CEN/TC 451

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Design, construction, operation and decommissioning of borehole heat exchangers

Planung und Bau von Erdwärmesonden

Design, contruction et mise en place des boucles de sondes géothermiques pour les pompes à chaleur et le stockage d'énergie

ICS:

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European foreword

This document (prEN 17522:2020) has been prepared by Technical Committee CEN/TC 451 “Water wells and borehole heat exchangers”, the secretariat of which is held by AFNOR.

This document is currently submitted to the CEN Enquiry.

1 Scope

This document covers standardization in the field of geological and environmental aspects, design, drilling, construction, completion, operation, monitoring, maintenance, rehabilitation and decommissioning of borehole heat exchangers for uses of geothermal energy.

The direct expansion and thermal syphon techniques are excluded from this document

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 12201-1:2011, *Plastics piping systems for water supply, and for drainage and sewerage under pressure - Polyethylene (PE) - Part 1: General*

EN 12201-2:2011, *Plastics piping systems for water supply, and for drainage and sewerage under pressure - Polyethylene (PE) - Part 2: Pipes*

EN 12201-3:2011, *Plastics piping systems for water supply, and for drainage and sewerage under pressure - Polyethylene (PE) - Part 3: Fittings*

EN 12201-5:2011, *Plastics piping systems for water supply, and for drainage and sewerage under pressure - Polyethylene (PE) - Part 5: Fitness for purpose of the system*

EN ISO 15875-1:2003, *Plastics piping systems for hot and cold water installations - Crosslinked polyethylene (PE-X) - Part 1: General (ISO 15875-1:2003)*

EN ISO 15494, *Plastics piping systems for industrial applications - Polybutene (PB), polyethylene (PE), polyethylene of raised temperature resistance (PE-RT), crosslinked polyethylene (PE-X), polypropylene (PP) - Metric series for specifications for components and the system (ISO 15494:2015)*

EN ISO 22391-1, *Plastics piping systems for hot and cold water installations - Polyethylene of raised temperature resistance (PE-RT) - Part 1: General (ISO 22391-1:2009)*

EN 1057, *Copper and copper alloys - Seamless, round copper tubes for water and gas in sanitary and heating applications*

EN 12449, *Copper and copper alloys - Seamless, round tubes for general purposes*

EN 1965-2, *Structural adhesives - Corrosion - Part 2: Determination and classification of corrosion to a brass substrate*

EN 12168, *Copper and copper alloys - Hollow rod for free machining purposes*

EN ISO 1127, *Stainless steel tubes - Dimensions, tolerances and conventional masses per unit length (ISO 1127:1992)*

EN 10216-5, *Seamless steel tubes for pressure purposes - Technical delivery conditions - Part 5: Stainless steel tubes*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
aquifer
underground geological formations containing water that can be partially mobilised by gravity and which of permeable and/or cracked or fractured rocks that allow enough transmission of groundwater to create a significant flow and catchment of a significant amount of water

Note 1 to entry: An aquifer can be fully or partly saturated.

Note 2 to entry: Its upper limit is called the "top of the aquifer" and its base is called the "bottom of the aquifer"

3.2
aquitard
body of rock or stratum of sediment that retards but does not prevent the flow of groundwater from one aquifer to another

3.3
borehole heat exchanger
BHE
consists of the borehole with a loop, to circulate a heat transfer fluid, and a borehole filling

3.4
BHE loop
part of the pipe system in the borehole, which contains the fluid for heat transfer

3.5
heat transfer fluid
HTF
fluid circulated through the BHE for the heat transport

3.6
BHE system
one or more BHE connected in one hydraulic circulation system

Note 1 to entry: It does not include the heat pump or circulation pump

3.7
ground source heat pump system
GSHPS
BHE system including the horizontal piping, manifolds, the heat pump and circulation pump

3.8
BHE field
area with several BHEs systems that are not connected in the same hydraulic circulation system

3.9
backfill
material used for refilling any borehole or trench

3.10
grout
backfilling material composed of cement and water mixture and other additional components (clay minerals, etc.)

3.11
fluid
gas, vapour, liquid or combinations thereof

4 Geological and Environmental aspects

4.1 General

The design shall check whether the location of the planned installation is situated in any areas defined in spatial planning documents. These could be areas of special protection of natural resources (water protection, nature protection) or areas of specific risks (endangered areas, landslides, contaminated sites, etc.).

If the installation would be situated on such protected areas, it shall be verified that the design is in accordance with the specific geological conditions.

It shall be checked whether there are hydrogeological conditions (artesian aquifers, shallow groundwater table, perched groundwater, etc.) that could require special consideration or even impact or risk assessments.

The designer shall assess whether the available geological and hydrogeological information is sufficient for the project in question.

4.2 Geological and hydrogeological risks

4.2.1 Artesian aquifers

When the drilling penetrates into an artesian aquifer, the groundwater level rises over the orifice of the borehole. Uncontrolled upwelling and pressure loss would occur from use of improper drilling techniques or equipment selection. In certain cases, the upwelling (into shallower aquifers) might not be directly evident. This represents the main risks when artesian aquifer is penetrated.

Drilling in the artesian aquifer is a risk. Special specifications regarding drilling methods and BHE construction shall be implemented.

4.2.2 Stacked aquifers with different groundwater potential

Drilling through sealing layers between aquifers could result in leakage from one aquifer to another and result in impact on chemical characteristics of groundwater or hydraulic conditions. This could also cause an undesired drop or increase of groundwater level in one or more aquifers. Consequences could be decreased productivity of water sources or deteriorated formation conditions.

Groundwater flow conditions and qualities can also be affected adversely where drilling penetrates two or more groundwater layers. In this case, the possibility of uncontrolled water exchange between the individual aquifers via the borehole needs to be taken into account. A hydraulic short circuit should be avoided for groundwater protection reasons, especially where one of the penetrated layers contains highly mineralized or contaminated groundwater.

If drilling would cross through several aquifers, at least the aquitards shall be sealed.

4.2.3 Groundwater and soil chemistry

The chemical composition of the groundwater (high sulphate concentration, high salinity, etc.) could adversely affect the sealing properties and stability of the backfilling.

Drilling or excavating near mineral water springs or wells could adversely affect the mineralogical composition of groundwater.

4.2.4 Gas occurrence

Under certain geological conditions, gas of geogenic origin can accumulate in cavities and trap structures in the subsurface. When drilling in these areas, the gas could leak uncontrollably through the borehole and pose a safety risk (toxic or explosive gases) or an environmental risk (greenhouse gases). Gas deposits could occur in areas with volcanic activity or above geological layers containing coal, peat, hydrocarbons, sulphides, etc. If the risk of drilling gas at the project site is known or can be predicted based on geological research, certain safety measures (e.g. explosion protection concept, special backfill material) are required or the drilling depth shall be limited or the drilling shall be terminated.

4.2.5 Ground stability

Unstable ground could be found especially in the following geological situations:

— intensively fissured, faulted and breccia zones, provoking formation of natural or anthropogenic cavities;

— soft fragile rocks representing unstable ground (e.g. volcanic or sedimentary rocks).

4.2.6 Swelling and shrinking minerals or soils

Presence of evaporates or swelling clays presents a risk of subsidence or swelling in the case of connection of shallow or deep aquifers with evaporitic or clay layers because of unsuitable or hardly feasible underground operations.

4.2.7 Contrasting geological sequence (Alternated bedding)

Geology is highly diverse, and could range from structures represented by unconsolidated sand, clay and gravel going to very complex situations including unconsolidated or consolidated sedimentary (sandstone, limestone – fissured and frequently karstified) or crystalline (metamorphic and igneous) rocks. An adequate knowledge of the geological conditions and associated hydrodynamic properties of the selected site represents the base for any BHE drilling project. Adequate prior analysis of site conditions raises the probability of an efficient and long-lasting product; this also contributes to the management and protection of groundwater resources (quantity and quality) to be exploited through future projects (e.g. water wells of different purposes and configurations).

The lithological description of the geological sequence be drilled and the structural characterization of the site area are both compulsory in order to provide sufficient information for the preparation of a BHE design and provision of adequate drilling machineries and auxiliary equipment for efficient construction works; whilst avoiding, minimizing and/or controlling the potential geologic risks during drilling.

Depending on the complexity of the project and of the geological conditions, the standard set of topics to be described should refer to the following aspects (if appropriate):

— occurrence and description of the regional geologic structure(s) - sedimentary basin, folded structures and/or faults;

— the lithological (specific) description (from bottom to top or reverse) of the litho-stratigraphic units (formations, beds, layers, or horizons) to be drilled;

— occurrence and characterization of local tectonic (structural) discontinuities – faults, fissures, fractures (particularly in case of hard rocks);

— occurrence and characterization of dissolution voids and channels (in case of carbonate and evaporite rocks);

— hydrological aspects (groundwater chemistry, redox potential, depth of sweet/salt level, level of phreatic groundwater, regional groundwater flow for every aquifer, hydraulic conductivity, porosity / thermal parameters);

— inventory of other users in the vicinity (groundwater extraction wells, groundwater energy wells, borehole heat exchangers).

4.2.8 Karst geology

Karstified zones can represent strong heterogeneity of the ground and risk of caverns. High probability of occurrence of caverns leads to several risks: collapsing of borehole, subsidence of the ground, losses of drilling fluids, problems with backfilling, turbidity and solids in groundwater, unstable temperature of groundwater (too low in winter, too high in summer), hardly predictable, unreliable modelling.

Geological and hydrogeological conditions in the depth of karst area are often not sufficiently known to make a reliable prediction without additional investigation.

4.2.9 Frost susceptibility

Because the temperature of the fluid in the BHE can be below 0 °C, there could be a risk of freezing the soil causing upheaval of the horizontal part and affect the sealing properties of the borehole filling and the natural sealing layers around the borehole.”

The sealing grout of the borehole heat exchanger should be adapted to the actual physiochemical conditions, naturally occurring or due to operation of the system. It should not be negatively affected by freezing and should withstand a negative temperature of the heat transfer fluid that returns to the geothermal heat exchangers up to −3 °C, keeping its physiochemical and mechanical properties intact.

4.2.10 Groundwater protection area

The risk of BHE in groundwater protection areas is the degradation of the groundwater quality due to:

— introduction of pollutants from the surface;

— leakages of the heat transfer fluid;

— mixing of groundwater of different quality;

— changing the biological composition of the groundwater.

Areas of interest to drinking water supply can be protected areas. In such areas, installations could require special authorisations.

4.3 Anthropogenic risks

Interactions between the built environment and the subsoil could impose constraints on the realization of borehole heat exchangers. Also, underground structures can impact the groundwater flow.

When planning a borehole heat exchanger, the potential risks and impacts of sites should be evaluated, such as presence of:

— areas of archaeological interest;

— nature protection areas;

— unexploded ordnance;

— contaminated soil;

— mining areas.

Drilling impacts on the piezometric level of the groundwater should be assessed. The presence of thermal anomalies (geothermal gradient, hot spot) shall be evaluated in order to adapt the dimensioning of the BHE and the materials used for the drilling and construction of the BHE.

4.4 Environmental aspects

4.4.1 General

Environmental aspects shall be considered throughout the whole construction process.

4.4.2 Influence on groundwater

Regulations and the regional planning targets shall be complied with during planning, construction and operation of ground source heat pump systems.

Within the scope of the applicable water law and – to the extent required – mining law procedures, the desired uses should be harmonized with the water management targets with respect to the local situation by imposing usage terms.

Groundwater should be managed in a way to avoid adverse changes to its quantity and chemical composition. From this, it follows that:

— groundwater should be treated carefully;

— hazardous substances should not be allowed to enter the ground or penetrate into the groundwater zone;

— thermal use of the underground in drinking water protection areas, in catchment areas of drinking water aquifers and in protection areas of mineral springs is generally prohibited. Exceptions shall be examined according to the relevant circumstances;

— in groundwater protection areas or other designated zones, the drinking water supply takes priority over any thermal use of groundwater layers. This principle applies also for registered domestic wells not covered by an official protection area. Exceptions shall be examined according to the local regulations;

— the backfill of the borehole has to use suitable materials (in accordance with local regulations). This may include sealing clays and/or grout depending on the risk to the aquifer. Suitable materials are described in Clause 6.

4.4.3 Environmental Impact Due to Construction Works

4.4.3.1 General

Environmental aspects shall be considered throughout the entire construction process. Systems for the thermal use of the underground should be constructed and operated without adverse impact on the environment. Any harmful effects shall be avoided. Such consequence could be caused by unsuitable materials/fluids of the drilling process or the thermal impact on the ground/groundwater due to the operation of the heat exchanger.

4.4.3.2 Materials

Materials installed underground shall be rated non-harmful to groundwater and environment and non-corroding. Pipes, backfill materials, etc. should be suitable for use in groundwater.

When using metal pipes in borehole heat exchangers in exceptional cases, attention should be paid to sufficient wall thickness, metal quality and corrosion prevention, and the chemical composition of the groundwater shall be considered. Attention should be paid to the consequences where heat transfer media or working fluids could leak into the air, soil or groundwater.

If water/anti-freeze mix is used as heat transfer fluid, it shall be considered that, in case of leakage, corrosion inhibitor or other additives can have negative impacts on the environment.

4.4.3.3 Drilling Process

Drilling companies involved in BHE projects shall make sure that qualified staff is operating any drilling activities and warrant that equipment conforms to health and safety standards and is regularly maintained and checked. This can be warranted through a recent maintenance certificate. Drill rigs, drilling rods, accessories and materials should not cause contaminants to enter the underground/soil. Appropriate precautions should be taken to prevent contamination and similar. Pollution of surface water due to dumping of drilling mud or highly mineralized groundwater shall be avoided. The use of mud additives with clearance certificates is permitted in accordance with any conditions imposed by the authorities. Only mud additives [5] may be used that do not cause chemical/biological changes in the underground. National guidelines shall be applied. The quality of the discharge water shall comply with the required quality of the responsible sewage water company.

Pollution of natural greens, roads, buildings or other infrastructure due to dirt, fluids, oil spill or unnecessary noise and vibration of the drilling process shall be avoided.

