power consumption (usually metered); pressure in BHEX (manually, e. g. monthly); minimum brine temperature & heat pump output temperature (heating supply) appr. SCOP and temperatures from heat pump internal measuring devices (low cost sensors); mostly manual checking (G) Manual checking on the monitoring devices of the heat pump unit (especially incoming BHE temp), and the pressure level of the BHE loop (S, T)
II	Display monitoring with data acquisition device using high resolution sensors (C, D, J) As above, but perhaps with higher frequency and sometimes with automated data collection (S) automated data acquistion device using high resolution sensors (T) Use of eletctric power meter and heat flow meters of high quality with connection to automatic data aquqistion; main BHEX temperatures (in and out); main heat pump temperatures (in and out); gound temperature along a BHEX or with a additional ground probe in a certain distance to BHEX, if nexessary (i. e. forced by regulations or authorities); graphical display and central data collection (and evaluation) on BEMS or other computer (G)
III	Graphical display monitoring with data acquisition/analysis system using high resolution sensors on BEMS (C, J) SCADA system on GSHP and additional sensors for monitoring environmental impact (D) As above, with automated data collection, but for larger systems a number of more parameters collected from the control/monitoring system (S) automated data acquistion device using high resolution sensors, environmental data (ground temperature changes) (T) Two levels are enough (G)

Table A3-3: Needed monitoring level for different size of GSHP system

	Size of GSHP system	Construction	Adjustment	Operation			energy transaction
				Sustainability of BHEX	COP and SPF	Environment assessment	
China	Small	I	I	I	I	I	I
	Medium	I	I	II	III	II	II
	Large	I	I	III	III	III	III
Swenden	Small	I	I	I	I	I	I
	Medium	I	I-II	I-II	I-II	I	I-II
	Large	I	II-III	II-III	II-III	I-II	II-III
Turkey	Small	I	I	I	I	I	I
	Medium	I	I	II	II	II	II
	Large	I	II-III	II-III	II-III	III	II-III
Germany	Small	??	??	I	I	-	??
	Medium	??	??	II	II	II	??
	Large	??	??	II	II	II	??
Denmark	Small		I		I	I	I
	Medium		I		II	I	II
	Large		II		III	III	III
Japan	Small	I	I	I	I	I	I
	Medium	I	I	II	II	II	II
	Large	I	I	III	III	III	III

Table A3-4: Applied sensor type and measuring time intervals

	Level	Needed sensors, monitoring device and data acquisition system								
		Liquid pressure [MPa] (p)	Liquid temperature [°C] (T)	Flow rate {L/min] (V)	Thermal output [kW] (Q)	Electric power [kW] (E)	Measuring interval [sec] (Δt)	Calorie [MJ] (ΣQ)	Ground temperature [°C] (Tg)	Ambient air temperature [°C] (Ta)
China	I	Pressure gauge	Thermistor on the pipe	Float type indicator	non	CT X Regular voltage	arbitrary time	non	non	Thermistor
	II	Pressure gauge	PT100 in the pipe	Ultrasonic type	ΔTVcpp	CT X Regular voltage	5min	ΔTVcpp ΣΔt	non	Thermistor
	III	Pressure gauge	PT100 in the pipe	Electro-magnetic type	ΔTVcpp	Electric power meter	10 min	Calorimeter	TC or PT100	Thermistor
Sweden	I	Manometer	HP display	?	?	?	?	?	none	Thermistor
	II	Manometer/Pressure gauge	HP display	?	ΔTVcpp	?	?	?	none	Thermistor
	III	Pressure gauge	PT100 in the pipes	Electro-magnetic type	ΔTVcpp	Electric power meter	?	?	Occasionally PT100	Thermistor
Turkey	I	Manometer	HP display	-	-	-	-	-	no	Thermistor
	II	Manometer/Pressure gauge	HP display	-	ΔTVcpp	-	-	-	no	Thermistor
	III	Pressure gauge	PT100 in the pipes	Electro-magnetic type	ΔTVcpp	Electric power meter	-	-	TC or PT100	Thermistor
Germany	I									
	II									
	III									
Denmark	I	Pressure gauge	PT100 at GSHP	Electro-magnetic type	ΔTVcpp	Not needed below 3 MWh/yr	arbitrary time		Not measured	Thermistor
	II	Pressure gauge	PT100 at GSHP	Electro-magnetic type	ΔTVcpp	Type not known	1 min/10 min		Not measured	Thermistor
	III	Pressure gauge	PT100 at GSHP and in ground/ground water	Electro-magnetic type	ΔTVcpp	Type not known	1 min/10 min		TC or PT100	Thermistor
Japan	I	Pressure gauge	Thermistor on the pipe	Float type indicator	non	CT X Regular voltage	arbitrary time	non	non	Thermistor
	II	Pressure gauge	PT100 in the pipe	Electro-magnetic type	ΔTVcpp	CT X Regular voltage	1 min/10 min	ΔTVcpp ΣΔt	non	Thermistor
	III	Pressure gauge	PT100 in the pipe	Electro-magnetic type	ΔTVcpp	Electric power meter	1 min/10 min	Calorimeter	TC or PT100	Thermistor

