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IEA ECES ANNEX 27 - Quality Management in Design, Construction and Operation of Borehole Systems

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ABSTRACT

Within the International Energy Agency Technical Collaboration Program ECES an international experts group IEA ECES Annex 27 was founded to elaborate measures and recommendations for quality management in design, construction and operation of systems with borehole heat exchangers like ground source heat pumps and borehole thermal energy storage. The goal is to provide practical experiences from the eleven participating countries in the different project phases for quality management. The goal is to analyze and compile this information for elaboration of guidelines and standards as well as for education of consultants, drillers, installers and operational staff. The results can also be valuable for experts in approval authorities.

The information collected for the design phase covers beside some general remarks activities like pre-feasibility study, feasibility study, detailed design, approval procedure and call for tenders. Recommendations on the scope of activities and content of the different steps are given with a focus on the target group consultants. The construction phase looks at legislation, site preparation, drilling, backfilling or grouting process, borehole heat exchangers, start-up and supervision of the construction process. Here the recommendations are targeting mainly for the drillers and installers but are important for the designers and approval authorities also. For the operation phase mainly requirements for monitoring are given, as this is the essential basis for analysis of the system operation and troubleshooting in case of problems. Beside the operational staff as the target group are consultants are important to include consider these aspects already in the design. Practical experiences, which problems and failures can occur, and potential solutions are given as well as recommendations how to avoid them throughout the whole project implementation.

1. INTRODUCTION

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

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

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

This will make GSHPs with BHEs and BTES technically safer, more cost effective and will strengthen the future usage of this technology. Consequently, the knowledge and confidence of the regulation bodies in this technology should be enforced to avoid ineffective restrictions resulting in increasing costs.

The specific objectives are:

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

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

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

1. design phase
2. construction phase
3. operation
4. problems, failures, investigation and solution and environmental assessment

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

Additional information is available from the Annex 27 website (http://www.eces-boresysqm.org).

2. DESIGN PHASE

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

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

A typical design phase covers the following stages:

- Pre-feasibility study
- Feasibility phase
- Detailed design
- Approval procedure
- Call for tenders

Depending on the size of the project, the different stages have to be worked out to more or less detail. Especially for small projects like family homes pre-feasibility and feasibility are often merged together and major parts integrated in the detailed design.

The following chapters summarize Gehlin (2019).

2.1 General Remarks on the Design Approach

The design varies with respect to borehole depth, distance between boreholes, working temperatures of the heat transfer fluid and mode of operation depending on the intended type of system.

For the design approach, a variety of tools of different sophistication is available. Software tools such as EED and GLHEPRO are typically sufficient for smaller systems. For larger projects with several boreholes, these tools are applied in the feasibility stage for first estimations while tools that are more sophisticated should be considered in the detailed design phase, especially for more complex systems. It is important to take into account already existing or planned new ATES, GSHP and BTES systems in the neighborhood due to mutual influence.

The heat source for a pure extraction system is the solar (and geothermal) heat stored naturally in the ground. However, also heat from solar collectors and waste heat from industrial processes (cogeneration included) are regarded as sources. Sector coupling by power to heat and BTES for storage is economically viable may play an important role in future. There are a number of other heat sources used in BTES systems, mainly for seasonal storage. Except for heat pump evaporators, cold surface water and cold air are the most common cold sources in cooling applications, but also snow and ice melting is used in some countries. Gas expansion in industrial processes may be another but rare application.

It is of great importance to differentiate between GSHP and BTES when it comes to distance between boreholes. The distance depends mainly on the application (GSHPs or BTES), the geological conditions (i.e. the ground thermal properties), intended final drilling depth (larger distance between deeper boreholes to prevent damage during drilling) and load characteristics. Optimal borehole distance ends up between 3-10 m for multi-borehole BTES systems. However, some countries have legislations stating distances that are more specific. In general, the distance would be closer for high temperature storage (HT-BTES). For independent boreholes which do not significantly interact thermally in systems for extraction of heat or cold only, a “safety” distance of 15-25 m seems to be applied in most countries (in some cases legislated), but the distance largely depends on the ground thermal properties and energy load profile. The distance is also of importance in order not to create a thermal impact on neighboring properties. In the Netherlands, even longer distances (sometimes 35-45 m) are required.

