IEA ECES ANNEX 27

Quality Management in Design, Construction and Operation of Borehole Systems

Final Report

Subtask 1: Design Phase

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Report Subtask 1: Design Phase

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

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Contents

1. 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 subject that the system serves (typically a residential or commercial/institutional building). Another set of parameters is related to surface and underground conditions.

Depending of 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 important to use a commonly applied system definition.

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, independently of country.

2. 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 EM2 in Lund stated that all systems that use boreholes for exchange of heat and/or cold should be considered in this annex. The different systems as defined within this annex are:

- *GSHP (Ground Source Heat Pump) systems are designed to extract thermal energy (heat or cold, i. e. extract or inject heat) from the underground that recovers in a passive way.*
- *BTES (Borehole Thermal Energy Storage) systems are designed with the purpose to actively store thermal energy (heat and/or cold) in the underground, most common seasonally.*
- *HT-BTES (High Temperature Borehole Thermal Energy Storage) systems are designed with the purpose to actively store heat at high temperatures in the underground, most commonly seasonally.*
- *Direct (geothermal) cooling systems are systems which use the underground directly as a heat sink for cooling without the aid of a heat pump/cooling machine*

The major part of the participating countries share this definition, while a few do not and others may not be familiar with the terminology, see ***Table 1***. In countries with already 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 above definitions 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.

3. Design approach

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 EED, GLHEPRO, GEO-HAND^{light}, GEOSYST, FEFLOW, GLD, EWS, GAIA, DST, SBM and SMP. General building and plant simulation environments like TRNSYS and IDA-ICE comprise 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 such as EED and GLHEPRO are user-friendly, fast and can be used to quickly try out many design variations, advanced simulation tools such as SBM, IDA-ICE and TRNSYS 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 2.***

It is recommended that tools such as EED, GLHEPRO and GEO-HAND^{light} are used in the feasibility stage of projects larger than single boreholes and that other, more sophisticated tools, should be considered in the detailed design phase, especially for more complex systems. It is also recommended to take into account already existing or planned new ATES, GSHP and BTES systems in the neighborhood.

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 the cooling system and waste cold from the evaporators of heat pumps.

However, also 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 3.***

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 4.***

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

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

Load characteristics

Heat and cooling loads

Many GSHP systems and BTES systems for older or large buildings especially for 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 6.*** 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 cold 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 preparation of hot (+60 ^{o}C) tap water. Tap water production tends to make up for an increasing fraction of the total heat consumption in such buildings, especially within the residential sector.

It is recommended to identify the maximum heating and cooling loads, the heating and cooling temperature programs and the expected usage of hot tap water in an early stage 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, also district heating and electric boilers is used, see ***Table 7***. 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 in a long-term perspective.

Peak cooling load shaving

Normally the peak load for cooling is covered by running 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 8***.

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

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 would be closer for high temperature storage (HT-BTES).

For independent boreholes (boreholes that do not significantly interact thermally) in systems for extraction of heat or cold only, a “safety” distance of 10-25 m seems to be applied in most countries (in some cases legislated), see ***Table 9***, 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 even larger 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.

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 taken into account.

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 10***, 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 decision of borehole depth.

Undisturbed ground temperature

The undisturbed ground temperature is an essential parameter that specifies 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. The undisturbed ground temperature used for design denotes the average undisturbed ground temperature calculated over the total borehole depth.

The temperature at 15-20 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 11.*** 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 that the undisturbed ground temperature is estimated 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 (“hot

cities"). In a later stage it is recommended to measure the temperature profile as a part of a thermal response test (TRT).

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 12.***

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 way above what is needed and have a negative effect on fluid thermal and flow properties as well as the costs. In the Netherlands higher concentrations are often used as that then acts 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 but 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 degrees as highest. However, HT-BTES applications (heat storages) operate with temperatures up to 80°C, see ***Table 13.***

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 14.***

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.

4. 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, if so is decided, to stop further development.

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 fuel fired boilers. If the result from this initial study comes out favorably, the project has a good chance to be further developed.

There seems to be consensus that a pre-feasibility report is a desktop study – if needed at all, see ***Table 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 easily achieved.

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 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.