Table A3-5: Monitoring points (you may draw a red circle on the needed item)

	Level	Monitoring points										
		Ref. pressure [MPa] (p)	Liquid pressure [MPa] (p)	Liquid temperature [°C] (T)	Flow condition (on/off) or flow rate [L/min]	Thermal output [kW] (Q)	Electric power [kW] (E)	Calorie [MJ] (ΣQ)	Ground temperature [°C] (Tg)	Ambient air temperature [°C] (Ta)	Error Massages	Operating hours and on/off times
China	I		·GHX side	·GHX side S/R	·GHX side (on/off)					·GHX side	·GHX side pump ·Ref. low pressure	
		·Condenser side ·Evaporator	·H&C side	·Setting ·H&C side S/R	·H&C side (on/off)		·HP unit				·Ref. high pressure ·HP Unit ·H&C side pump	·HP unit
	II		·GHX side	·GHX side S/R	·GHX side	·GHX side	·GHX side pump	·GHX side	·GHX side	·GHX side		
		·Condenser side ·Evaporator	·H&C side	·Setting ·H&C side S/R	·H&C side	·H&C side	·HP unit ·H&C side pump	·H&C side				·HP unit
	II		·GHX side	·GHX side S/R	·GHX side	·GHX side	·GHX side pump	·GHX side	·GHX side	·GHX side		
		·Condenser side ·Evaporator	·H&C side	·Setting ·H&C side S/R	·H&C side	·H&C side	·HP unit ·H&C side pump	·H&C side				·HP unit
Sweden	I		·GHX side	·GHX side S/R	·GHX side (on/off)					·GHX side	·GHX side pump ·Ref. low pressure	
		·Condenser side ·Evaporator	·H&C side	·Setting ·H&C side S/R	·H&C side (on/off)		·HP unit				·Ref. high pressure ·HP Unit ·H&C side pump	·HP unit
	II		·GHX side	·GHX side S/R	·GHX side	·GHX side	·GHX side pump	·GHX side	·GHX side	·GHX side	·GHX side pump ·Ref. low pressure	
		·Condenser side ·Evaporator	·H&C side	·Setting ·H&C side S/R	·H&C side	·H&C side	·HP unit ·H&C side pump	·H&C side			·Ref. high pressure ·HP Unit ·H&C side pump	·HP unit
	II		·GHX side	·GHX side S/R	·GHX side	·GHX side	·GHX side pump	·GHX side	·GHX side	·GHX side	·GHX side pump ·Ref. low pressure	
		·Condenser side ·Evaporator	·H&C side	·Setting ·H&C side S/R	·H&C side	·H&C side	·HP unit ·H&C side pump	·H&C side			·Ref. high pressure ·HP Unit ·H&C side pump	·HP unit

