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Standards and Guidelines for UTES/GSHP wells and boreholes

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Abstract

Starting from Switzerland in the 1990s and continuing in Germany from 1998 on, a number of guidelines and standards on shallow geothermal topics have been developed and published in Europe. Countries having some kind of standardisation and regulation today comprise France, Germany, Italy, Netherlands, Spain, Sweden, Switzerland and the United Kingdom. On the European level (CEN), only two standards with marginal interest for shallow geothermal exist today (EN 15450 on heating systems with heat pump, and EN 17628 on determination of thermal conductivity).

The topic most covered is the design and installation of borehole heat exchangers. However, other methods like horizontal loops, groundwater wells, thermal piles are dealt with in some documents.

The paper gives an overview of the development and status of shallow geothermal standardisation in Europe, and compares design procedures for borehole heat exchangers and their results according to the different standards. Depending on the procedures used (and the year when the respective document was written), substantial deviations can be seen.

A new attempt for harmonised standards in Europe is made with the creation of CEN/TC451 early in 2017, a technical committee with the task to develop standards for "Boreholes for water and geothermal" on the European level (CEN).

Keywords:

Underground Thermal Energy Storage (UTES), Ground Source Heat Pumps (GSHP), Borehole Heat Exchangers (BHE), Drilling, Standards, Regulation, Guidelines

1. Introduction

Shallow geothermal energy systems use the ground as source, sink, or storage medium for heat. The upper boundary of the realm of shallow geothermal is the earth surface, as stated in EU directive 2009/28/EU, Article 2(c): " *'geothermal energy' means energy stored in the form of heat beneath the surface of solid earth*" (this excludes, at least in European practice, the use of surface water bodies). The lower boundary, however, is less clear. For many years, an arbitrary depth of 400 m had been set, based originally on an incentive programme for deep geothermal energy use in Switzerland in the 1980s which excluded all installations less than 400 m deep. This 400-m-boundary later was included in the German guideline VDI 4640 and subsequently used in other documents. However, a trend towards deeper Borehole Heat Exchangers (BHE) exceeding 400 m depth emerged in recent years, first in Switzerland (Ebnöther, 2013). Regulatory limits, e.g. for simplified rules at shallower depth or for application of mining law rules for deeper boreholes, range anywhere between 100 m (France, Germany, and elsewhere) and 500 m (Belgian region of Flanders). So the author prefers to leave the issue of a lower boundary of "shallow" geothermal open. The deepest shallow geothermal installations are those with BHE, and the limiting factors of BHE depth are diverse, comprising mainly geology, pipe material, and drilling and installation technology. The typical depth of BHE today extends from 100 to 200 m (Figure 1).

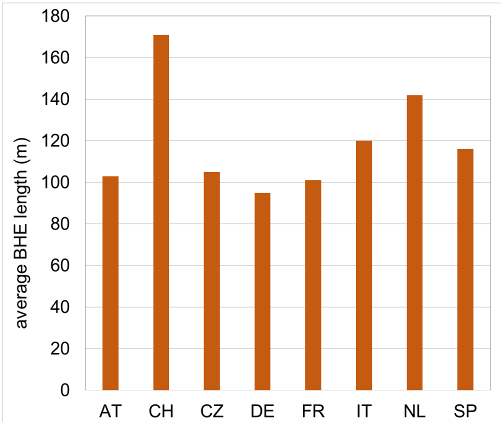

Figure 1: Average depth of BHE in some countries, as from sales numbers of a pipe manufacturer (after data from Ebnöther, 2013); BHE in Norway, Sweden and Finland, not shown here, often exceed 200 m

The main system concepts of shallow geothermal energy use are Underground Thermal Energy Storage (UTES) and Ground Source Heat Pumps (GSHP), with no clear boundary among them when considering large installations. The theoretical concept for a GSHP was already stated in a patent application more than a century ago (Zoelly, 1913); the first practical demonstrations of true GSHP, using basically the same technology as today, date from the 1940s in the USA and from around 1950 in Switzerland. A recent account of GSHP history is given in Sanner (2017).

The number of GSHP installations increased rapidly during the second oil price crisis around 1980 in some European countries (AT, CH, DE, FR, SE etc.), as the example of Germany in Figure 2 illustrates, – only to decrease drastically in the years after. A second, more sound development started slowly in the mid-1990s and peaked in 2008-2010 in several countries (not all experienced such an extremely pointed development as Germany in Figure 2).

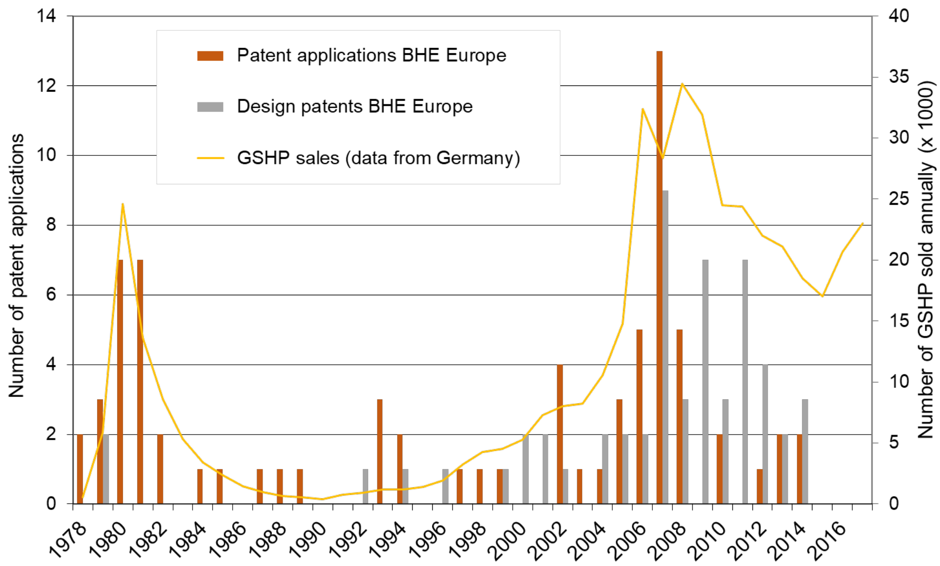

Figure 2: Number of patent applications and design patents (*Gebrauchsmuster*) in Europe from 1978-2014, compared to GSHP sales in Germany

The constant increase of GSHP installations in the 1990s and 2000s soon required some regulation and standardisation. Standards and guidelines as described in this paper supported the market growth, with numbers for all of Europe passing the threshold of 100'000 units per year in 2006/2007 (Figure 3). Since then, the market for GSHP was relatively steady in Europe, when all countries are considered; however, the total number decreased to about 80'000 units per year in recent years. The total number of GSHP installations in place in Europe at the end of 2015 was estimated at well above 1.7 million, accounting for a total installed capacity of almost 23 GW_{th} (EGEC, 2017). The number of true UTES installations is deemed to be much smaller, with a few thousand operational mainly in the Netherlands and Sweden, but also elsewhere (BE, DE, NO, etc.). UTES plants tend to be larger, in order to make use of a sufficient storage effect and to avoid the thermal losses small BHE fields or sets of groundwater wells have towards the surrounding ground.