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 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 18.***

In countries that have free availability to geological databases, it is recommended to always use such information, already at an 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 have to 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 19.***

Since groundwater always plays an important role for any project it is recommended to search for information on aquifers and groundwater level(s) already 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 20.***

To avoid damages to pipes (water, wastewater, gas, districted heating grids etc.) and cables (power, IT, etc.) below ground surface before placing the boreholes, these obstacles should be recognized at an early stage. This could also be done later on in a project development. However, there seems to be a free service on this issue in most of the countries, see ***Table 24.***

It is recommended to always make a survey on underground piping and cables or other infrastructural 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 already in the pre-feasibility stage. Some of these are pointed out in ***Table 21***. In tectonic areas, such as in Turkey, special considerations must be undertaken. 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 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 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 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 polluted 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 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

5. Feasibility phase

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 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.

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 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 start of drilling a permit may be needed.

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

If 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 29*** the test holes are later used 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 are normally similar to the bore depth in final system in all countries, see ***Table 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 31***. In other countries one borehole followed by a TRT is applied, but sometimes more for large-scale projects. Some countries try to follow the recommendations stated by previous ECES Annexes with more holes the larger the project is. Not all the test holes are necessarily used for TRT. 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-holes as required based on the size of project, site-specific geological and hydrogeological conditions and ambition of design quality. As a minimum requirement it is recommended to use one test hole and TRT test for 10-30 boreholes.

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 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 you only get cuttings and you are usually not able to measure the groundwater level and its changes during drilling). However, during the drilling the driller should be able to identify the main layers encountered and especially be able to identify sealing layers (aquitards).

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 answers obtained indicate that permeable zones or fractures are documented mainly by air-lifting measurements at air-drilling and loss of circulation when drilling with water or mud. It is essential that the driller be experienced, see ***Table 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 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 at 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 hole, 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 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 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.

Thermal response testing (TRT)

TRT services

One or several TRTs are commonly performed after completion of test holes. Evaluated parameters are used for the detailed design of the borehole system. As seen in ***Table 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.

Common duration of the test

The duration of TRT must be long enough to ensure a proper evaluation of thermal properties. According to ***Table 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 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, 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.

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 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.

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. 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 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 42.***

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

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 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.

Economic considerations

Investment cost

In general customers will be interested in the cost of the system. As shown in ***Table 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 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 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 47.***

It is recommended to use the expected seasonal performance factor (SPF) with a system boundary including at least 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 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 49.***

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

6. Detailed design

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 frames for design are given, while for option (B) the design is detailed and fully quotable for bidders.

According to ***Table 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.

Turnkey contracts

Turnkey design

A turnkey project is defined and executed slightly differently in the countries, see ***Table 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 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 53.***

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

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 occasionally hourly values are used, see ***Table 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 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 taking into account 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 discussed for every 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 not 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 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 chiller. In some countries the cooling demand is basis for the 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 57***, there is no standard solution. This indicates that there are several solutions 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 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 59***. Groundwater table may vary over the year.

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 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 but also the energy balance achieved by the system. In general, low groundwater flow velocities and systems with a high energy balance are not that 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).

Borehole heat exchangers (BHE)

A BHE is defined as the borehole including the pipes and the borehole filling (grout or 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

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 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.

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 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.

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 by a butt welding method. See ***Table 62***.

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

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 ºC 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: 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** in 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 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 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 66.*** Due to the construction especially the coaxial BHEs cannot be practically handled as a roll depending on the diameter. They are delivered to the construction site as prefabricated tubes and have to be welded on site at insertion in the borehole.

It is recommended to use BHE:s 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 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 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 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 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 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 subjects to research, see ***Table 72.***

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

Horizontal pipe system

Pipe material

Common practice is to use PE100 or similar for low temperature applications, and thermal resistant polymers for HT-BTES, see ***Table 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 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 take into account 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 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 76.*** To limit heat loss in the horizontal pipes they may be installed preferably in the un-saturated zone.

It is recommended to take into account 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 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 shaft is commonly used for the rest of the backfilling. See ***Table 78.***

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

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% (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. See ***Table 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.

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 80.***

It is strongly recommended to always make an environmental risk analysis showing that such risks have been taken into account 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 81.***

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

7. 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 82.***

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

8. Call for tenders

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 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.

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, CV:s etc.

As shown in ***Table 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 a 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.

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 85.***

It is recommended to always, one way or another, cover 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.