The undisturbed ground temperature is an essential parameter that strongly affects the design of GSHP systems. For BTES systems, it will be of less importance. This parameter affects only the heat losses to the surrounding. Design ground temperature denotes the average undisturbed ground temperature calculated over the total borehole depth.

2.2 Prefeasibility Study

Pre-feasibility studies are only carried out for large GSHP systems and BTES. The results will normally serve as a point of decision for clients to continue with the concept or, if so is decided, to stop further development. A prefeasibility report will typically be a desktop study based on inexpensive and easily achieved data. BTES or GSHP options are compared to other forms of heating and cooling, for example district heating/cooling or fuel fired boilers. If the result from this initial study comes out favorably, the project has a good chance to be further developed.

Depending on the project the content and lay-out of a pre-feasibility report may vary. However, site plans, topographic maps, geological maps, hydrogeological maps, databases on wells and boreholes, energy load and temperature demands, predesign and economic calculations to compare with other energy systems are important issues to cover. Data from existing wells and boreholes are very important for understanding the geology at any given site. Since groundwater always plays an important role for any project, it is recommended to search for information on aquifers and groundwater level(s) already in a prefeasibility stage. It is recommended to cover as much information as possible, especially on geo-conditions and energy load characteristics that may be easily found in databases.

Underground obstacles and limitations can affect the construction of a system significantly and therefore the check if a site for drilling is a restricted area and if there are any infrastructural installations beneath the surface is important already in the pre-feasibility phase. There is always a certain risk for damages caused by the local geotechnical properties, which have to be considered comparably. In tectonic areas, special considerations must be undertaken. It is recommended to always perform a geotechnical risk analysis.

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

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

2.3 Feasibility Phase

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

Test-hole drillings should be placed close to or preferably inside the final borehole field to be incorporated in the final system. Exact location is defined by geological conditions and land availability and survey of underground obstacles. In many countries a permit is already required for such test-drillings. The layout and especially the depth of the test-borehole should correspond to the final system to allow the usage later on. To avoid damages to underground infrastructure like pipes, cables or hazards due to unexploded ordnances before placing the boreholes, these obstacles should be recognized before starting the test drillings.

The documentation during test drilling is essential. Geological profiling by ocular classification of cuttings by the driller and/or sampling for analyses elsewhere seems to be sufficient. In general, detailed determination of stratigraphy (e.g. according to ASTM D2113 or ISO 22475-1:2006) is not required. However, during the drilling the driller should be able to identify the main layers encountered and especially be able to identify sealing layers (aquitards). In addition to drillers log it is recommended to document geological layers by sampling, especially in sediments and sedimentary rock. All aquitard layers are of special interest to document. Occurrence of one or multiple aquifers or permeable fracture zones may be important information for design of a borehole system, regardless where it is located. It is essential to know the groundwater level or hydrostatic pressure, but the possibility to measure this, depends on what drilling method is applied. However, true values will not be obtained until several hours (or even a day) after the drilling is completed. Drilling with mud will block the permeability, making measurements in borehole impossible. In such case the groundwater level may be obtained from measurements in nearby boreholes. Fracture zones, unstable hole, swelling clay, large water yield, loss of drilling fluid, etc. may all cause drilling problems. Such conditions are commonly noted down in drillers log. Documentation of drilling parameters such as rate of penetration (ROP), torque, Weight On Bit (WOB), and air pressure will help to understand the geological conditions on site. In commercial applications this kind of documentation is seldom performed.

A Thermal Response Test (TRT) is of great importance when it comes to reliability and quality of borehole system design. Large systems in an area with intensive variations in the geology on short distance may use more test-holes and TRTs to gain sufficient reliable data for the final design. This was already discussed in IEA ECES Annex 13 and 21. A recommendation is to use one test hole and TRT test for 10-30 boreholes. Not all the test holes are necessarily used for TRT, but it is important to keep good documentation during drilling, as this provides useful information of the homogeneity of the borehole field and thus indicates the need for multiple test holes and TRT. TRTs are commonly performed after completion of test holes. There is more information available on TRT equipment and methods within the IEA ECES Annex 21. Evaluated parameters are used for the detailed design of the borehole system.