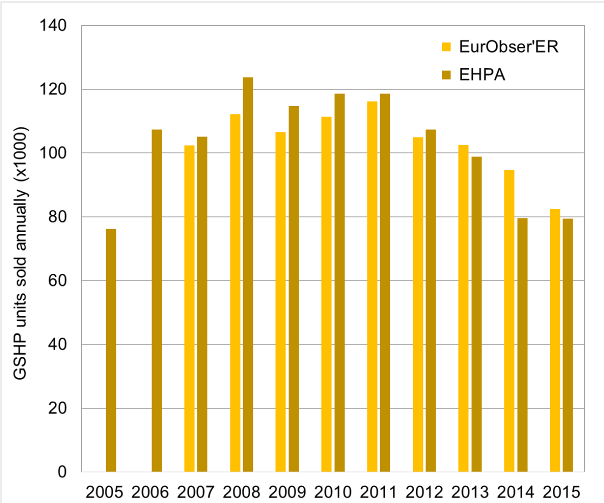

Figure 3: Annual GSHP sales numbers in Europe, after data from EurObser'ER and EHPA

Another aspect of an emerging and then maturing technology, besides increasing standardisation, is securing of intellectual property. A survey started by the author before 1990 and regularly updated until today identified about 200 patent applications and ca. 100 design patents ("*Gebrauchsmuster*" in German) filed in Europe to protect shallow geothermal technology items. While this survey cannot claim to be exhaustive, and has a definite AT-CH-DE-bias, it can be deemed representative nevertheless. The largest topic among the entries concerns BHE and tools or methods for BHE installation, counting almost 90 respective patent applications and close to 60 design patents. It is interesting to see how the number of patent applications faithfully follows the fate of the GSHP market (Figure 2).

2. Development of shallow geothermal standardisation

2.1. Early guidelines on ground heat use in Austria, Germany, Switzerland in the 1980s

The first European guideline documents on heat pump use in connection with shallow geothermal energy considered the impact of this technology on ground and ground water. In the late 1970s, groundwater wells and horizontal loops were the technologies used (Sanner, 2017), and thus concerns about thermal impact on the groundwater and leakage of working fluids were addressed. In Germany, where water management regulations are given by authorities on the level of states (*Bundesland*), a joint working group of the state authorities (LAWA) agreed on some fundamentals for the harmonised handling of such regulation. In LAWA (1980) mainly groundwater heat pumps are covered, however, an early version of coaxial BHE is also shown (Figure 4). A second printing of the 52-page brochure was required already few years later, and in 1983 a first addition to the LAWA paper was published. This 12-page additional document covered absorption heat pumps, heat pipes as BHE (one of the early records of this technology), and an updated list of heat pump working fluids.

Astonishingly, after these first documents from German authorities it took almost 30 years until an updated follow-up document on the federal level was published (LAWA, 2011), while numerous guidelines for GSHP licensing were issued at state level, beginning with the state of Baden-Württemberg in 1998. A list of state guidelines in force at the end of 2017 is given in Table 6 at the end of this paper. Similar environmental and licensing guidelines, often with related maps provided online via GIS, meanwhile are available in several European countries – a complete survey would go beyond the scope of this paper.

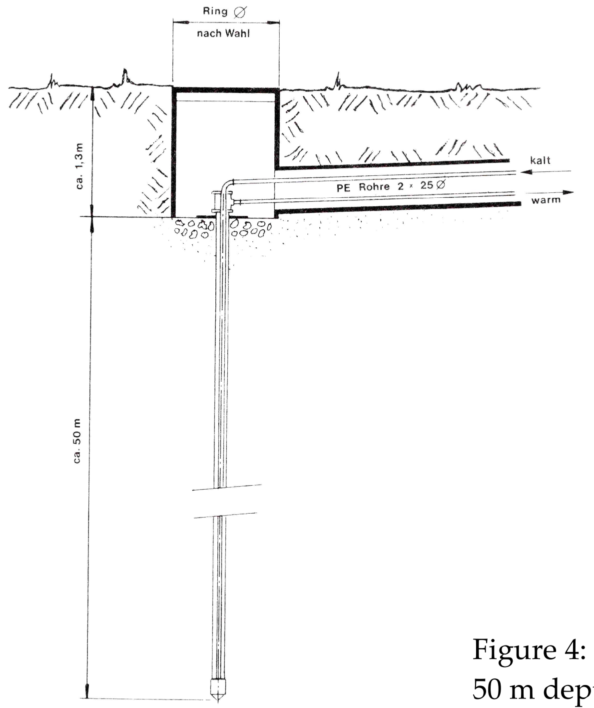

Figure 4: Sketch of coaxial BHE with 50 m depth from LAWA (1980)

On the technical side for planning and installation, a guide for coaxial BHE (of the type shown in LAWA, 1980; cf. Figure 4) was given by a manufacturer (WTA, 1981), including sizing recommendations and an early version of an on-site test for the thermal yield of the BHE in the given geology.

The first guideline in Austria has been issued in 1986 by the Austrian Association of Water Management, ÖWWV (today ÖWAV), considering ground water heat pumps (ÖWWV, 1986). The focus was mainly on groundwater protection. Like in Germany, all Austrian states meanwhile have documentation on GSHP licensing (Table 7). In Switzerland, issuing guidelines started with a collection of design criteria in 1988 (SIA, 1988) and a manual on BHE (Burkart et al., 1989). The first proper technical guideline, AWP Merkblatt T1, was published in 1992 (see 2.2), and was followed by environmental guidelines (BUWAL, 1994); Table 8 lists these and other older documents. The Swiss cantons started issuing guidelines on environmental evaluation and permitting in the mid-1990s, with Bern being the first; another first was a map of suitable or non-suitable areas in the canton Bern, provided in 1996. Today such documents exists in almost all of the 26 cantons, often complemented by maps.

2.2. AWP guideline in Switzerland

Switzerland was an early adopter and developer of BHE technology, with the first installation of a modern-style BHE made of PE-pipes in 1980 (Rohner, 1991). A technical compendium on BHE was published already in 1982 in Switzerland (Schwanner, Hopkirk, 1982). In 1992 the Arbeitsgemeinschaft Wärmepumpen (AWP) in Zurich presented a technical guideline on GSHP with BHE. This document, AWP Merkblatt T1 'Wärmepumpenheizungsanlagen mit Erdwärmesonden' (heat pump heating systems with borehole heat exchangers, Table 8), was the first in Europe to

- define factory-produced BHE loops,
- specify a minimum distance of 5 m between BHE,
- and stipulate grouting of the borehole annulus by pumping grout down to the bottom of the borehole in a pipe and filling the annulus from bottom to top.

Figure 5 shows a schematic from this guideline. AWP developed it into a full set of documents, covering all ground coupling methods (and in addition the use of surface water), with the latest and last version issued in 2007 (Table 1). Today, AWP does no longer exist, and the AWP guidelines are no longer required, superseded by the Swiss standards SN 546 384/6 and SN 546 384/7 (cf. Table 9).