5 System description

5.1 General

The BHE system can be divided into four subsystems (Figure 1):

1) Borehole heat exchanger

2) Horizontal piping

3) Manifold

4) Thermal plant (technical room) with heat pump installation

NOTE The heating system, in the house including the heat pump, is not discussed in the text.

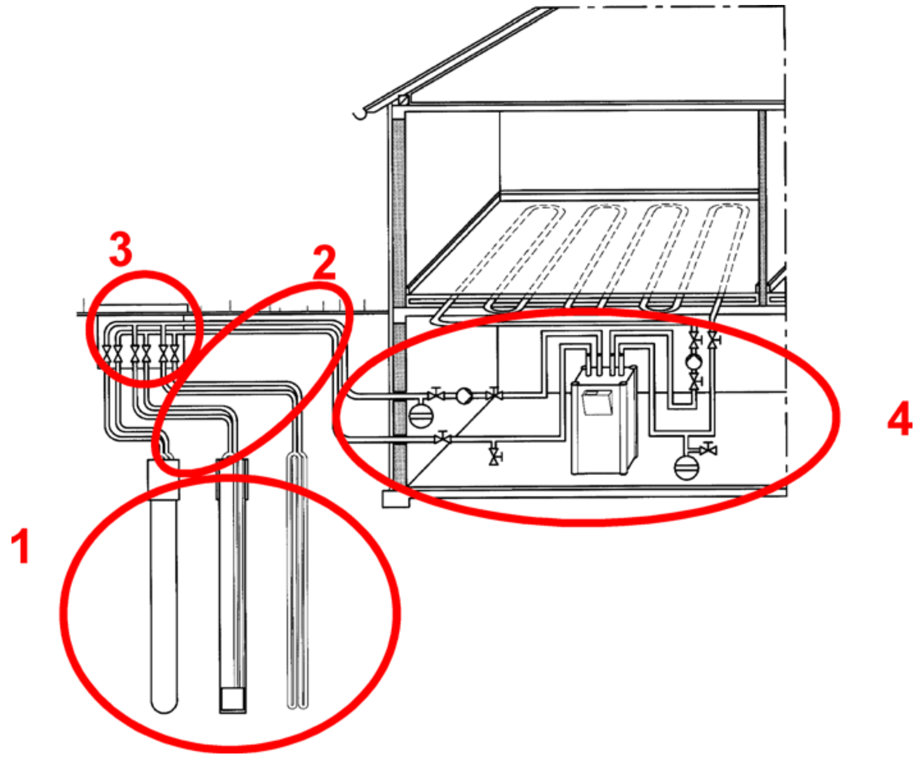


Figure 1 — Example of a GSHPS with BHE

The BHE represents the heat source (heating mode) or heat sink (cooling mode) for the system. BHE are made in various versions (see Figure 2) each with different properties.

5.2 Borehole heat exchanger

There are several possibilities to configure loops of BHE. The most common types of BHE are the following three:

— single U loop (Figure 2a);

— double or Multiple U loop (in Figure 2b a double U loop is shown);

— co-axial loop (Figure 2c).

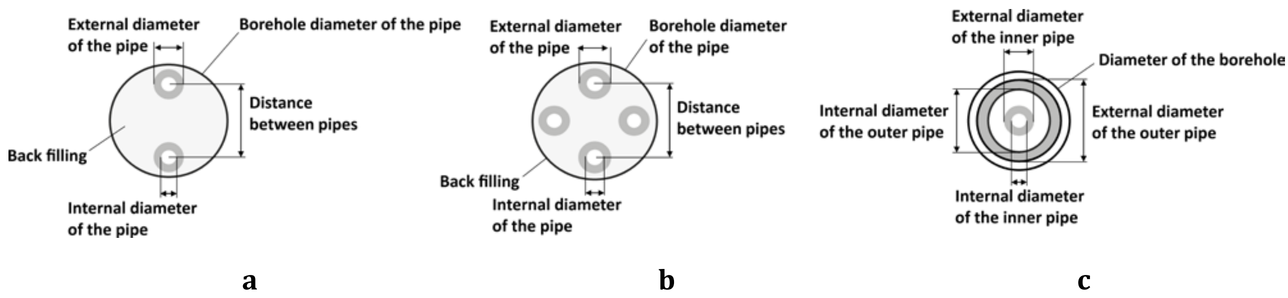


Figure 2 — Types of typical BHE: single U loop (a), double U loop (b), co-axial (c) loop

The BHE is characterized by the average borehole diameter and the depth.

The BHE loops are characterized by their pipe material and their inner and outer diameters. For U-loop heat exchangers, the average distance between the pipe centres results from the geometries of the pipes, their installation arrangement and the borehole. This is called shank spacing. The space between the pipe and the borehole wall is filled with a backfill material (6.2).

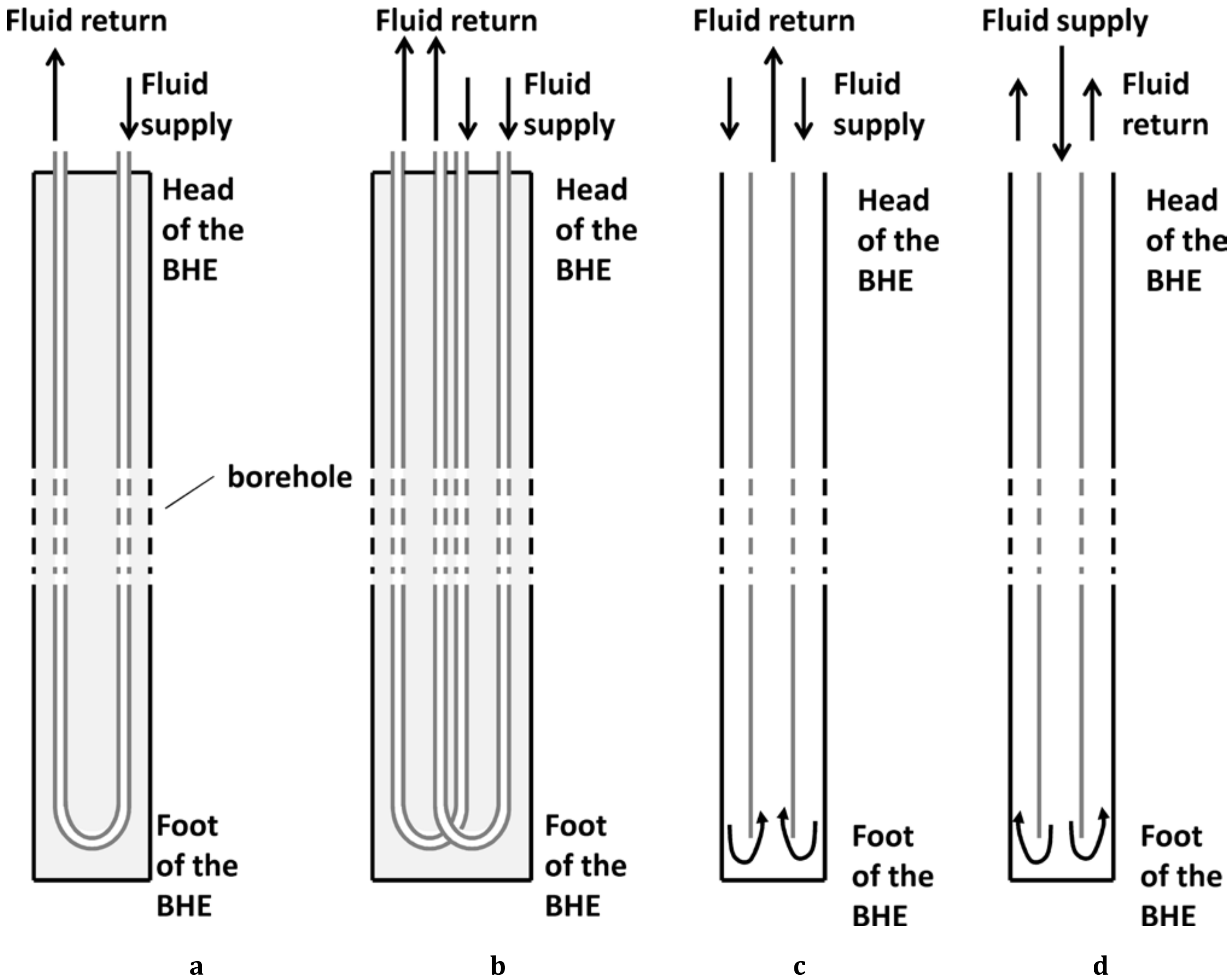


Figure 3 — Types of typical vertical BHE: single U pipe (a), double U pipe (b), co-axial with water supply in the annular section (c), co-axial with water supply in the central pipe (d)

The design shall meet environmental (see Clause 4) and construction (see Clause 8) aspects of this document.

The quality and operational life of the heat exchanger loop depends on the pressure class, the wall thickness and operating temperature. The internal and/or external hydraulic pressure along the length of the BHE shall be considered during all construction and operation phases.

5.3 Horizontal piping

The horizontal piping is the circuit connecting the BHEs, to the manifolds and to the thermal plant. Annex A is giving information on the insulation of horizontal piping.

5.4 Manifolds

The purpose of the manifolds is to connect all individual horizontal pipes into one hydraulic circuit and to ensure and control the volume flow of the fluid in the individual BHEs.

It may consists of: isolating valves for each circuit, a flow balancing valve for each circuit, pressure gauge and de-airing assembly.

5.5 Thermal plant

The design of the thermal plant is determined by the applications: heating, cooling or combined heating and cooling. This could be either in direct or indirect way; indirect means in combination with a heat pump for adjusting the temperature level.

For the design of the part of the thermal plant relating to the borehole heat exchanger (source/sink) circuit, the following should be considered:

— for passive cooling or heating systems an additional heat exchanger could be needed to separate the BHE circuit from the user (emission system) circuit;

— for passive cooling systems temperature control on the user (emission) side should consider potential condensation;

— for systems with heat rejection during mechanical cooling operation, condensing temperature control could be needed;

— de-airing and dosing system could be required.

6 Materials

6.1 General

A BHE system consists of several components made from different materials, which shall meet specific requirements regarding durability, life expectancy and environmental impact.

6.2 General Properties

6.2.1 General

Due to the nature of a vertical borehole installation, e.g. lack of access, risks for the environmental underground and long design life, a very high level of quality and durability of material as well as related knowledge shall be required to construct BHE loops. BHE pipe manufacturer and installer should be aware of this technology with current practices.

All materials used underground shall have no chemical reactivity with the underground minerals and fluids. The materials itself and their decomposition products shall be non-harmful to groundwater and environment even after the end of functioning. They shall be corrosion proof or shall have a proven long-term reliable corrosion protection. Pipes, backfill materials, etc. should be suitable for use in ground.

The lifetime of a BHE loop is influenced by the choice of material, the pressure load (internal and external pressure, pressure class of the pipes) and temperature range during operation. Loop materials installed in a backfilled borehole should be selected in accordance with an anticipated design lifetime of the BHE of at least 50 years to ensure a level of quality.

For some materials, there exist standards giving pressure class and reduction coefficient for different temperatures. Alternatively, a material certificate from an accredited test laboratory for the intended application can be obtained. For high temperatures, materials shall be selected according to the limitations and prescriptions from the manufacturer.

6.2.2 Plastic materials

Polymer materials are mainly used in the BHE loop and the horizontal connection pipes but also for corrosion protection of metallic BHE pipes. Typical polymer for BHE loops is high density polyethylene with designations of PE 100. Characteristics of the material in the form of raw material and pipe mechanical characteristics shall be in accordance with standard EN 12201-1 and EN 12201-2. Fittings and joints shall meet requirements of EN 12201-3 and EN 12201-5. Dimensional properties (e.g. nominal diameter, ovality, inner smoothness of the probes etc.) may deviate from EN 12201 series. The manufacturer shall warrant that the loops and connections are made from verifiable grade raw material from a producer of PE pipe materials, which meet the requirements of EN 12201-1.

Other material that might be used in the BHE loop and the horizontal connection pipes are (but are not limited to) PE 100-RC, PE-RT, PE-X. Table 1 gives the materials used for pipes and fittings with related standards.

Table 1 — Relevant standards for pipes and fittings made from polyethylene

Designation	Relevant standards for the material
PE 100	EN 12201-1:2011, EN 12201-2:2011, EN 12201-3:2011, EN 12201–5:2011
PE 100-RC	EN 12201-1:2011, EN ISO 15875-1:2003
PE-RT (Typ I/Typ II)	EN ISO 15494, EN ISO 22391-1
PE-X	EN ISO 15494

Polymeric materials used for the underground installation shall meet the requirements concerning pressure resistance, temperature resistance, durability and weldability according to the relevant standards given in Table 1. Delivered BHE loops shall be traceable to the production consignment, batch and even raw material properties.

For each project based on the depth of the borehole and other parameters like heat carrier fluid, backfilling material etc., the proper pressure class and size of the loop shall be selected. Pipes and fittings for BHE shall meet at least the same pressure requirements. Table 2 gives mechanical and dimensional properties of different size of loops for PE 100 for a typical U pipe installation.

Table 2 — Characteristics of a typical U pipe loop with a PE 100 material

Nominal pipe size (OD mm)	Standard dimension ratio	Maximum operating pressure (bar) at 20 °C	Wall thickness (mm)	Ring stiffness (kN/m^2)	Thermal conductivity W/(m·K) at 20 °C
32	11/13,6/17	16/12,5/10	3,0/2,4/2,0	83,3/41,7/20,4	0,42
40	11/13,6/17	16/12,5/10	3,7/3,0/2,4	83,3/41,7/20,4	0,42
45	11/13,6/17	16/12,5/10	4,1/3,3/2,6	83,3/41,7/20,4	0,42
50	11/13,6/17	16/12,5/10	4,6/3,7/3,0	83,3/41,7/20,4	0,42

If the design temperature of the heat carrier fluid is more than 20 °C then the pressure reduction coefficients shall be considered according to EN 12201-1:2011 (Table 3).