	Level	Monitoring points										Operating hours and on/off times
		Ref. pressure [MPa] (p)	Liquid pressure [MPa] (p)	Liquid temperature [°C] (T)	Flow condition (on/off) or flow rate [L/min]	Thermal output [kW] (Q)	Electric power [kW] (E)	Calorie [MJ] (ΣQ)	Ground temperature [°C] (Tg)	Ambient air temperature [°C] (Ta)	Error Massages	
Turkey	I		·GHX side	·GHX side S/R	·GHX side (on/off)					·GHX side	·GHX side pump ·Ref. low pressure	
		·Condenser side ·Evaporator	·H&C side	·Setting ·H&C side S/R	·H&C side (on/off)		·HP unit				·Ref. high pressure ·HP Unit ·H&C side pump	·HP unit
	II		·GHX side	·GHX side S/R	·GHX side	·GHX side	·GHX side pump	·GHX side	·GHX side	·GHX side	·GHX side pump ·Ref. low pressure	
		·Condenser side ·Evaporator	·H&C side	·Setting ·H&C side S/R	·H&C side	·H&C side	·HP unit ·H&C side pump	·H&C side			·Ref. high pressure ·HP Unit ·H&C side pump	·HP unit
	III		·GHX side	·GHX side S/R	·GHX side	·GHX side	·GHX side pump	·GHX side	·GHX side	·GHX side	·GHX side pump ·Ref. low pressure	
		·Condenser side ·Evaporator side	·H&C side	·Setting ·H&C side S/R	·H&C side	·H&C side	·HP unit ·H&C side pump	·H&C side			·Ref. high pressure ·HP Unit ·H&C side pump	·HP unit
Germany	I		·GHX side	·GHX side S/R	·GHX side (on/off)					·GHX side		
		·Condenser side ·Evaporator side	·H&C side	·Setting ·H&C side S/R	·H&C side (on/off)		·HP unit					
	II		·GHX side	·GHX side S/R	·GHX side	·GHX side	·GHX side pump	·GHX side	·GHX side	·GHX side		
		·Condenser side ·Evaporator side	·H&C side	·Setting ·H&C side S/R	·H&C side	·H&C side	·HP unit ·H&C side pump	·H&C side				
	II		·GHX side	·GHX side S/R	·GHX side	·GHX side	·GHX side pump	·GHX side	·GHX side	·GHX side		
		·Condenser side ·Evaporator side	·H&C side	·Setting ·H&C side S/R	·H&C side	·H&C side	·HP unit ·H&C side pump	·H&C side				

Country	Level	Ref. pressure [MPa] (p)	Liquid pressure [MPa] (p)	Liquid temperature [°C] (T)	Flow condition (on/off) or flow rate [L/min]	Thermal output [kW] (Q)	Electric power [kW] (E)	Calorie [MJ] (ΣQ)	Ground temperature [°C] (Tg)	Ambient air temperature [°C] (Ta)	Error Massages	Operating hours and on/off times
		Monitoring points										
Denmark	I		·GHX side	·GHX side S/R	·GHX side (on/off)					·GHX side	·GHX side pump ·Ref. low pressure	
		·Condenser side ·Evaporator side	·H&C side	·Setting ·H&C side S/R	·H&C side (on/off)		·HP unit				·Ref. high pressure ·HP Unit ·H&C side pump	·HP unit
	II		·GHX side	·GHX side S/R	·GHX side	·GHX side	·GHX side pump	·GHX side	·GHX side	·GHX side		
		·Condenser side ·Evaporator side	·H&C side	·Setting ·H&C side S/R	·H&C side	·H&C side	·HP unit ·H&C side pump	·H&C side				·HP unit
	II		·GHX side	·GHX side S/R	·GHX side	·GHX side	·GHX side pump	·GHX side	·GHX side	·GHX side		
		·Condenser side ·Evaporator side	·H&C side	·Setting ·H&C side S/R	·H&C side	·H&C side	·HP unit ·H&C side pump	·H&C side				·HP unit
Japan	I		·GHX side	·GHX side S/R	·GHX side (on/off)					·GHX side	·GHX side pump ·Ref. low pressure	
		·Condenser side ·Evaporator side	·H&C side	·Setting ·H&C side S/R	·H&C side (on/off)		·HP unit				·Ref. high pressure ·HP Unit ·H&C side pump	·HP unit
	II		·GHX side	·GHX side S/R	·GHX side	·GHX side	·GHX side pump	·GHX side	·GHX side	·GHX side		
		·Condenser side ·Evaporator side	·H&C side	·Setting ·H&C side S/R	·H&C side	·H&C side	·HP unit ·H&C side pump	·H&C side				·HP unit
	II		·GHX side	·GHX side S/R	·GHX side	·GHX side	·GHX side pump	·GHX side	·GHX side	·GHX side		
		·Condenser side ·Evaporator side	·H&C side	·Setting ·H&C side S/R	·H&C side	·H&C side	·HP unit ·H&C side pump	·H&C side				·HP unit