The duration of TRT must be long enough to ensure a proper evaluation of thermal properties. It is recommended to use a duration of at least 48 hours and check automatically for convergence during the ongoing measurement, to find out if a longer test duration is needed. For evaluation of data obtained from TRTs, the line source method is commonly used. This approximation is only valid when all measured parameters are exact and the heating/cooling load is observed to be very stable. Groundwater flow and load variations make this method unusable. When the prerequisites for the line source approximation are not fulfilled, more advanced evaluation methods are required. The equation for a line source or cylinder source can be used at each time step during the measurement, and the average injected power rate between two measurement steps may be used as a step-pulse. If measured data show stable conditions the line source approximation can be used. As this is typically not the case, it is recommended to use more advanced evaluation methods and check for convergence.

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

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

There are a number of possible impacts from construction and operation of borehole systems that should be addressed. This seems to be a concern in most countries.

In the feasibility stage of a given project the information gained during test drilling, TRT evaluation and energy load profiles allows a pre-design of the borehole system. These data are preferably used for the first simulations with Earth Energy Designer (EED) or other similar software design tool. Based on this design, first economic considerations are possible, which is one of the major interests of the customer.

A rough investment cost calculation can be carried out for the pre-designed system based on experience from other similar projects. The operational cost is roughly estimated by using the expected amount of used energy and seasonal performance factor (SPF) using the current price for e.g. electricity. The maintenance cost of a borehole system should, if correctly designed and constructed, be very low or practically zero. Some maintenance is associated with the heat pump side of the system, and some control of pressure, purging and heat carrier fluid quality is needed. The expected seasonal performance factor (SPF) with a system boundary including at least boreholes, circulation pumps and compressors is used to estimate the energy savings from the system. A rough estimate of profitability may be obtained by the use of straight payback time and/or return of the investment. If life cycle cost analysis (LCC) is asked for in the feasibility stage it is recommended to use a life-time of at least 40 years for the borehole system.

2.4 Detailed Design

In principle there are two contractual options of which one is commonly known as “Turn Key Contract” (A) and the other is commonly named “Performance Contract” (B). For option (A), the contractor will both design and construct the plant, while for option (B) the design is performed by the customer with the help of consultants. This means that there are differences in details when it comes to the tender documents. For option (A), commonly only frames for design are given, while for option (B) the design is detailed and fully quotable for bidders. Both options are used frequently, however option (A) for smaller and not too complicated plants, while most countries use option (B) for larger and more complex applications.

It is important to find out the load profile regarding heating and cooling energy for the building, so that the modeled design is accurate. Ensure interaction between building designer and the designer of the BTES/GSHP system. For modeling of smaller and less complex projects monthly load values can be used. For larger and more complex load characteristics hourly values should be considered. Both energy demand and capacity must be accounted for. Supply and return temperatures in heating and cooling systems are controlled by the site-specific outdoor temperature variation over the year. In general, most countries relate to the outdoor temperature, but in climates with moderate variations (maritime climate) a fixed temperature may be used. The ground temperature and heat carrier fluid temperature is not the same.

For studying and analyzing of different layout options typically simulation tools are used. The number of boreholes, their depths and configuration is determined by using such design tools using the given load and the thermal parameters of the underground. The groundwater level is important for defining the thermally active length of the boreholes in non-backfilled applications as the piping above groundwater level is surrounded by air and has no thermal contact with the borehole wall. In such cases the groundwater level should be measured to define the thermally active borehole depth. Additionally, the groundwater table may vary over the year.

Natural groundwater flow will have an impact of the thermal behavior of the borehole systems. For GSHP systems, this may be a benefit, while BTES systems may be negatively affected. Most countries are aware of the impact that groundwater flow may have on the system performance, but this is due to the high effort normally not modeled. The effect of groundwater flow is complex as the effects depend on the relative length of the borehole affected by the groundwater flow, the groundwater velocity but also the energy balance achieved by the system. In general, low groundwater flow velocities and systems with a high energy balance are not affected by groundwater flow, while systems with high groundwater flow velocity and low energy balance are affected much more.

One of the main assumptions with virtually all software tools used in the design of borehole heat exchangers is that heat conduction is the only transport mechanism and therefore the groundwater flow is neglected. If groundwater flow does affect the heat transport around the borehole heat exchanger different effects may arise depending on the context:

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

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

Polyethylene pipes (PE 100), are most commonly used in low temperature or moderate temperature applications. The U-bend at the bottom of the borehole is welded by the manufacturer by a butt-welding method. For connection of the vertical pipes of the BHE to the horizontal collection system special electrofusion-joints are used.