Table 3 —Pressure reduction coefficients for PE 100 (EN 12201-1:2011)

Temperature (°C)	Pressure reduction coefficient
20	1,00
30	0,87
40	0,74

NOTE The allowable operating pressure (PFA) is derived from the following equation:

$$PFA = fT \times fA \times PN$$

where

fT is the coefficient in Table 3;

fA is the derating factor (or uprating factor) related to the application (for the conveyance of water fA = 1);

PN is the nominal pressure taken as a value.

The pressure drop of all components of the BHE or GSHP system should be provided by the designer.

6.2.3 Connection methods

Materials used for pipes and fittings shall meet the requirements of the standards listed in Table 1 independent of the application. Due to the different material specific properties, different connection methods and installation techniques can be applied according to the Table 4. Acceptable methods of joints in the loop are electro-fusion fitting, butt fusion and socket fusion. Fusion processes shall be carried out strictly in accordance with the manufacturer's instruction and procedures by suitably trained personnel.

Table 4 —Connection techniques

Material	Installation without sand bed	Connection method [a]
PE 100	No	EF, BW, SW, CF
PE 100-RC	Yes	
PE-RT (Typ I/Typ II)	No	
PE-X	Yes	EF, CF, SS

[a] BW butt welding
SW sleeve welding
EF electrofusion fittings
CF clamp fittings
SS sliding sleeve

The only acceptable methods for joining buried polyethylene pipe systems shall be heat fusion process by EF. Welding shall only be carried out by a welder who is competent and authorized.

Any welding shall be done in accordance to national regulations. The welding equipment should be automated and regularly calibrated. Welding shall only be carried out by a welder who is competent and authorized.

6.2.4 Metallic materials

When using metal pipes and other components in borehole heat exchangers in exceptional cases (such as heat pipes), attention should be paid to sufficient wall thickness, metal quality and corrosion prevention. In addition, the chemical composition of the groundwater shall be considered. The durability shall be guaranteed by using protection systems. In any case, these analyses shall be carried out in the framework of environmental and risk analyses (standard on environmental and risk protection).

The most common metallic materials used are copper, brass and stainless steel. Besides the requirements given in the standards listed in Table 5, there could be further requirements especially for underground installation, which shall be met also.

Table 5 — Relevant standards for pipes and fittings made from metallic materials

Material	Relevant standards for pipes and fittings
Copper	EN 1057
Brass	EN 12449, EN 1965-2, EN 12168
Stainless steel	EN ISO 1127, EN 10216-5

The utilization of metallic components should be avoided if possible.

6.2.5 Heat transfer fluid

For temperatures in the circuit permanently above 0 °C, water can be used as heat transfer fluid. If pure water is used in the circulation medium, water quality is crucial for corrosion and bacteriological activity (which could lead to corrosion, bio-fouling) and can differ significantly from location to location. Important with respect to corrosion is the pH-value (pH: 8,5 – 9,5), oxygen content (<0,05 mg_{O_2}/l) and the mineral content (electrical conductivity < 100 µS/cm).

For temperatures below 0°C at any point or time of operation, antifreeze shall be added to avoid any freezing damage of the system. The concentration of antifreeze should be as low as possible according to the design of the system and frost protection required for any component.

The heat carrier fluid shall:

— be compatible with all the materials which the fluid could be in contact with. Special considerations should be given to corrosion risks;

— present no aggressiveness towards the materials used in the whole plant;

— be non-hazardous;

— be non inflammable (at least in the typical concentrations used for the purpose of the document).

Typical antifreeze fluids are ethylene glycol, propylene glycol, ethanol and sometimes salt-solutions. It should be considered that some brands include additives against biodegradation and corrosion, which could be toxic in groundwater and persistent.

They differ significantly in density and viscosity, which is important for the pressure drop.

In the design, the actual values at the mixing ratio and operating temperature shall be used.

6.2.6 Backfilling material

6.2.6.1 General

The borehole backfilling material is responsible for complete filling of the borehole without any voids. It shall seal the borehole over the entire length especially to seal any penetrated aquitard and avoid any connection of aquifers. Additionally it shall provide mechanical stability and good thermal contact between the loop and the borehole wall.

6.2.6.2 Grouting material

The grouting material shall fulfil minimum requirements with regard to the slurry density represented by the water/solid value (given by the manufacturer/supplier), the slurry stability and rheology, the compressive strength and the hydration heat.

General grouting material requirements are:

— the choice of backfill or grouting materials shall be adapted to the special geological and hydrogeological settings on a given site;

— permanently stable after curing;

— resistant against chemical attack (sulfate, etc.) by groundwater, soil and gas;

— resistant against temperature influences in operating temperature range of the BHE. If frost resistant grouting is used the frost resistivity behaviour of the surrounding underground shall be considered;

— the grouting material shall not exceed a sedimentation rate of 2 % after 24 h;

— the permeability of the grouting material itself should be equal to or less than $1\ 10^{-10}$ m/s;

— the density of the suspension should be higher than 1 300 kg/m^3 and shall be 250 kg/m^3 higher than the drilling fluid;

— the viscosity of the suspension (marsh time) should allow pumping down the borehole;

— enhanced thermal conductivity is recommended.

The parameters (the list above and the recipe) to be considered of a specific grouting material should be given by special data sheet from the manufacturer of the material. The package material should mention the date of the manufacture.

The user of the grouting material should ensure that the parameters of the grout material producer achieved on-site with the used mixing procedure and the provided water.

Industrially premixed and quality controlled grouting materials are recommended to keep the required quality standard.

Instead of grouting slurry in some cases, swelling clay pellets can be used.

6.2.6.3 Other backfilling materials

Other backfilling material requirements are:

— resistant against chemical attack by groundwater, soil and gas;

— in general, sulfate resistance sealing materials are recommend;

- resistant against temperature influences in operating temperature range of the BHE. If frost resistant sealing is used the frost resistivity behaviour of the surrounding underground shall be considered;
- enhanced thermal conductivity to the value of the surrounding underground is recommended;
- if sealing is required, the permeability of the sealing material itself should be less than $1\ 10^{-10}$ m/s. The sealing should be equal to or better than the surrounding geology;
- the material shall be well sorted (homogeneous).

The parameters to be considered of a specific grouting material should be given by special data sheet from the manufacturer of the material.

The choice of backfill or grouting materials shall be adapted to the special geological and hydrogeological settings on a given site.

6.3 Component selection criteria

6.3.1 General

The material and component selection shall be based on the material properties given in 6.2, the environmental impact and the specific design criteria of the project.

6.3.2 BHE loops

In the majority of the systems, the operational temperature is significantly below 40 °C, higher temperatures could occur only in special applications. Typically, a hydraulic system is pressurized to avoid cavitation in the circulation pump. The pressure class is determined by the sum of the hydrostatic and the operational pressure.

The selection criteria of BHE loop materials are:

- operational temperature;
- operational pressure;
- depth of the water table in relation to the depth of borehole determines additional hydrostatic pressure;
- general ground quality;
- loop foot protection, in case of sharp rock in the borehole to avoid any damage;
- groundwater level;
- pressure drop at the required flow rate;
- thermal characteristics of the loop.

6.3.3 Horizontal pipes

The selection of the horizontal piping material shall meet the same temperature requirements as the BHE loop pipes. In 6.2.2 also the properties regarding connections are given.

6.3.4 Manifolds

Manifolds including all fittings shall meet the same requirements on temperature resistance and pressure class as the horizontal and/or connecting pipes. The same applies for the design life.

The selection of manifolds shall consider the placement outside or inside the building.

Manifolds need to have easy access for inspections and maintenance. It is necessary to have a venting device in the manifolds for air purging. If the manifold is located in an underground manifold chamber, the traffic load should be considered.

6.3.5 Heat transfer fluid

The heat transfer fluid shall comply with criteria in 6.2.5.

The selection criteria should be:

— anticipated operating temperature;

— required temperature safety margin;

— materials compatibility;

— environmental considerations (e.g. water in groundwater protection area).

7 Design

7.1 Steps of Design

The design consists in the overall combination of the following steps:

— collection of information: all information required for the case study shall be collected;

— definition of geological characteristics of the ground (thermal properties, drillability, easiness of installation of pipes, groundwater flow, etc.);

— select possible lay-out of the BHE system, with reference to the available space;

— temperature selection: decision on which temperature limits shall be fixed in winter and summer operating conditions;

— sizing, number of individual BHE, depth of BHE, spacing between BHE;

— hydraulic design;

— heating and cooling thermal capacity and peak load duration;

— heating and cooling energy demand (base load);

— system performance for different operating conditions.

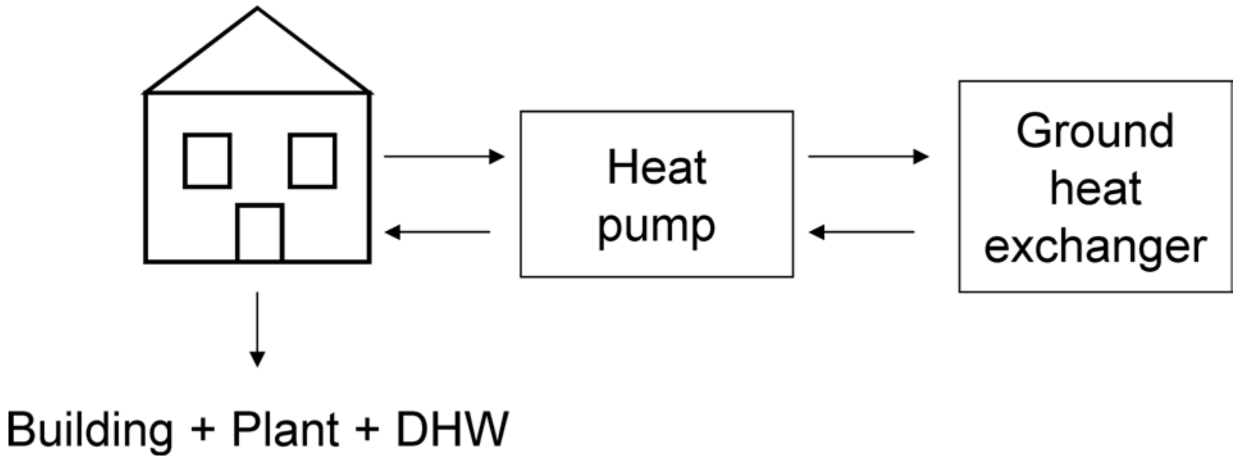
Sizing is the core part of the design and shall be interconnected with the design decisions in an iterative way.

Once the sizing has been completed and the design conditions are satisfied, then the hydraulic design takes place.

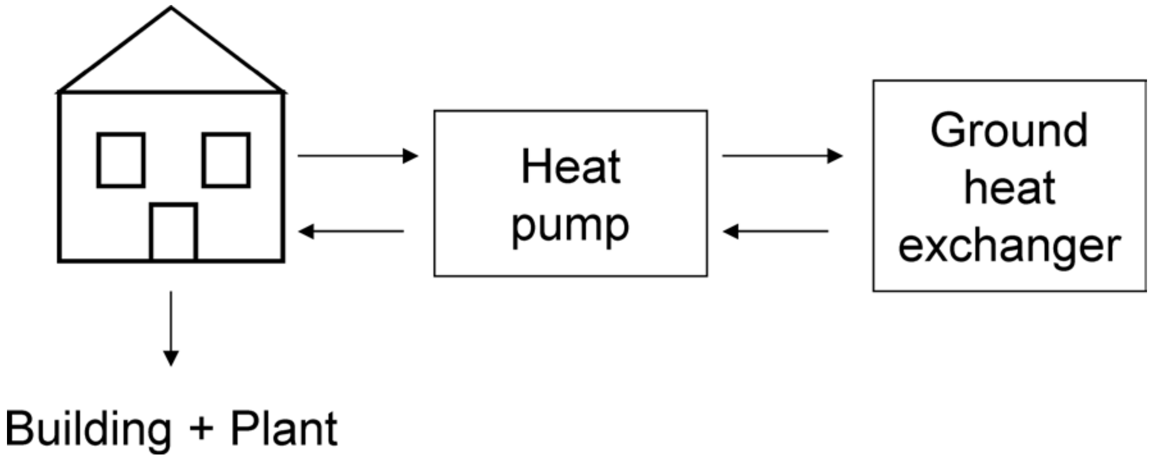
7.2 Sizing

7.2.1 General

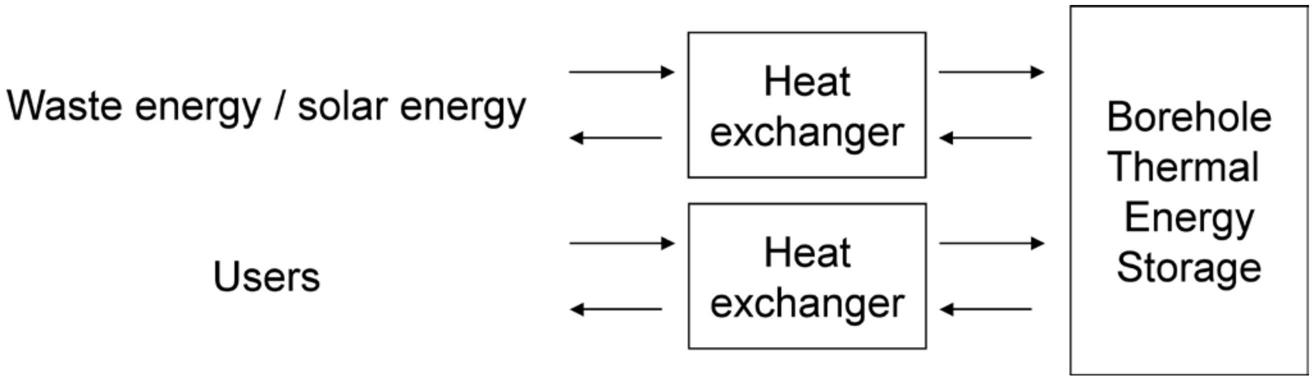
The present document defines the procedure for determining the design of heat exchanger system. BHE can be used for the coupling with heat pumps for heating and/or cooling purposes. In this case the BHEs is part of a Ground Source Heat Pump (GSHP) system. BHEs can also be used for direct transfer of ground thermal energy without heat pump (direct heating/cooling). BHEs can also be used for storing energy in the ground (usually waste heating or solar thermal energy). The current document covers all these technologies, which are described on the Figure 4.



a)



b)



c)

Figure 4 — BHE system (DHW: domestic hot water)

The production of heating, cooling and domestic hot water can be fully covered by the geothermal system or may be associated eventually to another heating/cooling system and/or other renewable energy sources.