Appendix 3-2 – Sensor Calibration

Temperature sensor calibration

The range of temperature of heat carrier fluid in BHE systems are commonly -10 ~ 40 °C. Therefore, the temperature sensors are calibrated by using the constant temperature bath and the temperature sensor for calibration. Figure B-1 shows the diagram of the temperature sensor calibration. The temperature sensors and the temperature sensor for calibration are put into the water in the constant temperature bath and the water temperature is kept constant. Then, the temperatures measured by the temperature sensors and temperature sensor for calibration are compared. If the temperature sensor installed in the constant temperature bath has high accuracy, it is possible to calibrate the temperature sensors by comparing the temperature measured by the sensors and the temperature displayed on the constant temperature bath.

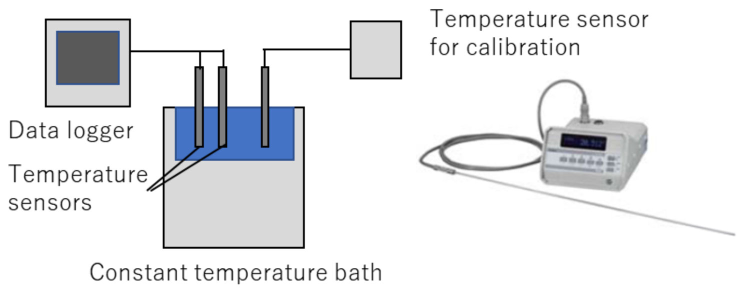

Figure A3-1: Diagram of temperature sensor calibration

Flow sensor calibration

Figure B-2 shows the diagram of the flow sensor calibration. The flow sensors are connected to the flow sensor for calibration. If it is difficult to use the flow sensor for calibration, the measuring cup is used. The flow sensor calibrated by measuring the time when water collects in the measuring cup.

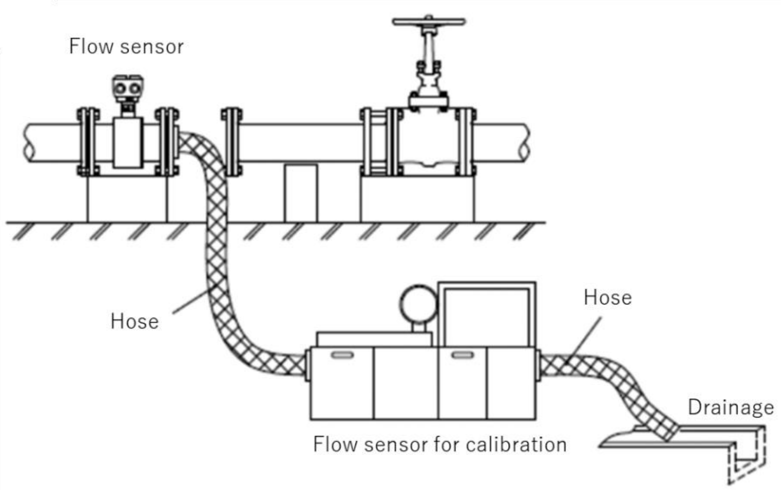

Figure A3-2: Diagram of flow sensor calibration

Appendix 4 – Country Answers Given by the Experts for Subtask 4

Appendix 4-1 – Answers on Design Mistakes

Table A4-1: Design Mistakes

<table>
<tr><td>Canada</td><td>Under- sizing of BHE is most common in commercial applications where the vast majority of buildings are cooling dominant. Under-sizing of the BHE results in:

Upward Temperature drift
The requirement for supplemental conventional cooling equipment
Reduced overall efficiency of the GSHP System as EWT increases
Increase in GHG emissions from design intent

One of the largest “issues” is the lack of GSHP specific training for design engineers. The majority of design engineers do not use an ACCURATE building energy model as an iterative design tool. The influencing factors of superior GSHP engineering are not fully understood and as a result designs are substandard. These factors include:

A complete understanding of the energy loads of the building and how changes can affect BHE sizing:

Building orientation – North, East South, West;
Natural and artificial shading;
Glazing choices;
Building envelope material choices;
Occupancy schedules;
Lighting loads;
Plug loads;
Make-up air schedules and sources;
Computational Fluid Dynamic (CFD) simulations;
Variable Frequency Drives for correctly sized circulation pumps;
Hybrid solutions for addressing peak load demands