PE pipes for pressure applications (such as GSHP systems) are classified by minimum required strength (MRS) based on the international standard ISO 9080. The last current generation PE pipe is known as PE 100 in which the digits show the MRS class. According to ISO 9080 the minimum required strength (MRS) at 20 ºC and 50 years for a pipe with SDR 11 is 10 MPa for PE100 and 8 MPa for PE 80 giving the design stress 8 MPa and 6.3 MPa, respectively and safety factor 1.25.

High temperature BTES (HT-BTES) applications will demand other types of polymer material for both BHE and horizontal piping. For HT-BTES systems, special types of polymers that can stand higher temperatures are chosen, such as PE RT type II, PP, PEX and some other thermoset materials. At present PEX would be the most temperature resistant plastic that can endure long termed exposure up to +70 °C and for short durations up approximately +90 – 95 °C.

The strength properties of the BHE will be different depending on whether grouted or non-grouted boreholes are used. Either way, the properties of the BHE are of utmost importance. There seems to be an agreement on bursting pressure, collapsing pressure, extension coefficient and change of strength with increased temperature. For grouted boreholes, also the contact between the grout and the pipes is of importance.

To ensure high quality BHEs are mainly manufactured in each country in a controlled factory environment, but in a few countries also imported. Manufacturing and testing are obviously performed according to standards. Due to the construction, especially the coaxial BHEs with large diameter cannot be practically handled as a roll. They are delivered to the construction site as prefabricated rods tubes and have to be welded on site at insertion in the borehole. In this case a controlled environment has to be provided at the site.

The BHEs are connected to the collection pipe system by electrofusion joints (or similar) according to specifications from the joint manufacturer and/or standards. Pipes must be sufficiently cleaned and certain weather conditions avoided.

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

A variety of prefabricated out-door field manifolds have been developed and are commonly used. Less common are designs on site. Occasionally the manifolds are placed indoors. Except for very shallow systems the boreholes and field manifolds are connected in parallel in order to minimize the flow resistance in the system. It seems like common practice to use high efficiency heat carrier fluid circulation pump for larger systems and flow control valves on manifolds.

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

For the horizontal pipe system (collection system) the same material should be used as for the BHEs. Common practice is to use PE100 or similar for low temperature applications, and thermal resistant polymers for HT-BTES. The horizontal pipe systems must resist the weight of e.g. heavy vehicles and the collapse strength should therefore be considered. The pipes should be laid 20 – 30 cm below the frost-free depth (ca. 1 – 1.2 m below the surface) in order to avoid elevation of the soil. This elevation occurs if the layer of ice around the horizontal pipes (due to sub-zero operating temperatures) and the frozen soil layer above the horizontal pipes freeze together. SDR 17 in smaller dimensions is the common practice. Depending on the bed depth of the horizontal pipes, the ground temperature can be significantly higher or lower than at the surface. Therefore, the horizontal pipes of systems with operating temperatures below the minimal ground level temperature can contribute to peak load shaving. The overall impact mainly depends on the length of the pipes and the borehole discharge temperature. It is recommended to take into account the hydraulics of the system, the depth and length of the pipe system as well as the impact from the surface to choose a suitable and safe dimension and strength.

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

It seems to be common practice to embed the pipes with sand without stones with sharp edges and to close that layer with a geotextile. Soil material from digging the shaft is used for the rest of the backfilling.

Commonly ethanol, ethylene and propylene glycol mixed with water are used as heat carrier fluids. Ethanol is preferably used in water-filled boreholes at a concentration of maximum 28% (not flammable), and glycol in grouted boreholes at a concentration up to 30 %. Propylene glycol has a comparably high viscosity which makes it less favorable as heat carrier fluid. The ethanol mixtures may be mixed with additives that make it undrinkable. Pure water is used in systems that work well above the freezing point and in systems used for storage of heat only. Corrosion inhibitors and other additives should be avoided if possible. It is recommended to use environmentally safe heat carrier fluids and not unnecessarily high concentrations.