7.2.2 General methodology

7.2.2.1 General

The general methodology to achieve the proper sizing of a BHE field is described in Figure 5.

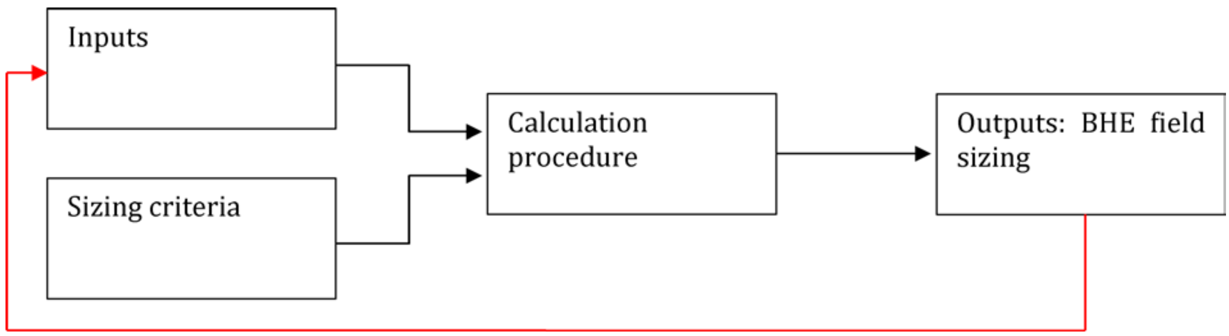


Figure 5 — General sizing methodology

7.2.2.2 Inputs

The inputs below shall be considered for the design phase:

— thermal properties of the borehole and the ground (specific heat capacity, thermal conductivity, undisturbed ground temperature profile). Thermal conductivity, undisturbed ground temperatures can be determined *in situ* by the Thermal Response Test procedure, which is described in detail in 7.2.4. The thermal borehole resistance can be calculated from the test results and the geometry of the BHE construction;

— load input: energy demand (kWh) and peak power (kW and duration in hours). For direct transfer systems, and direct heating/cooling systems, these inputs relate to loads for BHEs. For GSHP systems, these inputs usually relate to loads for the heat pump, i.e. at user/building side;

— energy performance of the ground source heat pump system for the different operating modes of the project;

— expected geometry of the BHE (borehole diameter, shank spacing) and properties of the filling material (e.g. thermal conductivity, specific heat capacity, density);

— heat transfer fluid properties at operating temperatures (viscosity, density, specific heat capacity, thermal conductivity);

— heat transfer fluid mass flow rate;

— available area;

— operation life of the project.

7.2.2.3 Sizing criteria

The designer shall define also sizing criteria, in accordance with the state of the art, his own experience, and possibly specific requirement from the building owner/constructor. The sizing criteria shall comprise at least:

— operating temperature constraints on the heat transfer fluid inside BHE loop. Two different constraints can be defined:

  — a BHE inlet temperature lower limit shall be defined for the heating mode, i.e. ground heat extraction mode. This lower limit shall be properly defined to prevent failure due to freezing of ground surrounding the BHE, to prevent freezing of heat transfer fluid, or to comply with the operating conditions of the heat pump. This lower limit may be above zero, for example when BHE loops are filled with pure water;

  — a BHE inlet temperature upper limit shall be defined for cooling mode, i.e. ground heat injection mode. This upper limit shall be defined to ensure that the system meet requirements for BHE loop material lifetime and environmental constrains.

Other additional sizing criteria may be chosen by the designer, such as a global efficiency level of the geothermal system, temperature constraints on the surrounding ground, the pressure drop of the hydraulic circuit.

A proper BHE design shall comply with the sizing criteria, which have been defined for the entire operation life of the project.

The depth of the horizontal piping has to be sufficient in order to limit the thermal influence from the surface and reduce the risk of mechanical damages. Insulation may be installed if necessary or if the designer shows the advantages. The diameter of the horizontal piping shall be chosen by limiting the pressure losses, taking into account the operating temperature, the roughness of the pipe, the increase in the viscosity in case of anti-freezing fluids, usually in the horizontal piping it could be recommended to work in laminar conditions. Also in this case the pressure losses contribute in the auxiliary power of the pump.

7.2.2.4 Calculation procedure

The design should establish the correct sizing of the BHE as a function of the inputs that comply with the sizing criteria defined by the designer. Depending on local hydrogeological conditions the mechanism of heat transport in the ground can be mainly conductive, mainly convective or mixed.

NOTE Most design methods do not account for ground water flow

Depending on the type of BHE system and on the accuracy level required, different calculation procedures may be implemented. These procedures are described in 7.2.5.

7.2.2.5 Outputs

All the parameters defining the BHE field geometry constitute the outputs of the sizing procedure:

— number and depth of BHE;

— type of BHE selected and pipe dimensions;

— spacing between boreholes, and layout (geometry) of the entire BHE field;

— thermal resistance of the borehole;

— operating temperatures during the operational life;

— the maximum pressure drop.

The design should document the inputs used, the calculation results, a layout drawing of the BHE system and horizontal piping, the schedule and specifications in a report.

7.2.3 Thermal properties of the ground

From the thermal point of view, the ground may be subdivided into two different layers:

a) a more shallow layer where the ground is affected by the external atmospheric conditions, i.e. dry bulb temperature, solar radiation infrared heat exchange with the sky. This part can be used for the horizontal piping evaluations and for the first part of the BHE, but is usually not considered in the calculations;

b) a deeper layer where the ground is not affected by the seasonally varying external atmospheric conditions. The properties of the undisturbed ground are those used as sizing procedure inputs.

In both cases, the ground thermal conditions can be influenced by the presence of water, which, depending on its velocity, could affect the heat transfer of the ground heat exchanger and on the possible seasonal thermal storage.

Ground thermal properties that are considered as inputs for BHE sizing procedure are the following ones:

— volumetric heat capacity of the ground;

— ground thermal conductivity;

— undisturbed ground temperature.

Other thermal properties may also be taken in account:

— geothermal gradient;

— geothermal heat flux.

Thermo-physical characteristics of the ground may be evaluated by a geological survey of the site. As a preliminary analysis previous geological analyses in nearby locations or geological maps of the zone can be analysed as well as available climatic data.

Such evaluations can be later confirmed in the realization phase and maybe validated with a TRT.

As reference for the calculations the most common types of ground and the related typical values of the thermal properties are reported in Annex D.

Once known the thermal properties of the ground layers (λ_h) and their thicknesses (D_h) the following equation can be used for calculating the average thermal conductivity of the ground (λ) to be used in the calculations:

$$\lambda = \frac{\sum_{h=1}^{n} \lambda_h \cdot D_h}{\sum_{h=1}^{n} D_h}$$

The volumetric heat capacity can be calculated as average for the different layers:

$$\rho \cdot c_p = \frac{\sum_{h=1}^{n} \rho_h \cdot c_h \cdot D_h}{\sum_{h=1}^{n} D_h}$$

As for the volumetric heat capacity in unconsolidated grounds, the following equation can be used for each layer:

$$c_h = (2{,}7\ \varphi_h + 1{,}9\ \varphi_m + 4{,}2\ \phi)\ \mathrm{MJ/(m^3\ K)}$$

where

c_h : Volumetric heat capacity soil layer h (MJ m^{-3} K^{-1});

φ_h : fraction of organic material;

φ_m : fraction of mineral material;

ϕ : fraction of water (usually pore space).

7.2.4 Thermal Response Test (TRT)

7.2.4.1 General

The TRT procedure presented below is the classical type 1 TRT based on injection a constant heat flux. Other types of test exist and could give more information depending on the local conditions.

The measurement of the response of a system on the stepwise change of an input parameter is a common physical principal to determine certain physical properties. In the context of the thermal use of the underground with borehole heat exchangers, this procedure is used in a thermal response test (TRT). In a TRT, a specified and constant thermal power is injected in (or extracted from) the underground and the temperature development at the borehole inlet and outlet is measured. In combination with a mathematical model, the temperature development allows the determination of thermal parameters like the thermal conductivity of the underground and the borehole thermal resistance of the BHE, parameters which are typically used in design calculations. A TRT is carried out with a mobile test equipment, which is installed directly at the borehole during the test.

7.2.4.2 Theoretical Background

A theoretical model of the heat transport between the heat source (sink) BHE and the surrounding underground is the basis of the evaluation. The model parameters are determined to fit the calculated fluid-temperatures to the measured ones. Typically, the thermal conductivity of the underground and the borehole thermal resistance of the BHE are the determined model parameters.

Evaluation procedures mainly differ from the degree of detailing of the used model, which indeed has an impact on the design of the test equipment and the test performance. The most common model is the line source approximation.

7.2.4.3 Line Source Approximation

The mean fluid-temperature as a function of time for the one-dimensional conductive heat transport of line source in the underground can be described by Formula 1 if the following limitations (simplifications) are complied with:

— the heat transport in the underground results from conduction only;

— the underground is assumed to be homogenous with uniform thermal properties (in practice this means that the average equivalent thermal conductivity of the soil profile is obtained);

— the thermal properties of the components in the borehole (e.g. pipes, borehole filling, heat transport fluid, etc.) are considered to be equal to them of the underground;

— the underground has a uniform temperature before starting the test;

— the heat is injected (extracted) by an infinite line source in the centre of the borehole with constant power

$$T_f\left(t\right) = \frac{\dot{Q}}{H \cdot 4 \cdot \pi \cdot \lambda} \cdot \ln\left(t\right) + \frac{\dot{Q}}{H} \cdot \left[\frac{1}{4 \cdot \pi \cdot \lambda} \cdot \left(\ln\left(\frac{4 \cdot a}{r_b^2}\right) - \gamma\right) + R_b\right] + T_b \qquad (1)$$

where

$T_f(t)$	mean fluid-temperature (arithmetic mean fluid inlet and outlet temperature at time t in °C;
t	time in s;
$\dot{Q}$	total heating power injected into the underground via the BHE in W;
H	length of the BHE in m;
λ	thermal conductivity of the underground in W/(m·K);
a	thermal diffusivitys; $a = \lambda / c_v$ in m^2/s;
c_v	volumetric heat capacity of the underground in J/(m^3·K);
r_b	borehole radius in m;
γ	Euler-Mascheroni-number ≅ 0,5722;
R_b	borehole thermal resistance in K/(W/m);
T_b	undisturbed ground temperature in °C.

By merging the parameters constant in time Formula 1 can be can be simplified to a linear function of the logarithm of time with the slope k and the intercept m (Formula 2)

$$T_f\left(t\right) = k \cdot \ln\left(t\right) + m \qquad (2)$$

From this results:

$$\lambda = \frac{\dot{Q}}{H \cdot 4 \cdot \pi \cdot k} \qquad (3)$$

and

$$R_b = \frac{H}{\dot{Q}} \cdot \left(m - T_b\right) - \frac{1}{4 \cdot \pi \cdot \lambda} \cdot \left(\ln\left(\frac{4 \cdot a}{r_b^2} \right) - \gamma \right) \tag{4}$$

However, this approximate solution is valid only for a time, which is not to close to the start of heating at t = 0 s hence for a time bigger than the theoretical minimum time criterion:

$$\frac{a\, t_s}{r_b^2} \geq 5$$

where

a thermal diffusivity; $a = \lambda / c_v$ in m^2/s;

t_s starting time of the evaluation in s;

r_b borehole radius in m.

Additionally a physical minimum time criterion exists, defining the validity of the evaluation model used, which is related to the deviations of the real heat transport from the ideal model assumptions. For estimation of the physical minimum time criterion, the convergence of the sequential forward-evaluation can be used. The evaluation is carried out stepwise for a time interval t_S to $t_S + n\,\Delta t$ (n = 1, 2 …), thus the result for λ becomes a function of the length of the evaluation time interval. This successive increase of the evaluation time interval results in a curve of λ, which only converges against a constant value (result), if:

1) model assumptions are correct;

2) starting time of evaluation t_S is not too small;

3) measurement/evaluation time is long enough.

A too small measurement interval results in high statistical variability. For a valid test evaluation the curve should converge within a default interval $\lambda \pm \Delta\lambda$ ($\Delta\lambda/\lambda$ = ± 5 %) over at least 20 h.

7.2.4.4 TRT Test Apparatus

The requirements on a TRT test apparatus – hydraulic circuit, sensors and data acquisition – as well as the planned test performance are closely related to the evaluation method.

Typically, a preselected constant heating power is injected in the BHE. It is recommended to design the hydraulic concept for testing of different types of BHEs (single-U, double-U, etc.). Also safety issues like thermal expansion of the fluid, prevention of overheating and flow problems shall be considered. The thermal power shall be constant for the use of the line source approximation for test evaluation. The injection power shall be adjusted to the length of the BHE in order to achieve a reasonable ΔT (inlet, outlet) which is important for high accurate temperature measurement. The heat capacity of the fluid selected for the test shall be well known. High effort in the quality of the test apparatus has a significant impact on the quality of the test.