Interpreting TRT report results;
Basic economic analysis is not understood.
Full on-site inspections during the installation process including a proper testing regime for all installation aspects.
</td></tr>
<tr><td>Denmark</td><td>The most often occurring error is under dimensioning of BHE resulting in freezing conditions of the soil. This has been directly observed in both vertical and horizontal systems. Some of these systems are known to have been shut down due to very high electricity consumption (under dimensioned HE loops).Some early BHEs were made of aluminium, resulting in corrosion and subsequent shutdown of the system(s).</td></tr>
<tr><td>Finland</td><td>In Finland slight under sizing of BHEs (single BHEs or BHE fields) is common (poor, decreasing COP/SPF value), although this has not been officially reported. Some more dramatic under sizing cases (freezing) are known but not officially reported. In some cases the fundamental reason behind the under sizing is wrong determination of loads, in some cases technical problems and poor technical design. Sometimes the reason is poor BHE design and/or misunderstanding of geological conditions.. Neglecting the effect of groundwater level (active</td></tr>
</table>

	borehole length) or the much smaller thermal conductivity of the overburden soil => under sizing of BHE. Misunderstanding or neglecting the geological factors is quite common and TRT tests are not always performed even when designing BHE fields. Misuse of HP manufacturers' designing programs is quite common (for example design BHE fields with these programs even though they do not consider the distance and interaction between the BHEs).Adding more loads afterwards change an owersized HP into an undersized HP. Without adding more capacity to BHEs, the HP is not working anymore as it was designed to.
Germany	*More than half of the design errors lead not only to insufficient heating power and too high heating costs, but also to failures in the overall system. Therefore, often unexpected costly repairs/replacements of components (heat pump, hot water tank, components to make the heat source accessible etc.) have to be conducted, statistically in the first two years after the initial installation [5]. A case with (commonly used) PE-pipes permeable for CO2 from surrounding earth structures showed the effects of poor choice of materials. CO2 from natural resources diffused the pipes especially well under pressure and interrupted the continuous operation [9].*
Netherlands	*No operational problems known* *What we know is that all suppliers tell us their system performs better than design but why that are the case is unknown. For example, it could be that the design with a temperature of 0 oC after 30 years (with an unbalanced heating / cooling demand) the performance in the first 10 years will be higher than specified at the design temperature of 0 oC* *Overall, with many systems in operation, we do not get feedback about significant problems or high perceived running cost of ground source systems – for air source this is different, problems with high running cost and issues with noise emissions occur!* *Main problem currently is in planning large developments of individual systems where one needs to account for the effects of adjacent systems* *In the past there have been some documented problems with:* • *Noise emissions (badly acoustically insulated heat pumps)* • *Design of electrical supply for housing blocks (grid issue)* *In the design we may note several issues with incorrect use / quality control of the design methodology (apart from miss-interpretation). This included: using wrong temperature (average ground temperature instead of surface temperature) in combination with geothermal flux, not checking Reynolds numbers in design, using fluid properties at freeze point instead of operating temperature (higher viscosity resulting in apparent low Reynolds and thereby high thermal resistance borehole), not evaluating simulation time, starting month or peak load duration. In general, lacking is a good design framework.* *In the construction phase issues have been noted with drillers not backfilling according to protocol.*
Sweden	***Inaccurate estimation of the energy loads for cooling and heating***

Most certainly there are several installations made that are designed from inaccurate estimates of the building heating and cooling loads. This is particularly true for new building with a lack of historic figures. Many times the loads are over-estimated for such buildings due to a conservative estimate done by the HVAC engineers. This may lead to oversized installations, and may cause several operational problems.

Misunderstanding of the geology, underground temperature, thermal conductivity

The geology, temperature and conductivity are well understood in general. For larger systems by test drillings and TRT, else by using databases and experience. Even so, unpredicted problems sometimes occur.

Undersized BHE

In Sweden under-sized number of boreholes and total length of BHE will lead to freezing of the groundwater-filled boreholes. The reason may also be that the boreholes are too closely spaced. Freezing may damage the BHE pipes by buckling due to high pressure. We have a couple of such examples that typically occurred after 5-10 years of operation. Typically, these systems are restored by melting of the ice, followed by addition of more BHEs and boreholes. Unfortunately, there are occasionally new installations that are undersized. At least one of these is presented at the Osaka meeting, also bringing up the flow rate issue.