List of tables:

Appendix 1 – Answers on systems and definitions

Table 1: Opinions regarding system concepts and definition

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 2 – Answers on design approach

Table 2: 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/m ^{3}.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 (^{o}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 (^{o}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 3 Typical 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 4 Other heat sources used

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 5 Cold sources

Belgium	*See table 3.*
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 6. Heat and cooling load 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 average 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 sytem 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 7. Peak load for heating (Auxiliary heating)

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 a 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 a 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 a 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 8 Peak load for cooling (Auxiliary cooling)

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 9 Distance between 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 10 Borehole depths and deviated (angled) boreholes

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 11 Ground temperature at 10-15 m

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 ℃ and 12 ℃*
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℃ and 20℃.*
Denmark	*Variations are smaller in Denmark for obvious reasons, but generally between + 10 and +11°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°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°C. It shows 12-13°C in the high altitude and high latitude area but 17-18°C in the low altitude and southern coastal area.*
Netherlands	*Between +8 and +14 °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°.*

Table 12 Types of antifreeze

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 13 Fluid working temperature

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°C as lowest (normally in February) and +32/+33°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°C as lowest (normally in February) and +14/+16°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°C as lowest and +30/+35°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°C as lowest (normally in February) and +14/+16°C as highest (normally in August).*
Turkey	*Winter -5°C,0 °C (Heating), 30-40 °C (Cooling) summer.*

Table 14 Freezing of boreholes

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 3 – Answers pre-feasibility studies

Table 15 Scope of a 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 16 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 17 Availability of geological/hydrogeological maps

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 18 Availability of geological data base

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 19 Hydrogeological information

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 20 Underground obstacles and limitations

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 21 Geotechnical conditions

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 22 Legal aspects with respect to property ownership

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 23 Environmental issues

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 Hydrolic Works works and municipality authority. Except ground water usage there is not any obligation. Environmental issues just depends on ownership's initiative.*

Table 24 Survey on underground 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 25 Economic considerations

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 4 – Answers feasibility studies

Table 26 Scope of feasibility studies

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 27 Placement 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 28 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 29 Later use of test holes

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 30 Depth of test holes

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 31 Number of test holes and TRT

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* m^2*.* • *One or more test holes are demanded if the application area of GSHP is more than 5000* m^2*.*
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 TRT:s.*
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 32 Documentation of stratigraphy

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 33 Documentation of permeable zones

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 34 Measuring of 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 35 Structural drilling problems

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 36 Documentation of drilling parameters

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 37 Availability of TRT service

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 38 Duration of TRT

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 39 TRT evaluation method

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 40 Use of geophysical methods

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 41 Groundwater protection

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 42 Potential for physical damages

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 43 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 44 Investment cost

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 45 Operational cost calculation

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 46 Maintenance cost

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 47 Calculation of energy savings

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 48 Profitability as straight pay-back time

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 49 The use of Life Cycle Cost analyses

Belgium	*Commonly used for a period of 20 years (technical life time 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 year 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 life time of mechanical units) with a rest value for the borehole system that has at least 60 years lifetime.*
Korea	*System life time is considered as 20 years and borehole life time is considered as more than 50 years.*
Netherlands	*Not normally calculated*
Sweden	*Commonly used for a period of 20 years (technical life time 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 5 – Answers detailed design

*Table 50 Common forms of contract**

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 6

Table 51 Understanding of turnkey ("design/build") projects

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 52 Review and commenting 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	*Yes.*
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 53 Handling of contracts and design performance

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 54 Load profiling

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 specify form and level of detail of the load profile.*
Japan	*Normally monthly loads. Maximum loads and integrated load for heating and cooling. Sometimes hoursly 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 55 Temperature demands

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 56 Heat load coverage

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 57 Cooling load coverage

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 58 Modelling of borehole fields

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 59 Influence of groundwater level

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 60 Influence of natural ground water flow

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 61 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 62 Material of BHE pipes and joints

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 63 Diameter and bursting strength

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 64 Quality criteria for BHE

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 65 Certification of material properties

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 66 Manufacturing of BHE

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 67 Welding methods and procedure

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 68 The use of spacers

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 69 Use of different manifolds (headers)

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 70 Connection of boreholes and manifolds

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 71 Use of flow control 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 72 Grouting material and procedures

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 73 Pipe material horizontal system

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 74 Dimension and strength of 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 75 Insulation of horizontal pipe systems

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 76 Placement depth of horizontal pipe system

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 77 Bottom bed material

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 78 Backfilling of pipe trenches

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 79 Use of Heat transfer fluids

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 that does not include 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℃. 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/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.*
Turkey	*Ethanol-water mixture (sometimes monoetylene glcohol) is used as well as pure water, which is common.*

Table 80 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 an 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 81 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 6 – Answers approval procedures

Table 82 Approval procedure for permit to install borehole systems

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 7 – Answers call for tenders

Table 83 Form 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 84 Quality and skills of contractors

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 85 Responsibility for damages caused by borehole systems

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.*