A typical test setup is shown in Figure 6 — Typical test apparatus

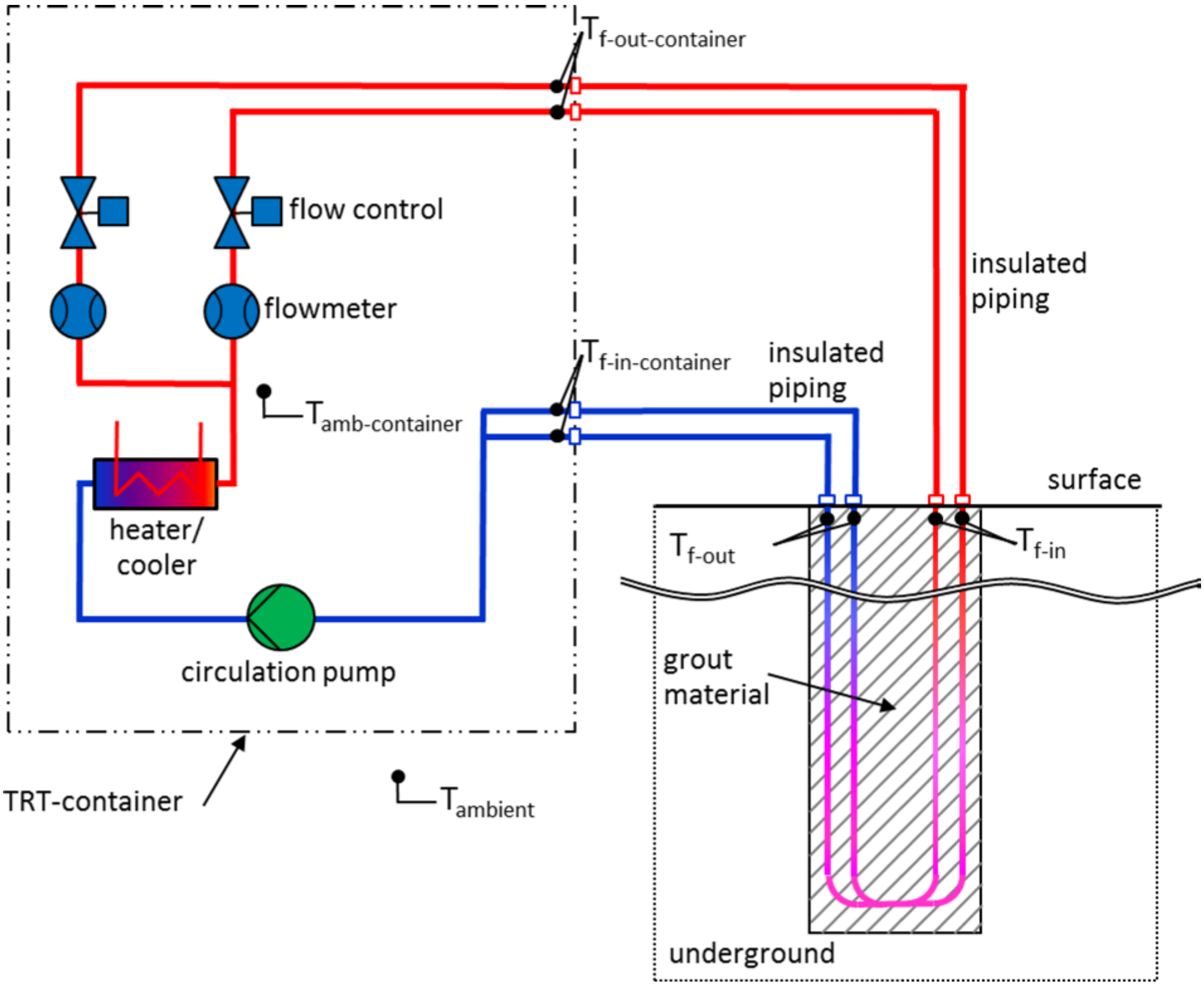


Figure 6 — Typical test apparatus

7.2.4.5 TRT Procedure

The test parameters shall be selected closely to the operational parameters of the later system operation and the test-BHE should be representative for the location and the BHE system planned.

Reliable information on the geology at site, the borehole, the filling of the borehole and the BHE is required for a resilient test. It is important that the construction of the BHE is finished and the borehole filled up to top. The BHE loop should be filled with fluid, which is in thermal equilibrium with the ambient underground. Activities in the surrounding of the tested BHE, which can affect the measurement, should be avoided.

The apparatus is filled with fluid, air purged and hydraulically connected to the BHE loop. It is recommended to insulate connecting pipes to avoid ambient influences on the measurement results.

The undisturbed ground temperature is measured directly before starting the test. It is important that the fluid is in thermal equilibrium with the surrounding underground. This measurement can be done either by lowering thoroughly a slim temperature sensor into the BHE loop or by circulating the fluid in the loop and measuring the temperature at the outlet for the first circulation of a fluid element through the loop. It is recommended to use turbulent flow. The test should not start until the thermal impact of the drilling and the backfilling procedure has disappeared.

After finishing the measurement of the undisturbed ground temperature the TRT can be started. A constant thermal power at constant flowrate can be achieved easily by controlling the electric power of the heating elements by using the temperature difference at the BHE inlet as measuring parameter. Thus disturbing ambient influences can be compensated easily.

7.2.4.6 Test Evaluation

The line source approximation described in 7.2.4.3 for test evaluation requires minimum effort and approximation errors are negligible small if all boundary conditions comply with requirements of the model.

The mean fluid temperature results as a linear function of $\ln(t)$ (Formula 2 and Figure 7 —Linear regression of the fluid mean-temperature as function of $\ln(t)$) and thermal conductivity can be calculated from these measurements by using Formula (3).

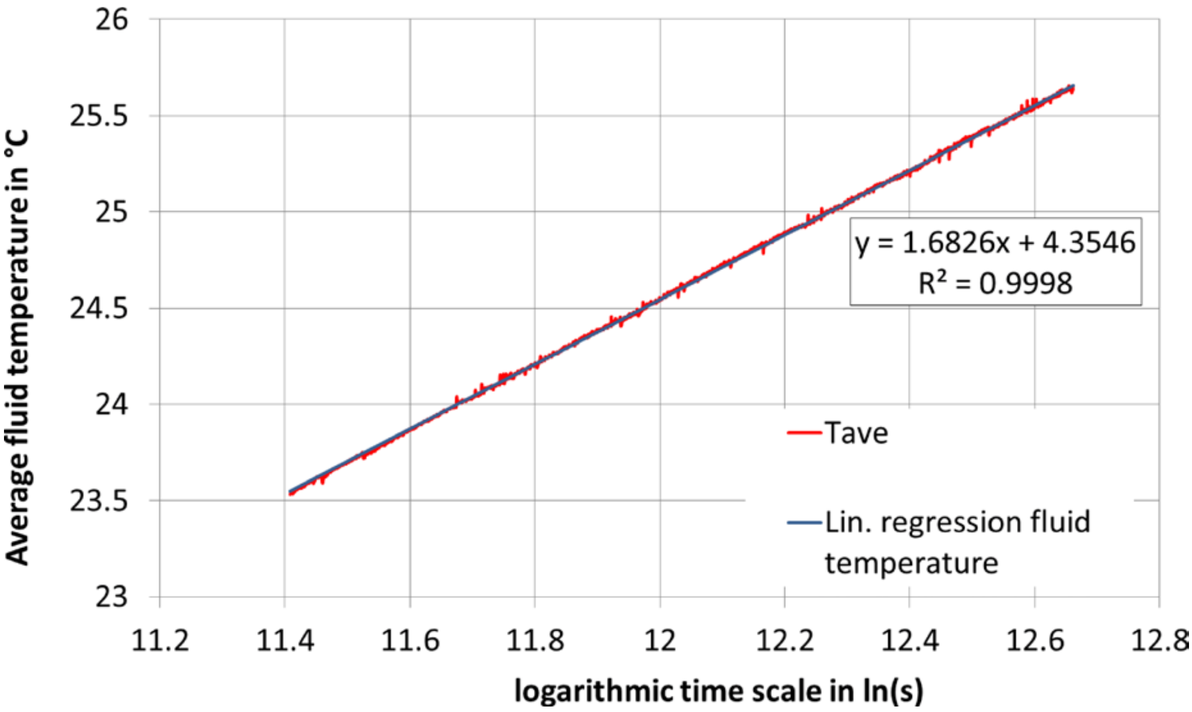
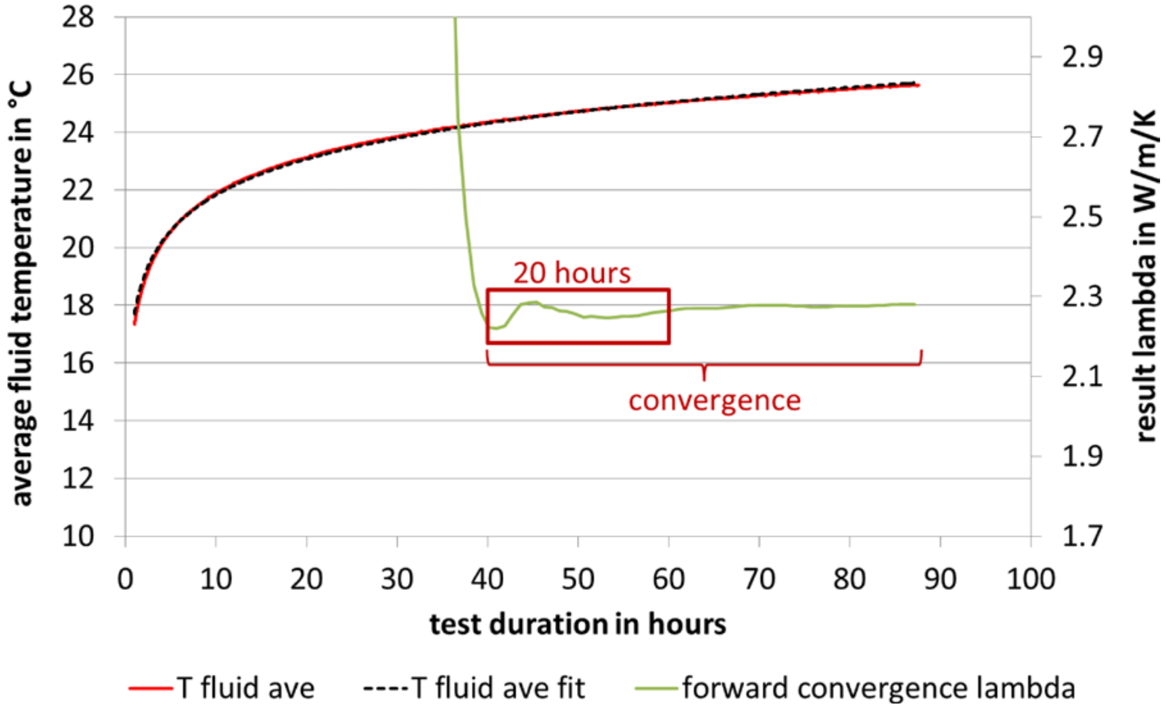


Figure 7 —Linear regression of the fluid mean-temperature as function of ln(t)

The borehole resistance and the volumetric heat capacity remain as undetermined parameters. It shall be considered that only one of these two can be determined if the other one is estimated. As the volumetric heat capacity is of minor influence on the temperature response and estimation is relative easy, this value is fixed as a boundary and should be given in the evaluation together with the results. The thermal borehole resistance can be determined from the Formula 4. A typical curve of the fluid mean temperature and the forward convergence curve of a TRT is shown in Figure 8.



Key

T fluid ave

T fluid ave fit

Forward convergence lambda

Figure 8 — Time dependent convergence of the thermal conductivity by using sequential forward evaluation

7.2.4.7 Correct Use of the Results

As the model used for evaluation of the TRT is an approximation, which requires several assumptions, the evaluated parameters shall be used directly only if the design model is conformable or compatible to that of the TRT evaluation. The use of a different design model requires again checking of the determined parameters by means of the measured data.

Additionally the agreement or consistency of further boundaries and operational parameters of TRT and system design shall be considered. Generally, operational parameters of TRT and the planned system should come close together; sometimes deviations cannot be avoided like:

— type of heat transfer fluid: water for TRT and water/antifreeze for the system;

— temperature regime: heating for TRT and cooling for the system;

— flowrate: different values for TRT and the planned system;

— construction of BHE: test BHE could differ from that of the system (e.g. length, borehole diameter, filling material).

In such cases the borehole thermal resistance shall be checked and if necessary converted with an appropriate borehole resistance model.

7.2.4.8 Documentation of Results

All information used for the performance and the data evaluation of the TRT and all results shall be documented in the report to be available for the later design. Monitoring data shall be archived and shall be available for later check with the design model.

7.2.5 Calculation procedure

7.2.5.1 Introduction

The aim of the calculation procedure is to ensure that the designed BHE complies with the sizing criteria. The main criteria are the minimum and maximum operating temperatures of the heat transfer fluid inside the BHE loop over the entire period under study.

The operating temperatures of the heat transfer fluid, at BHE loop inlet and outlet, are closely related to the current temperature distribution inside the BHE, the surrounding ground, and to the current level of thermal power exchanged with the ground, i.e. the load to the ground.

One of the problems with calculating the temperature response of the BHE is that the temperature in the ground volume changes as a function of the energy exchanged with the ground during the operational life of the system. Therefore, both the total energy exchanged (base load) with the ground as well as the maximal thermal capacity (peak load) need to be known.

From the energy demand profile of the user (“building”), the net energy load on the ground is calculated by:

— either a constant performance value is used for the different operating modes;

or

— a correlation between fluid temperatures and efficiency (usually a heat pump efficiency curve) is specified that related the system efficiency to the actual temperatures in the source and user circuits.

In principle the net load to the BHE system is calculate by:

— heating net load source circuit = user load * ((COP-1)/COP);

— cooling net load source circuit = user load * ((EER+1)/EER).

In many design software, the local and global process are de-coupled. The global process calculates the temperature response of the ground volume as a function of the energy load (kWh) while the local process calculates the fluid temperature as a function of borehole thermal resistance and specific heat flux (W/m) as well as duration of the peak load.

Depending on the calculation method employed, the designer might need to specify either:

— load (kWh) per hour or shorter time step for a full operational year;

— load (kWh) for each operating mode per month, or season and additionally thermal capacity and peak load duration (hours);

— total yearly energy load and thermal capacity and peak load duration.

Additional auxiliary systems have to be considered to specify the specific load of the heat pump

The designer might also need to specify the efficiency either by:

— temperature dependent efficiency correlations for the heat pump (including circulation pumps);

or

— constant efficiency factors for the different operational modes, where the factors are selected in a “conservative” manner (relatively high heating COP and relatively low cooling EER).

7.2.5.2 BHE models

The local heat transfer process in and around the borehole has a small spatial scale and short time scale. The global heat flow in the ground and thermal interactions between adjacent boreholes in a BHE field has a very large spatial and time scale. This is computationally challenging. Consequently, many different methods and software have been developed for the modelling of heat flow between the BHE system and the ground, ranging from analytical to numerical solutions.