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

2.5 Approval Procedures

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

2.6 Call for Tenders

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

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

Unforeseen damages caused by the borehole installation are of importance to regulate in the contract at least during the guaranty time (3-10 years). In some countries, this is dealt with by general clauses, in others they will be handled by the court of law. Responsibility for unforeseen damages should be in the contract and it should be demanded that people responding to the tender are certified and have correct insurances in place.

3. CONSTRUCTION PHASE

Here the construction phase for any closed loop borehole system used for extraction and storage of thermal energy in the underground by the use of borehole heat exchangers (BHE) is covered according to Bjorn (2019). The scope is the construction of the borehole, the installation and control of the BHE, the grout and the grouting process and documentation of borehole and BHE.

3.1 Legislation

The level of legislation on construction of borehole heat exchangers is known to vary a lot between countries. Rules and regulations may also vary within a specific country depending on the region. Furthermore, there may be variations in the legislation depending on the size of the borehole heat exchanger system. To complicate matters further some countries like Germany and Belgium have different regulations depending on which part or federal state of the country you are operating in. The various laws, acts, codes, standards, norms, guidelines, protocols, rules and regulations primarily focus on avoiding negative environmental effects from the construction and operation of the borehole. Information on how to construct and operate is much scarcer.

The legal enforcement is general by law and a permit is given by the local environmental agency. A permit will normally not need to be renewed. As ground source heating is a “new” technology compared to boreholes for drinking water and mining, it is common to see BHEs as an addition or as an implicit part to already existing rules. Even though there are differences in scope and not least in volume of the legislation, there are also a few important common denominators. The various acts express a general concern about potential negative effects on the quality of the groundwater. In countries where groundwater supplies a large part of the drinking water, the rules concerning sealing of the borehole are generally stricter and more comprehensive than in countries with less focus on the groundwater.

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

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

3.2 Site Preparation

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

In order to prevent accidents some countries require a Health and Safety plan for the site and work processes that may depend on the size of the construction site. If required it must be presented and approved by consultant and/or authorities prior to commencement of the construction.

A general official requirement is fencing around the work site. Furthermore, it is common practice that the site owner provides electricity and water to aid the drilling, but this is in no way mandatory. A plan for handling drilling mud and cuttings is also required in most countries.

Mapping or detection of underground installations will typically be the drillers responsibility. Checking for soil contamination will also be a part of the investigation prior to drilling. The site owner is normally responsible for checking whether a site is contaminated.

Generally, it will not be allowed to install BHEs in contaminated areas. If the driller unexpectedly hits contaminated soil, he has the responsibility to inform the planner and/or the authorities. He must also handle the contaminated soil/cuttings from the drilling. The same applies to spent drilling mud and excess water. In most countries, the use of watertight containers for drilling mud and settling of cuttings seems to be either mandatory or the norm. In some places, excavated pits are still being used. Generally, the handling of drilling mud/fluids/water is the responsibility of the driller. The deposition of these materials will normally have to be approved by the authorities.

3.3 Drilling

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

The chosen drilling method is closely related to the geology on the drilling site. In unconsolidated sediments rotary mud drilling is the method of choice. This will typically be direct flush but may also be reverse flush. The expected drilling depth may also influence the choice of method. There seems to be a tendency for the boreholes to become deeper. In Sweden, boreholes of 250 – 300 m are seen more and more often. Thermal short-circuiting is generally small in BHEs shorter than 300 m. In hard rock the drilling will typically be made by DTH with air lift to clean up. Alternative drilling methods may be appropriate in unconsolidated sediments. The driller must handle any situation with overflow of water, artesian water or release of underground gas and therefore the necessary means must be present at the drilling site. This will typically be packers and diverters.

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

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

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

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

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

3.4 Backfilling or "Grouting" Process

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

Most countries have a requirement for sealing penetrated aquitards as a minimum. Belgium and Germany is a bit stricter, demanding a complete grouting of BHEs. On the other hand, Sweden and Finland only have requirements for a sealing at the top of the borehole and a complete seal if the borehole is in a groundwater protection area or if a borehole connects two aquifers. Therefore, only a small number of boreholes are filled with sealing material in these countries. In addition to the sealing properties, the grout generally has to ensure a good heat transfer and protect the pipes against mechanical damage.