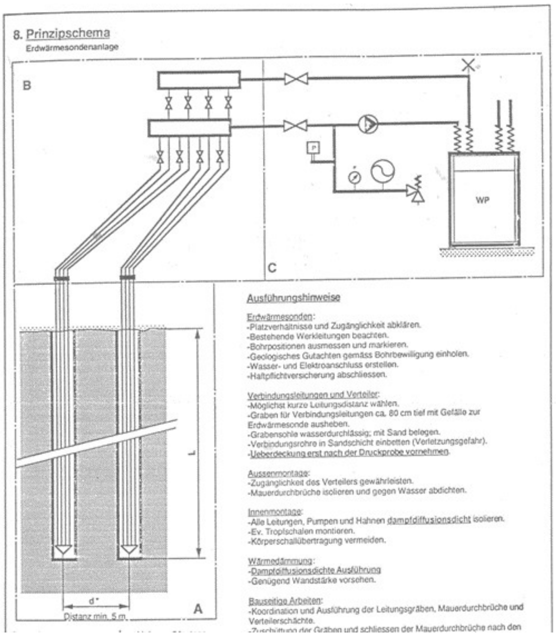

Figure 5: Schematic of GSHP with 2 BHE from AWP Merkblatt T1 of 1992

Table 1: List of last issues in 2007 of Swiss AWP guidelines concerning GSHP

Name/Number	Title original	Title English
AWP Merkblatt T1	Wärmepumpenheizungsanlagen mit Erdwärmesonden	Heat pump heating systems with borehole heat exchangers
AWP Merkblatt T2	Wärmepumpenheizungsanlage mit horizontalen Erdkollektoren, Erdwärmekörben und Kompaktkollektoren	Heat pump heating systems with horizontal ground heat exchangers, earth heat baskets and compact collectors
AWP Merkblatt T3	Wärmequellennutzung Grundwasser	Use of groundwater as heat source
AWP Merkblatt T5	Füllen von Erdwärmesondenanlagen	Filling of BHE installations

2.3. VDI 4640 guideline Germany

Almost from the beginning of GSHP use in Austria, Germany and Switzerland, the sizing of horizontal loops or BHE for a given heat pump and building was done by using the parameter 'specific heat extraction rate' (*spezifische Entzugsleistung* in German). The values were based on practical experience from the first plants. For horizontal collectors, a specific extraction rate of 25-30 W/m^2 of area was recommended, and for BHE a maximum of 54 W/m borehole depth was stated (both values from WTA, 1981). While design calculations had been suggested in North America already in the late 1940s (e.g. Ingersoll, Plass, 1948) and in Europe in the late 1970s (e.g. von Cube, 1977), and WTA (1981) had presented a kind of 'heat production test' with a mobile unit, the simple 'rule of thumb' of specific heat extraction was the design method of choice for most installers.

In Switzerland, a generic value of 55 W/m was used for BHE, while in Germany and Austria 50 W/m were considered appropriate. However, values of up to 120 W/m were reported in certain installations, presumably with substantial groundwater flow. In a survey in 1992, the author collected published data from GSHP installations, yielding an average of 62 W/m and a range of 27-119 W/m (Sanner, 1992). The specific heat extraction rate for horizontal loops in that survey varied from 7-30 W/m^2.

As long as single-family houses with a typical pattern of 1200-2000 full-load hours per year were considered, and specific heat extraction rates were not pushed above ca. 60 W/m, the BHE sizing with this rule of thumb was adequate. Differences in climate and geology resulted in varying efficiency, but did not jeopardize the overall functioning of the system. Sanner (1999) highlighted the limits of this method. For larger installations, easy-to-use PC software for BHE design (a precursor of the well-known 'Earth Energy Designer', EED) became available around 1990 (Claesson, Eskilson, 1988; Claesson, 1991).

However, with the market resurgence in Germany in the 1990s, leading to increased competition, cost-cutting was the order of the day. And because heat pump prices were more difficult to decrease, the easiest target was BHE length. Shorter BHE for the same heat pump size result in higher specific heat extraction, pushing the respective GSHP system beyond sustainable operation. As most problems with cooling down of the underground emerge only after a few years, the practice of under-sizing BHE length to cut cost was not realised by most costumers. BHE design resulting in heat extraction rates of 80-100 W/m, or even more, was not unusual.

In order to provide some guidance and to prevent GSHP-technology from losing its reputation due to numerous heat pumps running poorly or even stopped for good, in 1994 the author, at the time vice chairman of the German geothermal association (GtV), contacted the German Association of Engineers (VDI) to initiate a technical guideline for GSHP. VDI guidelines covered already many other aspects of heating and cooling, are well respected, and more flexible in content and less bureaucratic in drafting than DIN standards The respective committee, VDI 4640, was inaugurated in 1995 (Sanner et al., 1997), and the drafts of the first two parts (on generic and environmental issues and on GHSP design and installation, respectively) were published in 1998. The final versions came into force in 2000 and 2001, followed by a 3rd part on UTES in 2001 and a 4th part on direct uses (pre-heating/cooling of ventilation air and direct cooling) in 2004 (Reuss et al., 2006). Today four parts are available in final form, a 5th part (TRT) as published draft, and another draft, for the new version of the 2nd part (GSHP), is public since 2015. The current status can be seen from Table 9.

Guideline VDI 4640 elevated shallow geothermal energy use in Germany from the era of trial and error, from a scratch-built, relatively obscure niche technology, to an industrial product:

- VDI 4640-2 covers design and installation of GSHP with groundwater wells, horizontal loops, BHE, and some other systems like horizontal direct expansion, compact GHE, and thermal piles.
- VDI 4640-3 deals with UTES and includes systems using aquifers (ATES) as well as those using BHE (BTES).

For BHE, guideline VDI 4640-2 in 2001 limited the application of specific heat extraction rates to installations with less than 30 kW heating capacity and maximum 2400 full-load hours per year. For the design of larger installations analytical or numerical calculations were stipulated. Tables in VDI 4640-2 gave empirical values for specific heat extraction rates for horizontal loops and for BHE, dependent on soil or rock type (example in Figure 6). The draft of the revised version of VDI 4640-2 from 2015 substitutes the empirical values with those derived from calculation with EED, for 1-5 BHE, different thermal conductivity of the underground, and 3 different target values (0 °C, -3 °C, -5 °C) of minimum fluid temperature entering the BHE. Systems for heating only, for heating and domestic hot water, and for additional space cooling in summer are covered. This allows for much more accurate sizing of BHE (cf. 3.2).