There are also examples on frost heaving damages due to freezing around horizontal pipes, possibly also at borehole connections and casing.

Hydraulic layout (circulation pumps)

The pump size is normally not a problem. The pump is designed based on a certain flowrate for the BHE and a calculation of head loss. Besides they are often frequency regulated. However, many medium sized installations use heat pumps with inbuilt circulation pumps. This is OK for one single heat pump with one or perhaps two boreholes. For larger systems with many heat pumps in parallel, and many boreholes there are examples showing that this is not an optimal solution. The reason is that the inbuilt circulation pumps are designed for a certain friction loss at an optimal flow rate. If the designed friction loss is considerably exceeded, the incoming temperature from the BHE system is drastically lowered. In the worst case this will cause a shut-down of the system. –check-

Wrong interpretation of underground properties

Impact of vertical groundwater flow in the borehole during TRT results in false thermal values. If not recognized, this may lead to incorrect design.

Poor selection of materials

Nowadays all pipes and side equipment are developed to keep high quality standards. In former days, U-bends on BHE and welded plastic joints sometimes failed.

	There is also a tendency to choose above-ground manifolds instead of underground manifolds. The latter often have problems with water leakage leading to corrosion of metal parts such as valves.
Turkey	• *Misunderstanding of the geology, because in the feasibility stage geological engineer has not been involved* • *Thermal Conductivity measurement is performed, but not common.* • *Water mud loss a problem in some cases* • *Water inflow may occur (artesian conditions)*

Appendix 4-2 – Answers on Construction Mistakes

Table A4-2: Construction Mistakes

Canada	*In Canada & the USA, the GSHP industry uses the ANSI / CSA / IGSHPA C448 Bi-national Standard to address construction phase documentation This Standard will be revised / upgraded starting in January 2020.*
Denmark	*A number of errors/failures on requested issues have been observed:* • *Planned final borehole depth not reached* • *Installation depth of loop less than borehole* • *Air purging not acceptable* • *Sonic drilling has been observed to be problematic due to small drilling diameter (limited space for installation of BHE and tremie pipe for grouting).* • *Poor documentation.* • *Installation of U-pipe performed without reel.* • *Water/grout ratio not correct due to inappropriate mixer, resulting in large (10 %) settling of the grout material.* • *Drilling in mixed glacial sediments (sand/gravel interlayered with till) without a casing can often be observed to require a much larger than calculated amount of grout due to formation of cavities/material drop-in along the borehole.*
Finland	*Planned final borehole depth not reached* *We do not have exact statistics on that but I think we can have a level of 10 %. This is also an economical issue so sometimes it's easier to quit and continue on another place.* *Installation depth of loop less than borehole* *Statistics indicate that less than 1% has problem with inserting the BHE to full depth. In those cases the driller needs to bring back his machine and drill it up.* *Connection of boreholes during drilling* *No official statistics available, but it don't happen very often. A connection to another boreholes isn't a problem, connection to a water wells can sometimes cause temporary feculence in the water* *Pipe leakage*

	Leakage is less than 1 %usually caused by improperly welded connection between the BHE and the horizontal pipe system. This is normally observed during pressure testing of the brine system *Air purging* *There is always air to purge in the system and normal procedure is to add pressure and leave it for a few days and then purge air before starting the HP or use a pump whit an open tank to circulate brine fluid.* *Poor documentation while drilling* *It is not easy to discover small changes during drilling. Small cracks and small water yields are difficult to discover.* *Drilling problems* *There are different kind of problems, those who are possible to foresee and those not. Both are possible to avoid with education and experience. Those connected to equipment, machines and procedures to avoid in advance and the other ones what to do when it happens. Also to prepare right equipment*
Germany	*Different pressure levels between groundwater reservoirs can lead to hydraulic bypass (e.g. Staufen).* *Ineffective Backfilling due to mineralized or sulphating water and cavity formation with respect to drilling can also cause lowering of earth's surface. Examples for this can be found e.g. in Keuper (rise of ground water level due to missing seal of annular space) , Wiesbaden (water outlet due to water under artesian confinement), Böblingen (connection of anhydrite layer to aquifer leading to upheaving due to swelling of gypsum because of leaky seal of annular space), Kissing (drilling machine sinking into the ground) etc. [2,7,8,11].*
Japan	*During drilling* *1 Detention of rod during excavation of cohesive soil layer* *The reason was that the soil discharge to outside became bad. Therefore, the mud water was circulated instead of pure water to improve the soil discharge. If It became completely difficult to pull up the rod, drilling with large size ring bit were carried out and the inner rod was taken out.* *2 Core residue during rock drilling with ring bit* *Drilling was stopped and the all casing were pulled out.* *During or after inserting U-tube into borehole* *3 U-tube did not reach the scheduled depth* *The U-tube was taken out and drilling was carried out again.*