As the legislative demands for the grout concerns the sealing properties, it is possible to use other types of materials or installations in the borehole that have the same characteristics. This could be a sort of packer or cured-in-place liner. These technologies are not widely spread and may be used only if the concept is proven and accepted by the local authorities.

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

In some countries, bentonite is used to achieve the sealing properties. Industrial premixed grouting materials have cement and rock powder as main constituents. Quartz, in some form, seems to be the typical thermal enhancer. This may be as fine-grained sand or a quartz flour. Others use graphite to enhance the thermal properties even more. Cement contributes to achieve a high physical stability. In order to be able to document the position of a seal, magnetite can be added to a filling material (doped grout). It must be pointed out that smaller voids may go undetected.

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

For mixing of filling materials/grout continuous mixers are frequently used, perhaps primarily because they are easy to use, but there are known issues with the mixing ratio of the produced grout. Batch mixing will have a higher security for getting the correct mixing ratio. In Germany colloidal mixers is gaining a footing and is seen to replace the two other mentioned technologies. The mixing procedure ensures a homogenous product mixed in the correct ratio. Mixing and pumping are two separate processes.

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

Only Germany seem to have a procedure in case of loss of fluid during grouting. If the injected amount is the double or more of the calculated amount, the work must stop and the authorities must be informed. Gravel, sand or grout of a higher density or a packer may help solve the problem. The driller always has to be prepared to handle situations with loss of fluid

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

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

3.5 Borehole Heat Exchangers

The procedure to install the BHE-pipes is typically to put the single or double U pipe on a reel, either motorized or suspended from the drilling rig, and connect weights to the U-bend and fill the pipe with water. The necessary counterweight needs to be calculated. The weights and the water reduces the buoyancy in the mud- or water-filled borehole to install the BHE. Sometimes the BHE is already filled with antifreeze mixture instead of water. This will remove the process of replacing the pure water with antifreeze but may cause complications if the BHE turns out to be leaky or there is dirt in it. There may be some concerns about spilling antifreeze. Spacers and centralizers are often required in projects but in practice they often cause more problems than they provide advantages. During the installation care must be taken not to damage the pipes in the process.

Pressure tests or leakage tests are always required performed, but often there is no reliable procedure for the test. The duration of the test, the number of tests and the test pressure varies. The results of the tests are often found to be questionable. Significant leakage (order of magnitude liters per hour) can be detected easily while small leaks in the order of droplets per hour can't be seen by a pressure test. It is recommended to perform a leakage test before installation. Conditions must be in appliance with local regulations. The flow test may indicate installation errors and provides means to double check headloss calculations for the circulation pump. It is recommended to carry out a flow test and compare the results with the expected values.

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

Test protocols and documentation can provide valuable information for future problems and system modification. Generally this applies to larger systems and the terms will normally be evident in the contract. For smaller systems, it is necessary to document/test at least the following:

- Borehole position, dimension and depth
- Planned deviation of the borehole
- BHE length, dimension, type, pressure class
- Filling material and/or sealing material type, amount and position

- Result and conditions of leakage test
- Heat carrier fluid, type and concentration
- Result and conditions of flow test
- Flowrate, duration and result of de-aeration process
- Type of connection to horizontal pipes
- Position of the horizontal pipes
- Type, dimensions, equipment and position of manifold, if present

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

3.6 Start-Up

It is recommended to carry out a proper check of function and performance of the system at commissioning. A follow up check on function and performance after 5 years is suggested. As BHEs have a tendency to show indications of under-dimensioning after some years, this makes very good sense.

For commissioning, there is a general reference to the normal conditions for deliveries. Check-ups are primarily concerning mechanical parts, HP coolant and antifreeze levels.

It is recommended that the operator receive an instruction that gives him a basic understanding of how to run the system.

Sweden, Germany and The Netherlands have comparable and high levels of documentation and instructions that are handed over. The main elements are:

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

3.7 Supervision of the Construction Process

For bigger projects, it is generally the norm to have a consultant independent of the drilling company to do a running check up on the construction process but there is no standard as such. Sweden and Germany have a bit more regulated procedures. Turnkey contracts will typically have different conditions from trade or general contracts. E.g. supervision by consultant is much reduced or non-existing. Anyhow level of supervision during the construction process is recommended. The extent of supervision is related to the size of the project and the type of contract.