Underground	Specific heat extraction	
	for 1800 h	for 2400 h
General guideline values:		
Poor underground (dry sediment) (λ < 1.5 W/(m · K))	25 W/m	20 W/m
Normal rocky underground and water saturated sediment (λ < 1.5–3.0 W/(m · K))	60 W/m	50 W/m
Consolidated rock with high thermal conductivity (λ > 3.0 W/(m · K))	84 W/m	70 W/m
Individual rocks:		
Gravel, sand, dry	< 25 W/m	< 20 W/m
Gravel, sand, saturated water	65–80 W/m	55–65 W/m
For strong groundwater flow in gravel and sand, for individual systems	80–100 W/m	80–100 W/m
Clay, loam, damp	35–50 W/m	30–40 W/m
Limestone (massif)	55–70 W/m	45–60 W/m
Sandstone	65–80 W/m	55–65 W/m
Siliceous magmatite (e.g. granite)	65–85 W/m	55–70 W/m
Basic magmatite (e.g. basalt)	40–65 W/m	35–55 W/m
Gneiss	70–85 W/m	60–70 W/m
The values can vary significantly due to rock fabric such as crevices, foliation, weathering, etc.		

Figure 6: Specific heat extraction rates for BHE from VDI 4640-2:2001

3. Shallow geothermal standards as of 2017

3.1. Standards on GSHP and UTES in 8 European countries

The full list of specific standards on shallow geothermal technology is given in Table 9 at the end of this paper. At the turn of the millennium, such documents existed only in four countries in Europe: In Austria ÖWAV RB 207 from 1993, in Germany the draft VDI 4640 from 1998, in Sweden Normbrun 97 from 1997, and in Switzerland AWP Merkblatt T1 from 1992. Three of them are still in force today, in revised and updated versions, while AWP Merkblatt T1 was replaced by SIA 384/6, now SN 546 384/6 (Table 9).

The development of standards for GSHP in the UK was prompted by the planned introduction of a financial support scheme for renewable energy, the Renewable Heat Incentive (RHI). To secure proper design and installation, systems eligible to receive payments had to be built according to MIS 3005, a 'Microgeneration Installation Standard' first published in 2008. Microgeneration is a term referring to renewable energy installations on the consumer scale, and the Microgeneration Certification Scheme (MCS) had already been launched in 2006 within the 'Low Carbon Buildings Programme'. MIS 3005 already reached version 5.0 in 2017. For GSHP, the sizing tables MCS 022 from 2011 form an integral part, for design of the ground heat exchangers. Values are provided for BHE, horizontal GHE and 'Slinky' GHE, with the BHE data derived from calculations using EED. Complementary standards dealing more in detail with the ground-coupling part were published by the UK Ground Source Heat Pump Association (GSHPA), with documents on BHE, thermal piles, and horizontal GHE available.

The next standards published were in Switzerland:

- In 2010, SN 546 384/6 (sometimes listed as SN 565384/6) on BHE, the standard that superseded AWP Merkblatt T1.
- In 2015, SN 546 384/7 on GSHP with groundwater wells (open loop).

France and Italy started issuing several GSHP standards from 2011 on. AFNOR opened a range of numbers for standards on "Forage d'eau et de géothermie" (Boreholes for water and geothermal) in the series NF X10-950 to NF X10-999 (Table 9). The topics comprise BHE manufacturing (with separate documents on different materials), BHE installation, and groundwater wells for thermal use. In Italy, UNI 11466 - UNI 11468 cover the aspects of design, installation and environmental issues for GSHP, while UNI 11517 addresses the qualification of shallow geothermal installers (in accordance with Article 14 of EU-Directive 2009/28/EU).

The Spanish standard UNE 100715-1 from 2014 deals with design and installation of BHE. It is intended as the first of a series, covering also other ground-coupling methods; depending on the progress of CEN-standards for GSHP (see 3.3) and their national adaptation, this may no longer be required.

No true standards on shallow geothermal exist in the Netherlands, however, the country has regulations and guidelines that work well. In a relatively small country with densely populated regions, land use and also the use of the underground needs strict regulation. In July 2013 a governmental decree came into force, AMvB [1] Bodemenergie (earth energy), dividing shallow geothermal systems into three classes (closed loop <70 kW, closed loop >70 kW, open loop) and stipulating necessary efficiency, permitting and environmental requirements for each, including certification of installers. The decree also defines areas of interference ('interferentiegebied') and provides measures to regulate and protect neighbouring installations in these areas. On the installation side, the association Bodemenergie NL provided guidelines, with the last published version in 2006; the website https://bodemenergieNL.nl states end of 2017 that these are no longer available, awaiting update.

Most standards are rather dull, technical documents. A notable exception is the Swedish Normbrun, also in the most recent version of 2016. Nice aquarelle pictures visualise technologies and environmental problems and give an attractive look to the guideline (Figure 7), without lowering the quality of the technical content.

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[1] AMvB: Algemene Maatregel van Bestuur (General administrative regulation)

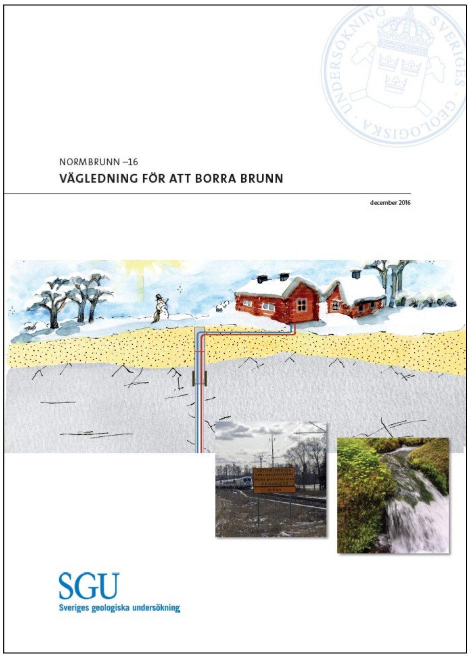

Figure 7: Cover page of Swedish guideline Normbrun-16 (2016)

3.2. Comparison of BHE design after valid standards

In most of the standards, stipulations for manufacturing of BHE pipes and for drilling, installation and testing are comparable, as well as design requirements for larger projects. Design guidelines for smaller projects, however, can result in very different BHE length. The main reason is that some standards still are based on the old, empiric values for specific heat extraction, while others use calculated values. Also the presentation of the values differ, in tables or in graphs. A comparison is made here using the different standards and methods, with the example of a virtual single-family house (Table 2).

The following standards are used for calculating the required BHE length for the house from Table 2: VDI 4640-2 (2001), tables with empirical values; VDI 4640-2 (draft 2015), tables with calculated values (EED); SN 546 384/6 (2010), curves and correction factors based on calculated values; and MIS 3005 (2017) with MCS 022 (2011), tables with calculated values (EED). Other standards do not offer own BHE design tables, but reference one ore more of those mentioned before: ÖWAV RB 2017 (2009) lists both VDI 4640-2 (2001) and SN 546 384/6 (2010) as suitable methods; NF X10-970 (2011) only provides a French reprint of the respective table from VDI 4640-2 (2001). Finally, UNE 100715-1 (2014) references IDAE (2012) as simplified design tool and otherwise requires numerical simulation [2]. For comparison, the BHE length was also determined with the software EED (first published in Hellström, Sanner, 1994).