	4 Damage of U-tube due to bending *The U-tube was taken out and drilling was carried out again. Then the new U-tube was inserted.* *5 Lack of weight* *The U-tube was taken out and the weight was increased.* *6 Descent of tube after pulling out of the casing* *Holding the tube at the top or infallible grouting.* *7 Water leakage after inserting U-tube* *The U-tube was taken out and drilling was carried out again. Then the new U-tube was inserted.*
	After the construction *8 Sinking of borehole top* *Infallible grouting. In Japan, the bean gravel or silica sand are considered as the most suitable grouting material.* *9 Ridge of borehole top* *The reason was that the U-tube top was higher than the freezing depth. Therefore, the U-tube top must be connected to the horizontal draw pipe at below the freezing depth.* *10 Water pipe freezing near the horizontal draw pipe that was connected to BHEs* *The reason was that the soil surrounding the horizontal draw pipe was frozen. Therefore, the horizontal draw pipe was insulated to prevent the soil freezing.*
Netherlands	*No, limited problems known but not documented. Artesian aquifers occur but over pressure not very high and are known as zones where permit is needed (and measures need to be taken). In zones with coarse gravels at depth (river areas) loss of drilling fluid and collapse of borehole may be issue.*
Sweden	*Planned final borehole depth not reached* *Statistics made within Annex 27 show that it is more common than anticipated. This is probably a result of increasingly deep boreholes that increases this risk. It appears that some 10% of the holes do not reach the target depth. Often additional boreholes must then be drilled.* *Installation depth of loop less than borehole* *The same statistics indicate that approx. 5% has problem with inserting the BHE to full depth due to bore structure and/or water holding zones.*

	Connection of boreholes during drilling *Again, the same statistics indicate a fraction of 2-3% for this type of incidents. There are ways to avoid this occurring, but that is a planning issue.* *Pipe leakage* *Leakage occurs occasionally, mostly due to improperly welded connection between the BHE and the horizontal pipe system. This will in most cases be observed during pressure testing prior to refilling of the shaft.* *Air purging* *Air purging is an essential issue performed after filling the system with brine. The first step is to use ventilation valves typically placed on the manifold and on high points on the indoor piping system. These valves are then closed and the fluid is circulated through an open vascular until no more air is observed. If not properly done, air may be trapped, causing an increased head loss and less efficient heat exchange. There are a few known cases in which a secondary air purging had to be performed a few months after start of operation. In other cases, air-leaking automatic air valves were not closed.* *To avoid problems with air (diffusion oxygen included) most larger system are equipped with vacuum air purges.* *Poor documentation while drilling* *Could be better, but drillers don't like to document more than necessary. Still, it is obligatory to report all boreholes to the Swedish Geological Survey by law.* *Drilling problems* *The drilling equipment and drilling methods are extremely well developed and uniform. The only real problems are related to unforeseen structures in the rocks such as fracture zones and deformation zones.* *Fracture zones with a high yield create the most pronounced problem for two reasons. (1) too much water when drilling with air will eventually stop the drilling before reaching the target depth, and (2) problems with disposal of the water, especially in cities. The latter problem is related to finely grained cuttings that are hard to separate. The demands from the authorities are very difficult to fulfil. At present there is no technical solution to that problem.* *Having compressed air introduced in the overburden may cause damage to buildings. A few examples of such damage have been experienced over the years. Drillers are educated to carefully drill for the casing in risky areas. This is a part of their certification.*
Turkey	*Water/grout ratio may not be correct.*

	Depending on highly fractured and unconsolidated rocks, installation velocity could be faster. In that case, distance between spacers could be longer (for example, instead of 3 meters, spacers can be placed in 5 - 6 meter); Wrong interpretation of the underground