In the practice of design of BHE systems usually the local and global process are de-coupled, the local process (heat exchange between the heat exchanger fluid and surrounding ground) is treated by the borehole thermal resistance while the global heat transport in the ground volume and between the individual BHE's is generally calculated using so-called G-functions. The G-functions are dimensionless functions describing the relation between temperature change, load and time for a specific BHE configuration, derived from more complex numerical or analytical solutions.

The designer shall indicate and should justify which methodology has been used for sizing the ground heat exchangers. Criteria for the selection of a specific methodology can be:

— occurrence of groundwater advection;

— relative importance of near surface temperature gradient (especially for BHE shallower than 40 m);

— dynamic coupling between BHE system and building load, for instance in hybridized systems;

— special configurations for which no G-functions are available.

7.2.6 Simulation

7.2.6.1 Starting time

Depending on whether the system is mainly used in heating mode or cooling mode the start time could affect the design result.

If the design calculation starts with the heating season, the ground is first cooled and all subsequent cycles are affected by this starting point. The same is true for starting the design calculation with a cooling season. When a system is used mainly for heating, starting with the heating season is in that sense a conservative design. However, if it is known that the actual system is commissioned before the cooling season, a significant reduction of the borehole heat exchanger size could be possible. The same is true for a system mainly used for cooling: starting with a heating season will be beneficial.

The designer evaluates the effect of the starting time (heating season or cooling season) on the result of the design and explains why a specific starting time has been selected for the calculation. If a conservative design is required in a heating dominated system the starting season is the heating season and in a cooling dominated system the starting season will be the cooling season.

7.2.6.2 Simulation/calculation time

The total simulation time, in years, can be an important parameter in the design calculations (see Annex B). As the operational life of a borehole heat exchanger system is very long (at least 50 years) the simulation time used in the design calculations needs to be in accordance with this operational life to ensure correct functioning and efficiency of the system.

Often default calculation length is used, e.g. 25 years. The calculation time needed depends on a number of factors for instance the total field size, spacing between the boreholes and the energy balance.

The sizing criteria relate to thresholds on the heat transfer fluid temperature (a low limit and/or a high limit). The designer shall plot the fluid temperature resulting from calculation as a function of time. These or at least the yearly highest or/and lowest temperature over the entire calculation period can be used to check the compliance of the simulated design with sizing criteria. Since the highest or lowest temperature is attained on the long term, at the last years of the simulation period, the total number of simulation years is a relevant parameter and shall be determined for each design studied.

For small systems, temperature variation rate tends to decrease rapidly, and a simulation period of 25 - 30 years is sufficient.

In a system where the heat extracted in winter and for tap-water production is balanced with the heat rejected during summer operation, the simulation time is of no consequence as the cycles repeat every year whereas in an imbalanced design the simulation time needed depends on the total field size.

To assess the required simulation time for larger borehole fields (either made up of individual systems or of collective systems) a saturation curve should be constructed. This curve is based on the normal system design parameters with only the number of time steps (usually years) is varied by stepwise adding five years to the total calculation period. The change in temperature, as a function of increasing length of the calculation period, is plotted. The simulation time is considered to be sufficient if the change in temperature with regard to the previous simulation period is less than 0,5 K (repeatedly adding 5 years to the calculation period).

7.2.6.3 Background

In an imbalanced design, the cumulative yearly energy imbalance on ground surrounding the BHE's leads to ground temperature change from one year to the next, which then also affects the temperature response variation, e.g. heat transfer fluid temperature. Due to thermal diffusivity effects from the ground surrounding the BHEs to the surrounding larger ground volume, the temperature variation rate tends to decrease in the long term as the total ground volume thermally activated increases.

For larger systems, due to less effective diffusivity effect from ground surrounding the BHEs to outlying ground, the temperature variation rates generally decrease more slowly than for small systems. Moreover, reducing the BHE spacing results also in higher change rate in temperature response from one year to another.

7.2.7 Hydraulic design

The hydraulic design consists in defining the mass flow rates, the pressure drops of the circuits, the selection of manifolds and valves, the choice of the pump and the possible hydraulic kit for the heat transfer fluid circuit.

The hydraulic design includes the report of the calculations as well as the drawings of the circuits (vertical and horizontal) with all required data such as pipe diameters.

The hydraulic design comprises:

a) size the pipes in such a way that a specified Reynolds number can be achieved;

b) calculate the pressure drop in a pipe system.

The flow rate is a function of a (selected) Reynolds number:

$$v = \frac{\mu \,\mathrm{Re} / \rho}{D}$$

In the vertical piping, a turbulent flow is favourable for the heat transfer but care should be taken regarding a pressure drop. In the horizontal connection piping, a laminar flow reduces the pressure drop.

— Expansion

The expansion vessel shall be properly designed taking into account the whole volume of fluid (inside the BHEs, in the horizontal piping, in the thermal room) and the operating temperatures of the heat carrier fluid.

8 Construction

8.1 General

The construction of borehole heat exchanger is in several countries subject to national legislation like the water law and/or mining law, etc. The level of legislation on the construction of borehole heat exchangers varies significantly in different countries and should be considered. In some countries, they can even vary on a regional level of federal states.

8.2 Site Preparation and planning

The accessibility, load-bearing capacity and space requirements (building site equipment in general, free access to the drilling point, transport routes, etc.) are to be ensured. The stability of buildings and/or foundations should not be endangered. Sufficient distances between boreholes and existing buildings should be maintained. Topsoil shall be removed and/or the site levelled if required. Fencing around the drilling operation could be required.

The location should be checked for underground infrastructure like media supply and disposal pipelines (gas, electricity, water, sewage, communication and data cables etc.). Corresponding documents and plans should be obtained and kept available during all construction work.

The site shall be checked for unexploded ordnance and site pollution. It shall be verified if any special permit are needed or regulatory constraints exist.

Adequate supply of electricity (voltage, power) and water (pressure, volume flow) as well as the disposal of waste water, soil, drilling cuttings, flushing and waste should be ensured.

Keep all relevant documents ready – e.g.: drilling permit, drilling certificates, mapping of underground infrastructure, information about drilling aspects (e.g. artesian groundwater).

Other limitations of the operating possibilities are to be observed.

8.3 Drilling

8.3.1 General

Drilling companies involved in BHE projects shall make sure that qualified staff is operating any drilling activities and warrant that equipment conforms to health and safety standards and is regularly maintained and checked. This can be warranted through a recent maintenance certificate.

The drilling method and technology shall be chosen according to the local geology and hydrogeological situation. The driller is responsible for final selection and implementation of the drilling method. Suitable materials, equipment and tooling should be available at the drilling site for immediate action in the event of accidents. Correct Personal Protection Equipment should be used, risk assessment should include but not be limited to assembly points, routes of escape and location of nearest hospital. On building sites first aiders should be identified, etc.

If a risk is identified, materials for the management for example of gas and artesian groundwater should be kept in stock in such a way that they can be used at short notice at any time. During drilling work, care shall be taken to ensure that the handling of materials does not lead to groundwater contamination. The drilling diameter should be chosen in such a way that damage-free insertion of the BHE pipes and gapless filling is possible. A smaller diameter is generally favourable for low borehole thermal resistance, but it shall be large enough to allow safe installation of the BHE and proper backfilling.

8.3.2 Drilling diameter

The choice of borehole diameter shall be adapted to the type of ground to be drilled in order to avoid the BHE loop blocking during its installation. The borehole diameter will be defined according to geology, depth and the installed BHE loop geometry.

8.3.3 Drilling fluid

Drilling fluid additives should be harmless to the groundwater. The water used to mix the drilling mud should be of drinking water quality. Groundwater may be used, if the quality is suitable. Drilling fluid additives should be avoided as much as possible.

If necessary only mud additives [1], which do not cause any chemical/biological changes in the underground, should be used for drilling. Drilling mud should be removed from the borehole and disposed of properly once the drilling work has been completed.

If unexpected losses of the drilling mud occur, safety measures shall be taken immediately.

8.3.4 Monitoring and Documentation of the Drilling Process

During drilling a minimum of monitoring is required. Observations regarding geology and hydrogeology shall be documented in a drilling log e.g. to check the geological assumptions of the design.

The petrographic sequence of layers encountered during drilling shall be documented by sampling. In addition, the groundwater levels shall be entered in the depiction of the petrographic sequence if the drilling method allows determining the groundwater levels.

The borehole log should have an identification label including the following information site name, date, position and identification of borehole, name of company and driller, name of sample examiner, etc.

The cuttings should be stored in suitable water tight containers, these should be permanently labelled with the following information: site name, date, position and identification of borehole, name of company and driller, name of sample examiner, the designation of the borehole, the depth of the sampling, etc.

The geological and hydrogeological situation can require a geophysical measuring of BHE drillings. The geophysical logs can e.g. help to verify the geological profile and hydrogeological situation. The choice of the method depends on the given situation.

In the case of large installations and unclear geological and hydrogeological situations an exploration drilling can be recommended. Then maybe also geophysical measurements and Thermal Response Test might be recommended. Normally the exploration drilling could later be used as a BHE.

8.3.5 Backfilling

Backfilling of a borehole heat exchanger serves different purposes:

— providing mechanical stability to the borehole: avoid collapse and damage to the installed BHE loop;

— provide thermal contact between the BHE loop and the borehole wall;

— provide environmental protection of the subsurface through sealing of the top layers;

— prevent mixing of water qualities by sealing aquitards;

— prevent upwelling in confined aquifers with artesian water.

8.4 Borehole Heat Exchanger Loop

A standard borehole heat exchanger loop consists typically of a U-bend bottom and continuous (one piece) vertical pipes. These borehole heat exchanger loops shall be produced and tested in the factory. The vertical part of the pipe shall not have any connection except to the bottom of the loop. It shall be thoroughly packed and transported to the construction site. Careful handling and safe storage at the site prevents damage to the BHE before installation.

The connection between the U-bend at the foot of the BHE loop and vertical pipes should be welded in the factory (Figure 3). The welding equipment should be automated and certified. Welding shall only be carried out by a welder who has been certified according to the national guidelines and who has a test certificate valid for the welding procedure. Every welding performed shall be documented. The production should be quality controlled by external supervisor.

For traceability BHE pipes should be marked with a manufacturer's identification, information on the material, batch identification and with the pipe dimension (SDR / pipe spec). Length markings should be printed on the pipes. It should start with 0 at bottom and increasing to the top.

Exceptions for special BHE constructions are possible like welding in the vertical part of coaxial BHEs, which have typically a large pipe diameter. In this case special welding devices and procedures for testing are required. The welding in the vertical part of coaxial BHE pipes could be done on the site providing that the applicable technical rules for the process are adhered. Welding shall only be carried out by a welder who has been certified according to the national guidelines and who has a test certificate valid for the welding procedure. All connections made on site should be documented.

8.5 Borehole Heat Exchanger Loop Installation

The heat exchanger loops in the boreholes typically comprise of either single-U, double-U, multi-U or of coaxial geometry to provide the required surface for heat transfer to the fluid (Figure 2).

Careful handling and safe storage at the site prevents damage to the BHE loops before installation. Therefore BHE loops shall be stored on pallets to ensure they are not directly in contact with the ground and the possible sharp stones that could exist at the site. The BHE loops should be visually inspected regarding scratches or other physical damages before the installation. Damaged pipes shall not be installed.

Installation of the BHE loops should be done from a decoiler to avoid damages.

For installation of the BHE loop in water/mud filled boreholes, it shall be filled with water and provided with a weight at the bottom before installation to compensate uplift.

During filling the BHE loops, the pressure difference between outside and inside the pipe shall be kept below collapsing pressure.

All connections shall be done by welding using socket welding fittings and preferably sleeve welding with integrated heating elements (electrofusion fittings), butt welding on the construction site should be avoided. Compression-fittings/clamp-fittings shall not be used underground.

The BHE loop head shall be sealed temporary with a fixed cap to avoid ingress of any dirt into the pipes until the horizontal piping is not connected.

8.6 Backfilling and Grouting procedure

8.6.1 General

The general purpose of backfilling is to provide sealing of the borehole along the whole borehole length and up to the surface. Backfilling is also responsible for good thermal contact of the BHE loop to the surrounding ground. Depending on the geological and hydrogeological situation, different constructions of BHEs are possible which require different types of sealing.

Sealing of boreholes by backfilling is of great importance to ensure that all aquitards, which have been penetrated, are resealed so that all groundwater pressure levels remain unchanged. The sealing of the BHE is not only dependent on the used backfilling material, but also from the used installations and the characteristic of the borehole. Thus the overall system consisting of pipes, backfilling material, geometric arrangements and the surrounding underground shall be considered. The backfilling of the borehole should be done directly after the installation of the BHE-loop. Specific injection pipes are required. A good thermal contact and sealing of BHE's is achieved by complete backfilling without any holes, air and water inclusions. A backfilling of the annular space from the ground surface is not allowed.

8.6.2 Grouting procedure

Thus, the grouting should be done in a type of contractor mode continuously from the bottom to top of the borehole but leaving the injection pipe in the borehole. Therefore, an injection pipe shall be installed together with the BHE loop down to the deepest point of the borehole. In special geological and hydrogeological settings, deep boreholes, etc. additional injection pipes in lower depths could be required. In such situation, the contractor mode backfilling process shall done stepwise.

If a casing is required, the casing can be removed from the borehole. Then the BHE is backfilled afterwards, but the suspension level should be kept always inside the casing. The limitations of the BHE pipes used shall be considered represented by the collapse pressure and the maximum allowed operation pressure of the pipes.

Mixer, pump and the injection pipes shall be proven to be appropriate. The mixing process shall be adjusted according to the selected backfilling material. The requirements from the backfilling manufactures shall be considered. Industrial premixed and quality monitored backfilled materials are standard – on site mixing shall be avoided.

The grout shall be mixed with water with the recommended mixing techniques.

Slurry density of each batch should be checked before injection to the borehole.

The grout slurry shall be injected in the borehole to fill it from bottom to top until there is slurry overflow at the top with the required density.