4. OPERATION PHASE

The operation phase is described in the following chapters according to Nagano and Katsura (2019)

4.1 Supervision of Operation

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

The monitoring of BHE and GSHP systems offers following information:

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

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

The suggested monitoring items in the BHE circuit in small systems are the fluid temperatures, pressure, and flow rate. Error messages displayed on the heat pump are also considered to be important. In large systems, the monitoring items to evaluate the efficiency are added and an automatized data acquisition is required. Beside management, reliability and performance aspects the influence on underground environment and groundwater are important and sometimes required by the approval. Underground temperatures or at least fluid temperatures at the inlet and outlet of the underground system can provide valuable information on the impact.

The GSHP system with BHEs does hardly required maintenance. However, in order to operational reliability of the GSHP system the following data can be easily checked:

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

The minimal and maximal temperatures into to the BHE can be assumed to correspond to the discharge temperatures of the brine out of the heat pump (evaporator or condenser) or out of the heat exchanger for direct geothermal cooling. These data can be picked up from most heat pumps. Furthermore, it might be worthwhile supervising the current amount of heat extracted/injected from/into the ground especially if a change of use of the building occurs. If the amount exceeds the design conditions, measures have to be taken to avoid too low or too high subsurface temperatures. For reliability purposes, a supervisory control of the system part BHE and HP (heat pump) is recommended, especially the temperatures and the pressure of the geothermal loop.

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

The influence of BHEs on the underground environment and groundwater can be estimated by supervising the discharge temperatures of the evaporator (in heating mode), the condenser (in mechanical cooling mode) or the heat exchanger for direct geothermal cooling (in direct geothermal cooling mode). If analyses that are more precise are required, costly investments might be necessary, e.g. additional drillings to supervisory control the groundwater level, regular sampling etc. Hence, it is recommended to supervise the temperatures into the BHEs at first. If the temperatures drop or rise beyond design limits additional measures have to be considered. Without obligations for a detailed supervision of the underground environment and groundwater, it is recommended to just supervisory control the temperatures into the BHEs.

4.2 Monitoring

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

Large systems typically have more sophisticated control or even a building services control system, which allows more sensors and even a data acquisition with a data storage option. In most cases automatic data evaluation and access to historical data is possible or can be implemented in the software without significant extra costs. Besides fluid temperatures and flowrate in the BHE circuit the electricity consumption of the circulation pump should be measured.

4.3 Evaluation

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

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

4.4 New Technologies Related to Monitoring

Recently, the monitoring systems or services with internet for small size systems are gradually available. Some heat pump manufacturers provide such services and the user has access to his data via internet and can get an overview and the present status of his system. Data can sometimes also be exported for further evaluation. Another company provides a smartphone application that can show the parameters. In addition, the heat pump can be controlled by the smartphone application.

5. PROBLEMS, FAILURES, INVESTIGATION AND SOLUTION

This chapter is based on Reuss and Karrer (2019). First, it has to be emphasized that in most cases we don’t have any problem with BHEs in GSHPs and BTES systems. The fraction of systems with problems compared to the total number of installations is very low. Nevertheless, there are some and there are some with very severe consequences. Thus, quality management has to consider such failures and provide measures to avoid making mistakes twice.

In general, the problems with BHEs can result from several activities carried out in a project. The reason may originate from the local geological and hydrogeological situation, which is not considered and handled properly due to misunderstanding of the geology. In addition, technical reasons and lack of technical skills can cause problems due to mistakes in the design and construction itself. To avoid such problems, both require well-educated and experienced consultants for design as well as highly qualified drillers and installers in the construction phase. But also local authorities responsible for the permit, which typically have excellent knowledge of the geology and hydrogeology in their area, have to consider the local situation during the approval process.

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

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

In design and construction groundwater protection has high priority and any degradation in quality due to

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

has to be avoided.

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

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

Potential solutions are additional boreholes, additional heat source for regeneration of the borehole, additional heating system and shut down of the ground source in critical times. The same situation can occur while retrofit activities when an old heat pump is replaced by a new and higher efficient one.

On contrary oversizing is typically not problematic in operation despite the fact that the investment is higher than necessary.