The results of the BHE sizing for the building in Table 2 are shown in Table 3. The substantial difference between BHE length sized after empirical values (the first two lines) and after calculated values (the rest) is obvious. The empirical design results in 33-38 % shorter BHE than

[2] The method in IDAE (2012) is intended for systems for heating and cooling, by calculating thermal resistance of the ground heat exchanger (incl. soil thermal properties) and the share of heating and cooling. It does not consider the long-term effects of unbalanced systems, and thus is not suitable for the example presented here.

determined by full EED calculation, with consequences in efficiency and long-term sustainability of the plants. The values obtained with design tables and curves based on calculation show a deviation of only -7 % to +12 % from the EED results. The old, empiric tables thus should be retired for good, also in more recent standards that reference them.

Table 2: Parameters of sample building and site for BHE design comparison (single-family house in central Germany)

Heat load according to DIN EN 12831	Q_H	12 kW
Full-load hours	t_a	1500 h/a
Heating supply temperature	T_s	30 - 35 °C
Annual HP efficiency	SPF	3.8
Heat extraction rate	Q_{BHE}	8.8 kW
Geology		Marlstone
Thermal conductivity marlstone (after VDI 4640-1)	λ	2.3 W/(m·K) variation 1.8 - 2.9 W/(m·K)

Table 3: Results of BHE sizing for building in Table 2, using different standards and EED calculation (limitations in certain standards respected)

Standard and source	Number of BHE	Depth of BHE	Total BHE length	Deviation from EED result
VDI 4640-2 (2001), generic values (also in NF X10-970, 2011, and ÖWAV RB 207, 2009)	2	73.4 m	147 m	-33 %
VDI 4640-2 (2001), specific rock values (also in NF X10-970, 2011, and ÖWAV RB 207, 2009)	2	67.7 m	136 m	-38 %
VDI 4640-2 (draft 2015), after values for 2 and 3 BHE	2 3	102.1 m 72.2 m	204 m 216 m	-7 % -2 %
SN 546 384/6 (2010) (also in ÖWAV RB 207, 2009)	2	123 m	246 m	+12 %
MIS 3005 (2017) with MCS 022 (2011),	2	110 m	220 m	0 %
EED-calculation	2	110 m	220 m	0 %

3.3. Geothermal standards on the European level

On an initiative of the French standards organisation AFNOR, on the European level a new technical committee CEN/TC 451 “Boreholes for Water and Geothermal” was created in the beginning of 2017. This title is derived from the group of French standards up to NF X10-999, ‘Forage d’eau et de géothermie’, and is rather open; so it might comprise everything from a garden well to a deep geothermal well of several kilometres. Currently CEN/TC 451 is renamed “Water wells and borehole heat exchangers” and is divided into two working groups, WG1 on water wells, and WG2 on borehole heat exchangers. Further shallow or deep geothermal technologies are not yet addressed.

Once CEN standards are finished, went through the phase of public consultation, and are confirmed by the national member organisations of CEN, they have to be adopted as national standards by these organisations and replace existing national standards with the same topic. This probably would be the case for the French, Italian, Spanish and Swiss standards. As the standards and guidelines from Austria, Germany, Sweden and the UK are not issued by CEN member organisations, they could stay in force even after the respective national organisations will have adopted the CEN standards as OENORM EN, DIN EN, SS EN or BS EN. Then in Germany VDI 4640 could be considered as a national annotation or commentary to the relevant DIN EN standards. However, in the case of contradicting statements, the DIN EN standard would be deemed more authoritative.

4. A glimpse westward across the Atlantic – standards in North America

This paper is written from a European perspective, and the author humbly admits being not qualified to comment authoritatively on North American standards. Considering the seniority of GSHP application in the USA over Europe and the sheer number of annual installations, an influence from across the Atlantic on European development cannot be denied, and thus a glimpse on what happened in North America seems necessary. Cooperation within the IEA heat pump programme and later also in the IEA energy storage programme was the key to exchange of ideas, experiences and best practice among European and North American experts (and others too, like Japanese and Korean). However, the approach to GSHP technology was slightly different on both sides: The author vividly recalls a moment at the IEA GSHP Workshop in Albany NY in October 1986 (Calm, 1987), when after some presentations from Sweden and Germany on how to improve GSHP efficiency and make the best heat pumps, a US colleague took over and started his presentation with the words: “And now let us talk about how to sell more ground source heat pumps”.

An example for early design and installation guidelines in North America is Hughes (1986), a “manual of accepted practices”, prepared for regional utilities Niagara Mohawk Power Corp. and Rochester Gas and Electric Corp. in cooperation with the New York State Energy Research and Development Authority (Figure 8). Presenting numerous easy-to-understand drawings, this manual was intended for practical use (and most of the content still is valid today, for US conditions). A key objective of this manual was to underpin an incentive programme for GSHP run by the utilities and to ensure respective quality work and best practice.

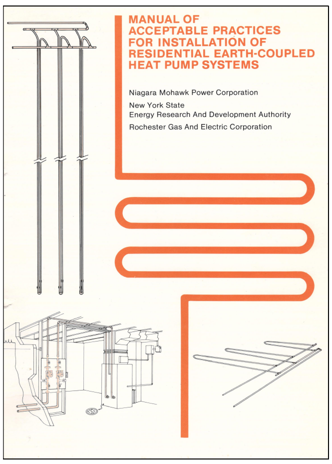

Figure 8: Cover page of New York state guideline from 1986 (Hughes, 1986)

A comprehensive manual on GSHP was presented by ASHRAE (Bose et al., 1985). For a more sophisticated and reliable design of GSHP, the National Water Well Association published a handbook on earth-coupled heat transfer, to offer design methods better than rules of thumb and simpler than numerical simulation, the latter being restricted to research centres etc. at the time (Hart, Couvillion, 1986).

The International Ground Source Heat Pump Association (IGSHPA), founded in 1987 in Stillwater OK, presented a first guide to GSHP installation in 1988 under the umbrella of the National Rural Electric Cooperative Association (IGSHPA, 1988), and installed a standards committee in 1994. Today, IGSHPA standards are accepted practice throughout North America. The latest version of the standards brochure, keeping almost the same title as the first IGSHPA publication from 1988, was published in 2017; Figure 9 shows the cover page (IGSHPA, 2017). In 2016, the standardisation bodies of both the USA (ANSI) and Canada (CSA) have issued a joint, comprehensive set of standards as ANSI/CSA/IGSHPA C448-16, covering the full field of GSHP applications. A list of the content of this set of standards is given in Table 4. Thus a single set of rules apply now across North America, something not yet achieved in Europe.