Typically, plastic is used for tremie pipes, steel pipes are not recommended

Alternative sealing concepts may be used if the concept is proven and accepted by the local authorities. The requirements of grouting depends on local geological and hydrogeological situations.

8.6.3 Other backfilling procedure

Instead of grouting slurry in some cases swelling clay pellets can be used. This requires special backfilling pumps and pressure monitoring system of the backfilling process. The injection pipe shall be removed stepwise. The pressure monitoring is required to make sure that the complete annular space is filled with the clay pellets

When backfilling with solids, the borehole can be backfilled with different materials (layered backfilling) where the sealing layers (aquitards) are backfilled with clay pellets. The remainder is backfilled with sand or gravel. It is essential that in such a backfilling procedure the exact depth of the sealing layers is known and also that the depth where the filling material is introduced is controlled.

Solids such as sands, gravels or bentonite pellets can be backfilled into the borehole by introducing them as a water/solid mix from the surface, by using an injection-pipe. To establish to what level the backfilling has progressed repeated dipping of the backfill depth is required. Also the measured depth needs to be compared to the borehole volume and required backfill volume.

8.7 Horizontal Piping

The horizontal connecting pipes should be selected for the local conditions. They need to ensure the same operational life (at the operational temperatures and pressures) as the vertical loop. The pipes should be put in a sand bed without stones and sharp particles unless the pipe and fitting material allows an exception, which shall be guaranteed by the producer. The minimum bending radius of the materials shall be adhered to.

Compression fittings should be avoided underground or made accessible for visual inspection via a manhole.

Multiple BHEs are connected to a manifold.

A marker tape should be installed above the underground pipes to indicate their location for later digging work.

The depth of the horizontal piping shall be sufficient in order to limit the thermal influence from the surface and reduce the risk of mechanical damages. Insulation may be installed if necessary or if the designer shows the advantages.

In any case, measure shall be taken to prevent freezing of the circulating heat transfer fluid. Horizontal pipes should be installed below frost depth but at least 0,8 m.

Cold system parts shall be installed with significant distance (>1 m) to supply and waste disposal lines otherwise the relevant part shall be insulated with material appropriate for underground use.

8.8 Testing of BHE – Leakage Check, Flow Check, Grouting Check, Geophysical Measurements

All U-bend fusion joints and BHE pipes shall be checked to verify leak free loop at the factory before packing and delivery.

Just before inserting the BHE loop into the borehole a thorough visual check regarding any damage shall be carried out and documented. The maximum allowed damage should be defined by the manufacturer.

Leakage check may be done before inserting the loop into the borehole.

When inserting the BHE loop in borehole, great care should be taken that the pipe shall not be scraped on sharp stones, an edge of the borehole casing steel pipe or buckled.

Right after insertion of the BHE loop and grouting of the borehole a pressure check can be carried out for leakage testing – very small leakage cannot be determined this way.

BHE pipes shall not be pressurized with air unless at low pressure and submergence in water.

After installation of the BHE loop and grouting a flow check shall be carried out and compared with expected values to detect an additional pressure drop by plugging or bending of pipes.

Volume, pressure and flowrate of grouting can be checked and logged during and after the filling process if e.g. a magnetite-doped grout is used by measuring the magnetic susceptibility from inside the heat exchanger pipe (grouting control).

Geological or hydrogeological settings can require the use of doped grouting materials (e.g. magnetite doping). The doped material allows a controlled backfilling process and subsequent measurement and verification of the BHE. Currently the use of grouting materials with a specific magnetic susceptibility is proven. In addition, also for the use of non-doped materials it might make sense to apply geophysical measurements to check the quality of a BHE. Thermal methods, e.g. temperature logs., TRT's and enhanced TRT's, short-term TRT's and other measurement methods, e.g. Gamma-Gamma-density logs could provide indications of the grouting quality.

All testing shall be documented

8.9 Manifolds

For systems with more than one BHE manifolds should be installed. The manifolds should have isolating valves for each BHE. Flow regulating valves are needed to allow hydraulic balancing of the system.

It is necessary to have a venting device in the manifolds for air purging.

Manifolds need to have easy access for inspections and maintenance.

— Manifolds are made from e.g. plastic, copper or stainless steel.

— Manifolds shall be factory manufactured under controlled and quality ensured conditions.

— All manifolds shall be hydrostatic tested by the manufacturer before delivery.

— Manifolds shall be pressure tested on site but not with air.

— Delivered manifolds shall be traceable to the production consignment, batch, and quality control.

— Connections to the manifolds require separate isolating valves.

— Flow regulation valves shall be installed to allow hydraulic adjustment for each individual circuit

— Manifolds with removable connections and working fluid with antifreeze shall be mounted in tight control shafts to avoid leakage into the underground.

Preferably, manifolds should be installed in chambers/shafts outside the building. The chambers should be liquid-tight and can be made of polyethylene material or concrete.

9 Start-up

9.1 General

Essentially borehole heat exchangers are considered to be maintenance free. However, the quality of the circulation medium is an important aspect of the functioning of the system.

During commissioning and before putting the system in operation it needs to be ensured that the circulation medium is:

— water quality used is drinking-water quality;

— not contaminated bacteriologically. This can be verified by laboratory analysis of a sample;

— not containing any fine material such as sand, gravel or PE scrapings. Before the heat pump and/or at the suction side of the circulation pump a filter should be installed;

— correct anti-freeze concentration. This can be verified in the field by a refractometer;

— is fully de-aired and at correct pressure (usual operating pressure is 2 bars, the actual static pressure required is a function of circulation pump net-positive suction head).

9.2 Heat transfer fluid

Before start up, the freeze point should be verified according to the design specifications and heat pump manufacturer requirements (6.3.5).

For temperatures permanently above 0 °C water can be used as working fluid.

If temperatures below 0°C could occur, antifreeze shall be added to avoid any freezing damage of the system.

The type of antifreeze shall be considered when selecting the other materials in the system (e.g. corrosion is critical when glycol and brass is combined without corrosion inhibitor).

As operation temperatures fall typically only a few degrees below 0 °C the concentration should not be higher than required. Concentrations higher than needed according to the minimum temperature have a negative effect on the fluid properties (viscosity) and thermal properties of the medium.

9.3 Filling of the System

Before connecting the BHE loop to the hydraulic system (e.g. horizontal collection piping, manifold, etc.) it is recommended to purge it thoroughly via an open vessel and check for contamination. When using antifreeze, it should be ensured that pure water from flushing of the system is completely replaced by the antifreeze mixture. Finally, the concentration of antifreeze should be proven and recorded in the documentation.

9.4 Drying of New Buildings

In the construction phase buildings made from concrete and bricks contain a high amount of water (concrete, plaster, gypsum, floor screed, etc.) and require drying towards the end of the construction with an extraordinary high heat demand. Typically, this is not considered in the design of the heating system. The additional heat demand shall be covered by other sources to avoid any permanent damage to the underground system.

9.5 Commissioning

A proper check of function and performance is recommended in particular the required flow rate, the temperature evolution under heat pump operation. This requires some minimum monitoring equipment.

Instruction of the operator is recommend enabling him to run the system and to optimize the performance. The checklist (Annex C) can be applied:

9.6 Documentation

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

10 Operation, monitoring and maintenance

10.1 Operation

Operation for the BHE system is mainly affected by the building characteristic, domestic hot water demand and by the heat pump system settings.

10.2 Monitoring

10.2.1 General

Purposes of monitoring are:

— to ensure the reliable function of the GSHP system in order to prevent any environmental pollution and degradation of system performance over the long term;

— to provide energy efficiency indicators on energy exchanges (extracted, injected, stored) needed for reporting the energy extracted from the underground (for heating purposes) and the energy injected into the underground (for cooling purposes);

— to provide technical information to allow optimized regulation of the system and for possible financial incentives.

The monitoring system can vary depending on the size of the installation and the objectives. It can be a manual recording and/or recorded data.

Parameters below may be monitored:

— temperatures with historical data

  — fluid temperature for supply and return circuits should be monitored at the boundaries of the heat pump equipment;

  — ambient temperature;

  — temperature in the ground;

— relative humidity;

— pressure: Differential pressure for each BHE system should be monitored locally with a manometer or pressure transducer positioned at the output of the probe loop;

— flowrate: Flowrate of the fluid running through the BHE system should be monitored at the boundaries of the heat pump equipment;

— operating energy input;

— energy exchanged with the ground;

— electricity consumption – for pumping and for compression - should be monitored at the boundaries of the heat pump equipment. For this purpose, the heat pump and the circulating pumps should be fed by dedicated electric circuits – enabling metering the electricity consumption.

Temperature (input and output) and pressure are parameters that should be measured for each system. To effectively monitor a system, one need to be able not only to monitor critical parameters but also have access to the individual BHE, either directly at the borehole or manifold.

NOTE In order to achieve the objective of the monitoring, data can be available from the heat pump control.

10.2.2 Temperature

The supply and return temperature of the BHE system shall be measured and logged.

The objectives of these requirements are to identify failure or fast identification of failure.

Regardless of what region in Europe and purpose of the borehole field it should be within prescribed limits. In conjunction with the temperature, there shall be a time parameter.

10.2.3 Pressure

The pressure shall be monitored since a loss of pressure indicates a change in the system, i.e. fluid is leaving the collector system and could harm the environment.

A critical lower limit should be decided and below that an alarm will set off, the circulation pump stop, so action can be taken.

10.2.4 Flow rate

For a BHE system to work efficiently the flow rate of the heat transfer fluid should be within set boundaries. Alternatively, temperature difference can be used as a measure of flow rate.

10.3 Maintenance

It is recommended to check the heat transfer fluid quality in a regular interval (for example 2 years).

Possible checks are

— glycol concentration;

— pH;

— electrical conductivity;

— biological quality.

Yearly maintenance of the BHE is recommended, inspection every six months is recommended during the first two years and especially for larger systems.

Purpose of the maintenance is to check the overall circulation medium quality, leakage (especially small leakage such as due to creep fracture, catastrophic leakage doesn't go undetected) and antifreeze concentration. Degradation of antifreeze concentration could be due to ingress of oxygen, tap-up with water in leaking systems or bacteriological degradation. In the latter case it should be noted that degradation products could increase acidity of the fluid.

Maintenance inspection may include:

— checking filters and cleaning or replacing filter mesh;

— checking and recording general fluid quality parameters (pH, conductivity). These parameters are mainly used to verify the quality of the medium is stable in the long term;

— checking and recording anti-freeze concentration;

— checking and recording borehole circuit static pressure when system is off;

— checking bacteriological quality by laboratory analysis.

Additionally temperature difference on the borehole circuit can be checked with heat pump in operation. If pressure gauges on flow and return side are available, pressure drop of the borehole heat exchanger can be registered and compared to design or commissioning values.

11 Renovation

If in case of renovation of a GSHP-system the heat pump is replaced by a new one with higher performance, the low temperature heat demand supplied from the underground increases.

The design and the heat demand shall be re-evaluated in accordance with a higher efficiency of the heat pump (e.g. reduction of the heating demand of the building, improve the energy demand by additional insulation measures). A redesign of the whole system is required.

12 Decommissioning

12.1 General

Decommissioning of borehole heat exchangers is the process that shall be carried out when a BHE for any reason is taken permanently out of operation. The purpose of the decommissioning is to prevent any adverse environmental effects that could occur as a result of an improper shut-down of the BHE system.

The potential adverse environmental effects in question are generally the same as those mentioned under Clause 4. The relevant items to be avoided in relation to decommissioning are:

— contamination of subsurface;

— contamination of surface water;

— contamination of groundwater.

Leaking of heat carrier fluid and lack of sealing of the BHE is considered to be the main risk factors that needs to be eliminated during decommissioning. Specific demands for decommissioning can be a condition in the permit given for construction of the BHE system.

12.2 Heat carrier fluid

The heat carrier fluid needs to be removed from the borehole heat exchanger loop and the connected horizontal pipes.

In order to avoid collapse of the borehole heat exchanger pipes, the heat carrier fluid shall be replaced with water (drinking water quality).

The horizontal pipes may be left air or water filled, or be removed entirely.

12.3 Borehole heat exchangers

12.3.1 Backfilled boreholes

The BHE loop should be sealed off against direct access. In case the BHE loop still can be accessed from the surface, it should be welded shut.

If there is an indication that the borehole was not sealed properly, at least the top of the borehole shall be resealed and, depending on the situation, additional technical measures could be necessary.

The welding instead of filling the BHE loop with a solid such as bentonite slurry is done in order to maintain the possibility of accessing the BHE loop with a tool for later bursting of the pipe and injection of a sealant into the borehole.

12.3.2 Water filled boreholes

The heat carrier fluid should be removed and replaced by pure water. The BHE loop should be closed with a cap or welded shut. The borehole itself is filled with coarse sand up to the level that's correspond to the casing shoe while the rest of the casing is filled with swelling clay pellets. Finally, the dug hole around the borehole is filled with common soil.

12.4 Horizontal pipes

Horizontal pipes can be removed or open ends on the pipes shall be welded shut. The pipes may remain in the ground.

12.5 Documentation

Documentation for the decommissioning should be compiled and handed over to the site owner and the relevant authorities.

The documentation should contain a description of the applied procedure and a horizontal plan with the position of the sealed-off borehole(s). The position can be x/y coordinates in a given national/regional reference system or position in relation to land register boundaries. The exact position is important to relocate the BHE.

Annex A
(informative)

Insulation of horizontal piping

In Table A.1, the suggested thermal resistance area around the pipe is reported. The resistance may be obtained by means of insulating materials above the pipes or by means of preinsulated pipes.

Table A.1 — Thermal resistance above the ground depending on the undisturbed ground temperature

θ_0 [°C]	17	15	13	11	9	7
R [m^2 K/W]	2,5	1,5	1	1,5	2,5	4

Annex B
(informative)

Example simulation time

The examples are not representative of all situations, for instance: the actual heating demand and soil thermal parameters will affect the results. For designs with a fully balanced ground energy demand profile (no net heat extraction or heat rejection to the ground on a yearly basis) the simulation time will not affect the results. For systems with a dominant heating or cooling demand the required simulation time to achieve a steady-state will depend on design parameters such as the total number of individual heat exchangers in the system, the distance between the heat exchangers and soil thermal parameters for instance.