Wrong determination of the load occurs usually due to changing user behavior or a climatic change compared to theoretical assumptions in the design process. Inaccurate estimates of the building heating and cooling loads lead to the same issue. Often the loads are over-estimated due to a conservative estimate done by the HVAC engineers. As a result, the system is over- or undersized and solutions as already mentioned can be applied.

Misunderstanding of the geology, underground temperature and thermal conductivity may result from mistakes in interpretation of data extracted from a geological database. In large BHE fields, the geology may vary over the size of the field or wrong measurements were taken in a TRT with wrong determination of the thermal properties. Geological expertise is required in planning of such systems to be able to check the data. The solution is again that of an over- or undersized system. Despite this enough test drillings adapted to the size of the BHE field and depth oriented geological TRT measurements and evaluation may help to avoid these problems.

A revision of the design by the construction companies is important for fast reaction in case of any problem during construction. The drilling may not be applied as planned in design phase (depth, diameter, etc.). This can be solved by a re-design according to new information by the driller. The most common problems during construction are:

- planned final borehole depth not reached - additional boreholes must then be drilled,
- installation depth of loop less than borehole depth - consider lower BHE length by re-design,
- connection of boreholes during drilling - there are ways to avoid this occurring, but that is a planning issue,
- pipe leakage - this occurs occasionally, mostly due to improperly welded connection between the BHE and the horizontal pipe system and is typically observed during pressure testing prior to refilling of the shaft,
- pipe clogging - in most cases an additional borehole is required,
- pipe collapsing - in most cases an additional borehole is required,
- air purging - this is an essential issue performed after filling the system with brine; ventilation valves are common on high points in the system; to void problems with air (oxygen diffusion included), larger systems are often equipped with vacuum air purgers;
- poor documentation while drilling – in many countries it is obligatory to report all boreholes to the geological survey,
- other geological and hydrogeological conditions than expected - change drilling and construction method and re-design.

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

While installing the BHE loop problems may occur like:

- U-tube did not reach the scheduled depth - take out the U-tube and drill again
- damage of U-tube due to bending - take out the U-tube, drill again if necessary and insert an new U-tube
- lack of weight - take out the U-tube and increase the weight
- descent of tube after pulling out of the casing - hold the tube at the top or infallible grouting

- water leakage after inserting U-tube - take out the U-tube, drill again and insert an new U-tube
- installation without reel has to be avoided because of the serious problems resulting.

In many countries, the proper sealing of boreholes by grouting is an important requirement. Therefor the grouting process has to be carried out thoroughly especially when an aquitards was penetrated while drilling. A special focus has to be put on the grouting material and the way of processing. The mixer used has to be appropriate for the material and the water/grout ratio has to be kept exactly. Some grout properties like density or marsh time can easily be determined at the site to verify the correct mixing. Settlement is a potential risk for improper grouting in areas of high geological risks like connection of aquifers with different pressure or water quality or high differences in water temperature or connection of anhydride layer to aquifer. A special focus has to be put on the thorough grouting. Magnetite doped grouting material allows for check of grouting quality of the entire borehole.

In some countries, a deeper environmental assessment is required which studies the influences of construction work and later system operation on the underground but especially on the groundwater mostly with respect to temperature changes. In addition, the above-mentioned geological and hydrogeological impact should be included.

6. CONCLUSIONS

The IEA ECES Annex 27 working group has collected and compiled current information from the participating countries on quality management in the various project phases from design, via construction to the operation. In addition, typical problems and failures measures to avoid them and potential solutions were collected. They can occur in any project phase and can have the full range of peculiarities from simple and easy to handle up to severe impact and complete removal.

It can be summarized that in most cases we don't have any problems, but it is important to be aware of it. Problems and damages have to be examined quantitatively in relation to the total number of installations also to show the real risk of this technology. A first analysis shows that the fraction of problems/damages is very low compared to the total number of systems. But up to now there are no official statistics on the number of boreholes, systems and applications available and even no statistics on failures. As approval authorities sometimes tend to fear the worst it is important to implement a quality management in this field to promote these shallow geothermal techniques. The intended guidelines will cover real practical and not so much theoretical problems and should help to equalize the competition between drillers and installers. They should serve as a general market support and to gain improved quality.

Currently the IEA ECES Annex 27 work contributes to the elaboration of the new European Standard CEN TC 451 WG 2 "Design and Construction of Borehole Heat Exchangers", which may be published in 2020.

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