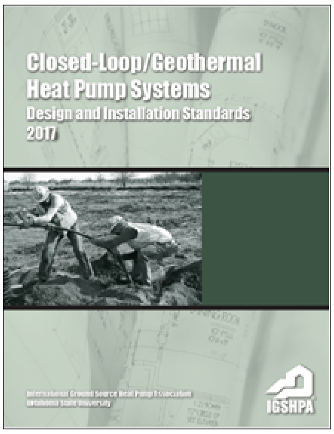

Figure 9: Cover page of IGSHPA standard brochure 2017 (IGSHPA, 2017)

Table 4: Subsections of North American standard ANSI/CSA/IGSHPA C448-16 "Design and installation of ground source heat pump systems for commercial and residential buildings"

Number	Title
C448.0	Design and installation of ground source heat pump systems - Generic applications for all systems
C448.1	Design and installation of ground source heat pump systems for commercial and institutional buildings
C448.2	Design and installation of ground source heat pump systems for residential and other small buildings
C448.3	Installation of vertical configured closed-loop ground source heat pump systems
C448.4	Installation of horizontal configured closed-loop ground source heat pump systems
C448.5	Installation of surface water (including submerged exchangers) heat pump systems
C448.6	Installation of open-loop systems ground water heat pump systems
C448.7	Installation of standing column well heat pump systems
C448.8	Installation of direct expansion heat pump systems

5. Conclusions and outlook

The number of standards on shallow geothermal technology is steadily growing (Table 5), with 29 documents from 8 countries and the CEN level in 2017 (Table 9). Beside these standards, numerous guidelines and best practice documents have been issued at regional level, or for certain aspect of the technology only – the tables in this paper can only give an idea of the variety.

Table 5: Number of shallow geothermal standards and countries involved 1995-2017

	1995 *	2008 *	2017
Standards	7	13	29
Countries	3	4	8 + CEN
	AT, CH, DE	AT, CH, DE, SE	AT, CH, DE, FR, IT, SE, SP, UK and CEN

* Sanner (1995), Sanner (2008)

The work of CEN/TC 451 hopefully will create some common basic standards for shallow geothermal applications for all of Europe. In a continent with a huge diversity in climate, geology and building practice, such standards can only lay the basis for the general requirements in practices and materials, while national (or even regional) documents will still be required to adapt shallow geothermal technology to the respective site.

The existence of thematic maps for shallow geothermal potential (rock type, thermal properties, etc.) and for groundwater and ground protection, usually available online as GIS, helps a lot in site assessment and design by providing crucial information and input parameters. The work of geological surveys in many countries and regions, supported by national or EU funds, has already resulted in a good coverage of Europe (e.g. regions in France, Northern Italy, Switzerland, Austria, Germany), and more is expected in particular in Poland, Czech Republic, Slovakia, Slovenia and others.

With appropriate standards for design and installation, up-to-date information on topics like groundwater protection, and on-line information on geological and thermal conditions, proper planning of high-quality GSHP and UTES systems is easier than ever. Additional measurement methods like TRT and software for detailed, bespoke design of ground-coupling systems can give extra accuracy where needed. The activities of CEN/TC 451 WG2 could, if resulting in suitable standards on the European level, help in deploy the best practice already achieved in the countries with standards listed in Table 9 to the rest of Europe.

Table 6: List of state guidelines for environmental evaluation and licensing of GSHP in Germany (status end of 2017); some states also provide related maps, often online via GIS

State	Title (German original title)	Topic(s) covered	Year of latest edition
Baden-Württemberg	Leitfaden zur Nutzung von Erdwärme mit Erdwärmesonden [1]	BHE (vertical loops)	2005
	Leitfaden zur Nutzung von Erdwärme mit Erdwärmekollektoren	Horizontal loops	2008
	Leitfaden zur Nutzung von Erdwärme mit Grundwasserwärmepumpen	Ground-water wells	2009
Bayern (Bavaria)	Leitfaden Erdwärmesonden in Bayern [2]	BHE	2012
Berlin	Erdwärmenutzung in Berlin, Merkblatt für Erdwärmesonden und Erdwärmekollektoren…	BHE and horiz. loops	2017
Brandenburg	Nutzung von Erdwärme in Brandenburg	BHE, horiz. loops, wells	2009
Hamburg	Leitfaden zur Erdwärmenutzung in Hamburg	BHE and horiz. loops	2016
Hessen	Erdwärmenutzung in Hessen, Leitfaden für Erdwärmesondenanlagen zum Heizen und Kühlen	BHE	2017
Mecklenburg-Vorpommern	Erdwärmesonden und Erdwärmekollektoren in Mecklenburg-Vorpommern	BHE and horiz. loops	2015
Niedersachsen (Lower Saxony)	Leitfaden Erdwärmenutzung in Niedersachsen, rechtliche und technische Grundlagen [3]	BHE, horiz. loops, wells	2012
Nordrhein-Westfalen	Merkbl. 48, Wasserwirtschaftliche Anforderungen an die Nutzung von oberflächennaher Erdwärme [4]	BHE, horiz. loops, wells	2004
Rheinland-Pfalz (Rhineland-Pal.)	Leitfaden zur Nutzung von oberflächennaher Geothermie mit Erdwärmesonden	BHE	2012
Saarland	Leitfaden Erdwärmenutzung	BHE and horiz. loops	2008
Sachsen (Saxony)	Erdwärmesonden, Informationsbroschüre zur Nutzung oberflächennaher Geothermie	BHE	2014
Sachsen-Anhalt	Erdwärmenutzung in Sachsen-Anhalt [5]	BHE	2012
Schleswig-Holstein	Leitfaden zur geothermischen Nutzung des oberflächennahen Untergrundes	BHE and horiz. loops	2011
Thüringen (Thuringia)	Nutzung oberflächennaher Geothermie, Arbeitshilfe zur wasserrechtlichen Beurteilung	BHE, horiz. loops, wells	2013

[1] since 2010 a series of documents on quality control of BHE have been added (LQS-EWS), latest issue in 2015

[2] in addition a detailed document on planning and installation of BHE, Merkblatt Nr. 3.7/2 (2012)

[3] draft version with intended revisions published in 2017

[4] new edition under preparation; in addition a general brochure "*Geothermie in Nordrhein-Westfalen erkunden · bewerten · nutzen*" on all geothermal technologies from 2011 exists

[5] in addition a document on quality control of BHE from 2016

Table 7: List of state guidelines for environmental evaluation and licensing of GSHP in Austria (status end of 2017); some states also provide related maps

State	Title (German original title)	Topic(s) covered	Year of latest edition
Burgenland	Wärmepumpen [1]	GSHP general	2016
Kärnten (Carinthia)	Merkblatt Grundwasserwärmepumpe	GW wells	2014
Niederösterreich (Lower Austria)	Wärmepumpen und Grundwasserschutz, Planung, Bau und Betrieb	BHE, horiz. loops, wells	2012
Oberösterreich (Upper Austria)	Merkblatt Erdwärmesonden (Tiefsonden)	BHE	2011
	Merkblatt Flachkollektor	Horiz. loops	2006
	Merkblatt Grundwasser–Wärmepumpen bis 5 l/s [2]	GW-wells	2006
Salzburg	Leitfaden Erdwärmesonden (Tiefensonden)	BHE	2017
Steiermark (Styria)	Die Gewinnung von Erdwärme in Form von Vertikalkollektoren (Tiefensonden) - Strategiepapier	BHE	2011
Tirol (Tyrol)	Leitfaden zum Bau und Betrieb von Erdwärmesonden in Tirol	BHE	2016
Vorarlberg	Nimm 4, zahl 1! Richtig heizen mit Erdwärme	GSHP general	2014
Wien (Vienna)	Erdwärme voraus! Die Erde als Energiequelle	BHE, horiz. loops, wells	2016

1 in addition a document with a map for BHE
2 complemented by 4 documents on well placement etc.