The required simulation time is analysed in this example by calculating a base-line design with a standard simulation time of 25 years and then using that design (borehole heat exchanger length fixed) to calculate the effect on heat transfer fluid temperature for different simulation periods (5 – 50 years with increments of five years). The temperature effect is expressed as the difference between subsequent calculations (temperature effect simulation time 10 years = calculated fluid temperature @ 10 years simulation – calculated fluid temperature @ five years simulation).

A criterion can be adopted to decide whether the simulation time is sufficient, for instance an added temperature effect less than 0,5 K.

1. Single house, unbalanced energy design

For a single house with a single heat exchanger from the saturation curve it is evident that a simulation time of 15 - 20 years would be sufficient. If the energy design is fully balanced there is no variation in temperature and even a one year design calculation would suffice.

In general, for small systems, temperature variation rate tends to decrease rapidly and a simulation period of 30 years is sufficient. See Figure B.1.

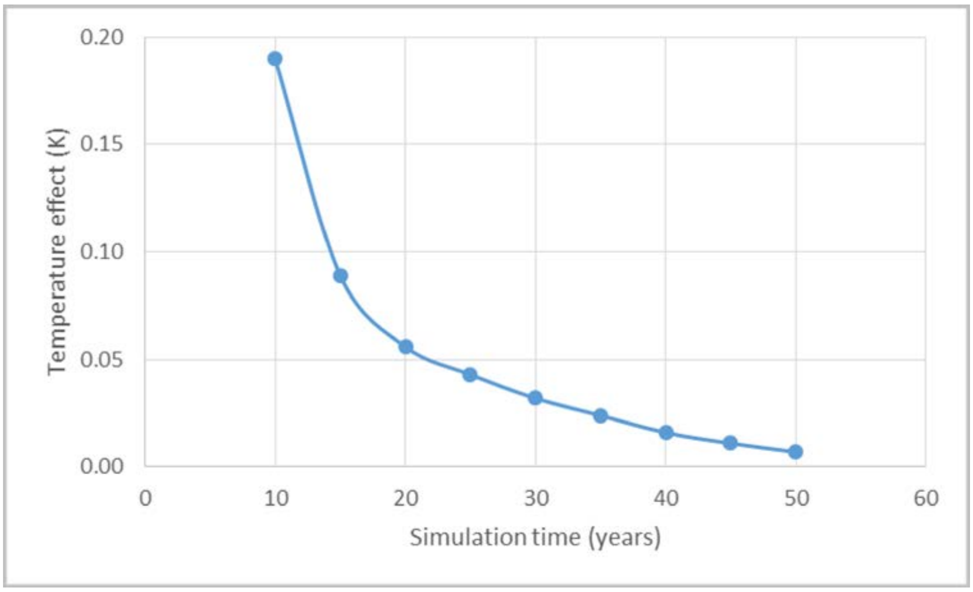


Figure B.1

2. Field of 30 houses with an unbalanced design

This is a simulation of a 3 × 10 borehole field (30 houses) with a distance between the boreholes of 7 m.

A simulation time of at least 30 years is required in this case: the difference in calculated temperature between the simulation with 30 years and the simulation with 25 years is 0,45 K.

See Figure B.2.

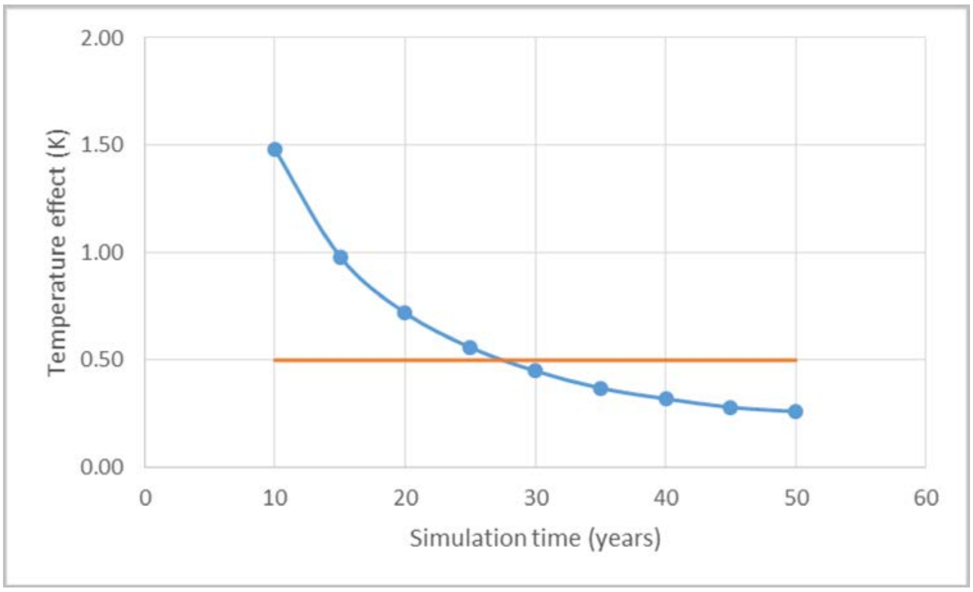


Figure B.2

3. Field with 400 houses with an unbalanced design

This is a simulation of a 20 × 20 borehole field (400 houses) with a distance between the boreholes of 7 m. In this case, evan after 70 years simulation, the temperature change with added time is still more than 0,5 K. If the intended operational life is limited to 50 years then a 50 years simulation would suffice.

See Figure B.3.

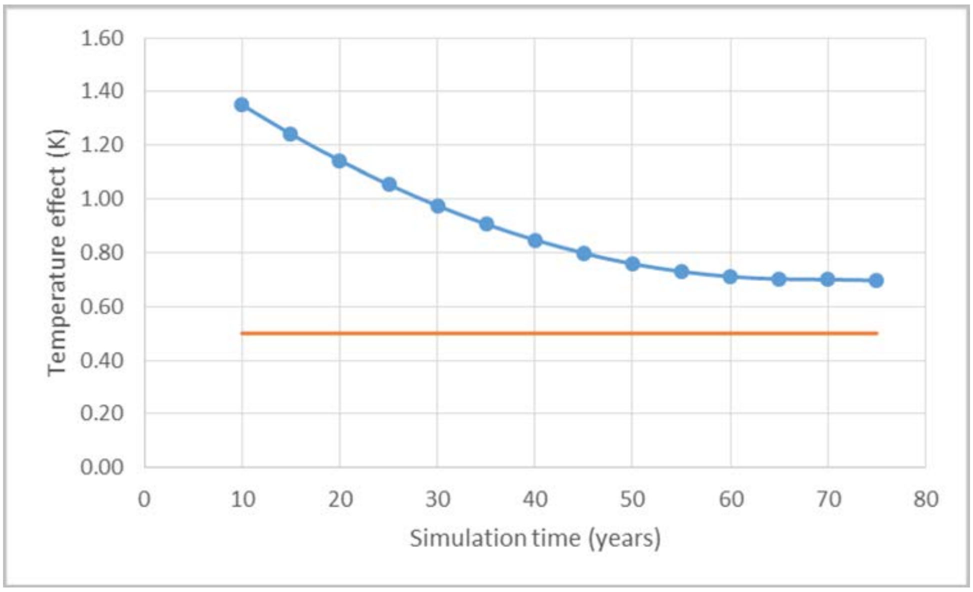

1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Temperature effect (K)
0
10
20
30
40
50
60
70
80
Simulation time (years)

Figure B.3

Annex C
(informative)

Commissioning Checklist

Technical plant room works normally comprise the positioning of all kit, establishing all piping connection and electrical connections (power and network) between kit and earth bonding. Subsequently the system is connected to the external power source and water mains, is filled with water and tested for leaks.

Note that the BHE system is commissioned separately and before the commissioning of the technical room. The commissioning of the BHE system will be done during and after the drilling works and horizontal connections. It mainly comprises the leakage- and pressure tests, flow tests and documentation of positions.

The technical commissioning of the BHE system comprises:

1) Purging of system

2) Leak test – testing of all connections and components

3) Strength test – test strength of PE material

4) Introduction of anti-freeze if needed

5) Circulation medium properties and quality assessment.

The commissioning of the technical room comprises:

A. Pre-commissioning

— Check that all equipment has been installed as per process and instrumentation diagram and technical design submission.

— Check that all equipment is correctly installed.

  — Electrical connections

  — Hydraulic connections, hydraulic network and flow directions

  — Mechanical aspects (accessibility of plant)

B. Electrical connections verifications: verify quality of supply and earth, phase rotation (if required) and earth-bonding.

C. Functional commissioning of plant

— Verification of all I/O: sensors correctly connected, motorized valves correctly connected, pump motors correctly connected, heat pump control correctly connected

— Verify all sensors functioning (sensor readout range and basic calibration)

— Verify all motorized valves functioning (correctly setting position and feedback)

— Verify all pump functioning, pump commissioning

— Verify heat pump operation and communication

— Check water pressure, water quality and de-airing

— Check and commission flow rates

D. Commissioning of heat pump unit

— Put heat pump into operation; perform all functional checks (e.g. fault interlocks etc.).

— Run heat pump on heating, DHW and cooling operation, collect operational data as reference data set (pressures, temperatures and current).

E. Operational commissioning of plant

— Verification of selection of operating modes and switching hydraulic and refrigerant side.

— Setting all initial set points and internal operational parameters

— Verification of communication and data-logging

F. Reporting and records

— Report of commissioning records and all system parameters

— Witnessing by client of system operation

The whole commissioning procedure is based on a set of commissioning sheets that are to be executed in order.

Annex D
(informative)

Examples of thermal conductivity and volumetric - heat capacity of the underground

The values can be used in the equation in 7.2.3.

	Type of rock		Thermal conductivity λ in W/(m·K)		Volumetric heat capacity c_V	Density ρ
				Typical value	in MJ/(m^3·K)	in 10^3 kg/m^3
Unconsolidated	Clay/silt, dry		0,4–1,0	0,5	1,5–1,6	1,8–2,0
	Clay/silt, water-saturated		1,1–3,1	1,8	2,0–2,8	2,0–2,2
	Sand, dry		0,3–0,9	0,4	1,3–1,6	1,8–2,2
	Sand, moist		1,0–1,9	1,4	1,6–2,2	1,9–2,2
	Sand, water-saturated		2,0–3,0	2,4	2,2–2,8	1,9–2,3
	Gravel/stones, dry		0,4–0,9	0,4	1,3–1,6	1,8–2,2
	Gravel/stones, water-saturated		1,6–2,5	1,8	2,2–2,6	1,9–2,3
	Till/loam		1,1–2,9	2,4	1,5–2,5	1,8–2,3
	Peat, soft lignite		0,2–0,7	0,4	0,5–3,8	0,5–1,1
Sedimentary rock	Clay/silt stone		1,1–3,4	2,2	2,1–2,4	2,4–2,6
	Sandstone		1,9–4,6	2,8	1,8–2,6	2,2–2,7
	Conglomerate/breccia		1,3–5,1	2,3	1,8–2,6	2,2–2,7
	Marlstone		1,8–2,9	2,3	2,2–2,3	2,3–2,6
	Limestone		2,0–3,9	2,7	2,1–2,4	2,4–2,7
	Dolomitic rock		3,0–5,0	3,5	2,1–2,4	2,4–2,7
	Sulphate rock (anhydrite)		1,5–7,7	4,1	2,0	2,8–3,0
	Sulphate rock (gypsum)		1,3–2,8	1,6	2,0	2,2–2,4
	Chloride rock (rock salt, potash)		3,6–6,1	5,4	1,2	2,1–2,2
	Anthracite		0,3–0,6	0,4	1,3–1,8	1,3–1,6
Magmatic rock	Tuff		1,1	1,1	Not available	Not available
	Vulcanite, acid to intermediate	e.g. rhyolite, trachyte	3,1–3,4	3,3	2,1	2,6
		e.g. latite, dacite	2,0–2,9	2,6	2,9	2,9–3,0
	Vulcanite, alkaline to ultra-	e.g. andesite, basalt	1,3–2,3	1,7	2,3–2,6	2,6–3,2

	Type of rock		Thermal conductivity λ in W/(m·K)		Volumetric heat capacity c_V in MJ/(m³·K)	Density ρ in 10^3 kg/m³
				Typical value		
	alkaline					
	Plutonite, acid to intermediate	Granite	2,1–4,1	3,2	2,1–3,0	2,4–3,0
		Syenite	1,7–3,5	2,6	2,4	2,5–3,0
	Plutonite, alkaline to ultra-alkaline	Diorite	2,0–2,9	2,5	2,9	2,9–3,0
		Gabbro	1,7–2,9	2,0	2,6	2,8–3,1
Metamorphic rock	Slightly metamorphic	Clay shale	1,5–2,6	2,1	2,2–2,5	2,4–2,7
		Chert	4,5–5,0	4,5	2,2	2,5–2,7
	Moderately to highly metamorphic	Marble	2,1–3,1	2,5	2,0	2,5–2,8
		Quartzite	5,0–6,0	5,5	2,1	2,5–2,7
		Mica schist	1,5–3,1	2,2	2,2–2,4	2,4–2,7
		Gneiss	1,9–4,0	2,9	1,8–2,4	2,4–2,7
		Amphibolite	2,1–3,6	2,9	2,0–2,3	2,6–2,9
Other materials	Bentonite		0,5–0,8	0,6	~3,9	
	Concrete		0,9–2,0	1,6	~1,8	~2,0
	Ice (−10 °C)			2,32	1,87	0,919
	Synthetics (HD-PE)			0,42	1,8	0,96
	Air (0 °C to 20 °C)			0,02	0,0012	0,0012
	Steel			60	3,12	7,8
	Water (+10 °C)			0,59	4,15	0,999

NOTE The density of unconsolidated rock varies greatly with stratification density and water content. In sandstone, conglomerates and breccia, there is an especially wide range of thermal conductivities. The important factors, in addition to the constituting material and its distribution and water saturation, are the type of binding material or matrix.

Bibliography

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