Table 8: List of older guideline documents in Switzerland (no list of the guideline documents of all 26 Swiss cantons is attempted in this paper!)

Name/Number	Original title	Title in English	Year
SIA D 025	Base de dimensionnement des systèmes exploitant la chaleur du sol à basse température	Fundamentals for dimensioning of systems extracting earth heat at low temperatures	1988
BfE Schriftenreihe Nr. 46	Erdwärmesonden-Heizanlagen	Heating systems with BHE	1989
AWP Merkblatt T1	Wärmepumpenheizungsanlagen mit Erdwärmesonden	Heat pump heating systems with borehole heat exchangers	1992
BUWAL	Wassergefährdende Flüssigkeiten: Wegleitung für die Wärmenutzung mit geschlossenen Erdwärmesonden	Fluids hazardous for water: Guidelines for heat extraction with closed borehole heat exchangers	1994
FWS	Anforderungen an Wärmepumpen für die Nutzung von Wärme aus Grundwasser, Oberflächenwasser, Erdwärmesonden, Erdregister	Requirements for heat pump installations using heat from groundwater, surface water, BHE, horizontal GHE	1996
SIA D 0136	Grundlagen zur Nutzung der untiefen Erdwärme für Heizsysteme	Fundamentals for using shallow geothermal heat for heating systems	1996

Table 9: Standards explicitly addressing shallow geothermal technology, in force or published as draft by end of 2017

Number	Original title	Title in English	year
		Europe – CEN [1]	
EN 15450	Heating systems in buildings – Design of heat pump heating systems	Heating systems in buildings – Design of heat pump heating systems	2007
EN ISO 17628	Geotechnical investigation and testing – Geothermal testing – Determination of thermal conductivity of soil and rock using a borehole heat exchanger	Geotechnical investigation and testing – Geothermal testing – Determination of thermal conductivity of soil and rock using a borehole heat exchanger	2015
		Austria	
ÖWAV RB 207	Thermische Nutzung des Grundwassers und des Untergrundes - Heizen und Kühlen	Thermal use of groundwater and underground - Heating and cooling	2009
		France	
prNF X10-950	Forage d'eau et de géothermie - Ciment pour géothermie - Exigences	Boreholes for water and geothermal - cement for geothermal - requirements	? [2]
NF X10-960-1	Forage d'eau et de géothermie - Sonde géothermique verticale - Généralités	Boreholes for water and geothermal - vertical borehole heat exchangers - General issues	2013
NF X10-960-2	(Forage … verticale) - Boucle de sonde en polyéthylène 100 (PE 100)	(Boreholes … exchangers) - pipe loops of polyethylene 100 (PE 100)	2013
NF X10-960-3	(Forage … verticale) - Boucle de sonde en polyéthylène réticulé (PE-X)	(Boreholes … exchangers) - pipe loops of cross-linked polyethylene (PE-X)	2013
NF X10-960-4	(Forage … verticale) - Boucle de sonde en polyéthylène de meilleure résistance à la température (PE-RT)	(Boreholes … exchangers) - pipe loops of polyethylene with higher temperature resistance (PE-RT)	2013
NF X10-970	(Forage … verticale) - Réalisation, mise en oeuvre, entretien, abandon	(Boreholes … exchangers) - Installation, commissioning, maintenance, abandonment	2011
NF X10-999	Forage d'eau et de géothermie — Réalisation, suivi et abandon d'ouvrages de captage ou de surveillance des eaux souterraines réalisés par forages	Boreholes for water and geothermal - operation, supervision and abandonment of groundwater wells for extraction or monitoring	2014
		Germany	
DIN 8901	Kälteanlagen und Wärmepumpen - Schutz von Erdreich, Grund- u. Oberflächenwasser	Refrigerating systems and heat pumps - Protection of soil, ground and surface water	2002

1 CEN standards are adopted by the member organisations and issued, usually translated into national language, with adding the own national acronym, e.g. DIN EN 15450 "*Heizungsanlagen in Gebäuden - Planung von Heizungsanlagen mit Wärmepumpen*" in Germany

2 referenced in NF X10-970, but not available at AFNOR – apparently not yet finished

Table 9 (continued): Standards explicitly addressing shallow geothermal technology, in force or published as draft by end of 2017

Number	Original title	Title in English	year
DVGW W 120-2	Qualifikationsanforderungen für die Bereiche Bohrtechnik und oberflächennahe Geothermie (Erdwärmesonden)	Qualification requirements for the sector of drilling technology and shallow geothermal (borehole heat exchangers)	2014
VDI 4640-1	Thermische Nutzung des Untergrunds - Grundlagen, Genehmigungen, Umweltaspekte	Thermal use of the underground - Fundamentals, approvals, environmental aspects	2010
VDI 4640-2 [3]	(Thermische … Untergrunds) - Erdgekoppelte Wärmepumpen	(Thermal … underground) - Ground source heat pump systems	2001
VDI 4640-3	(Thermische … Untergrunds) - Unterirdische Thermische Energiespeicherung	(Thermal … underground) - Underground thermal energy storage	2001
VDI 4640-4	(Thermische … Untergrunds) – Direkte Nutzungen	(Thermal … underground) – Direct uses	2004
VDI 4640-5 [4]	(Thermische … Untergrunds) - Thermal response test	(Thermal … underground) - Thermal response test	2016
Italy			
UNI 11466	Sistemi geotermici a pompa di calore - Requisiti per il dimensionamento e la progettazione	Geothermal systems with heat pump – requirements for the dimensioning and design	2012
UNI 11467	Sistemi geotermici a pompa di calore - Requisiti per l'installazione	Geothermal systems with heat pump – requirements for installation	2012
UNI 11468	Sistemi geotermici a pompa di calore - Requisiti ambientali	Geothermal systems with heat pump – environmental requirements	2012
UNI/TS 11487	Sistemi geotermici a pompa di calore - Requisiti per l'installazione di impianti ad espansione diretta	Geothermal systems with heat pump – requirements for the installation of direct expansion systems	2013
UNI 11517	Sistemi geotermici a pompa di calore - Requisiti per la qualificazione delle imprese che realizzano scambiatori geotermici	Geothermal systems with heat pump – requirements for the qualification of companies installing geothermal heat exchangers	2013
Spain			
UNE 100715-1	Diseño, ejecición y seguimiento de una instalación geotermica somera, parte 1: Sistemas de circuito cerrado vertical	Design, installation and maintenance of shallow geothermal installations – closed-loop vertical systems	2014
Sweden			
SGU Normbrunn-16	Vägledning för att borra brunn	Guideline for drilling of wells	2016

[3] draft of new, completely revised version published 2015

[4] published draft only (“*Gründruck*”)

Table 9 (continued): Standards explicitly addressing shallow geothermal technology, in force or published as draft by end of 2017

Number	Original title	Title in English	year
Switzerland			
SN 546 384/6 [5]	Erdwärmesonden	Borehole heat exchangers	2010
SN 546 384/7	Grundwasserwärmenutzung	Use of the heat of the groundwater	2015
United Kingdom			
DECC MIS 3005 (version 5.0) [6]	Requirements for contractors undertaking the supply, design, installation, set to work commissioning and handover of microgeneration heat pump systems	Requirements for contractors undertaking the supply, design, installation, set to work commissioning and handover of microgeneration heat pump systems	2017
GSHPA [7] (version 2)	Good practice guide for ground source heating and cooling	Good practice guide for ground source heating and cooling	2017
GSHPA [7] (version 2)	Vertical Borehole Standard	Vertical Borehole Standard	2017
GSHPA [7] (version 2)	Shallow Ground Source Standard	Shallow Ground Source Standard	2018
GSHPA [7]	Thermal Pile - Design, Installation & Materials Standards	Thermal Pile - Design, Installation & Materials Standards	2012

[5] sometimes also referred to as SN 565384-6

[6] in addition MCS 022: Ground heat exchanger look-up tables (2011)

[7] no numbers; an update (version 2) of the Thermal Pile standard to be published soon, and also plans exist for an Open Loop Standard (groundwater wells)

References

Bose, J.E., Parker, J.D., McQuiston, F.C. (1985). *Design/Data Manual for closed-loop ground-coupled heat pump systems*. Atlanta: ASHRAE.

Burkart, R., Hopkirk, R.J., Eugster, W.J., Rybach, L. (1989): *Erdwärmesonden-Heizanlagen*, Bern: BfE Schriftenreihe Nr. 46.

BUWAL (1994). *Wassergefährdende Flüssigkeiten: Wegleitung für die Wärmenutzung mit geschlossenen Erdwärmesonden*. Bern: BUWAL

Calm, J.M. (ed.) (1987). *Proceedings of the IEA Workshop on Ground Source Heat Pumps, Albany NY*. Karlsruhe: IEA HPC-WR-2.

Claesson, J., Eskilson, P. (1988). PC Design Model for Heat Extraction Boreholes. In: *Proc. Jigastock 88*, (135-137). AFME, Paris.

Claesson, J. (1991). PC Design Model for Thermally Interacting Deep Ground Heat Exchangers. In: *Proc. WS on GSHP Montreal, Rep. HPC-WR-8* (95-104). IEA-HPC, Sittard.

Ebnöther, A. (2013). The trend towards medium-deep geothermal systems. In *Proc. EGC 2013 Pisa* (SG1-02, 5p). EGEC, Brussels.

EGEC (2017). *EGEC Geothermal Market Report 2016*, Brussels: EGEC.

Hart, D.P., Couvillion, R. (1986). *Earth-coupled heat transfer*. Dublin OH: NWWA.

Hellström, G., Sanner, B. (1994). Software for dimensioning of deep boreholes for heat extraction. In: *Proc. Calorstock 94* (195-202). Espoo/Helsinki.

Hughes, P.J. (1986). *Manual of acceptable practices for installation of residential earth-coupled heat pump systems*. Syracuse NY: NMPC / NY-ERDA / RGEC.

IDAE (2012). *Guía técnica de diseño de sistemas de intercambio geotérmico de circuito cerrado*, Madrid: IDAE

IGSHPA (1988). *Closed loop / ground source heat pump systems: Installation guide*, Arlington VA: NRECA.

IGSHPA (2017). *Closed loop / geothermal heat pump systems: Design and installation standards*, Stillwater OK: IGHSPA.

Ingersoll, L.R., Plass, H.J. (1948). Theory of the ground pipe source for the heat pump, *ASHVE Trans*. 54, 339-348.

LAWA (1980). *Grundlagen zur Beurteilung des Einsatzes von Wärmepumpen aus wasserwirtschaftlicher Sicht*[3], Frankfurt: ZfGW-Verlag.

LAWA (2011). *Empfehlungen der LAWA für wasserwirtschaftliche Anforderungen an Erdwärmesonden und Erdwärmekollektoren*[4], Dresden: SSUL.

ÖWWV (1986). *Arbeitsbehelf 3: Wasserwirtschaftliche Gesichtspunkte für die Projektierung von Grundwasserwärmepumpenanlagen*[5], Vienna: ÖWAV, Bohmann Druck und Verlag.

Reuss, M., Konstantinidou, E., Sanner, B. (2006). 10 years VDI 4640 - German guidelines for Ground Coupled Heat Pumps, UTES and Direct Thermal Use of the Underground. In *Proc. Ecostock 2006* (5A-3, 8p). RSC, Pomona, Galloway NJ.

Rohner, E. (1991). Entwicklung und Stand der Erdsonden-Anlagen in der Schweiz. In *Ber. Symp. Erdgek. Wärmepumpen, IZW 3/91* (33-40). Karlsruhe.

Sanner, B. (1992). *Erdgekoppelte Wärmepumpen, Geschichte, Systeme, Auslegung, Installation*, Karlsruhe: IZW-Ber. 2/92.

Sanner, B. (1995). Standards and Regulations for GSHPs in Central Europe, *Newsletter IEA Heat Pump Centre* 13/4, 27-30.

Sanner, B., Hahne, E. & Konstantinidou, E. (1997). VDI-Richtlinie 4640 "Thermische Nutzung des Untergrundes". In *Ber. 3. Symp. Erdgek. Wärmepumpen, IZW 2/97* (7-12). Karlsruhe.

Sanner, B. (1999). Kann man Erdwärmesonden mit Hilfe von spezifischen Entzugsleistungen auslegen? *Geothermische Energie* 26-27/99, 1-4

Sanner, B. (2008). Guidelines, standards, certification and legal permits for ground source heat pumps in the European Union. In *Proc. IEA Heat Pump Conference 2008* (#4.02, 9p). Zurich.

Sanner, B. (2017). Ground Source Heat Pumps – history, development, current status, and future prospects. In *Proceedings of 12th IEA Heat Pump Conference* (paper K.2.9.1, 14p). Rotterdam.

Schwanner, I., Hopkirk, R.J. (1982). *Die vertikale Erdsonde als Energiebeschaffungssystem*. Zurich: BfE, Studie EPA Nr. 217.184

SIA (1988). *Base de dimensionnement des systèmes exploitant la chaleur du sol à basse température*, Zurich: SIA D 025

Von Cube, H.-L. (1977). Die Projektierung erdverlegter Rohrschlangen für Heizwärmepumpen, *KI Klima und Kälte* 5/6, 217–222.

WTA (1981). *Wärmepumpen-Energiequellen in Theorie und Praxis*, Worms: WTA company brochure.

Zoelly, H. (1913). *Heizverfahren*, Swiss Patent No. 59350, Bern: Eidgen. Amt f. Geistiges Eigentum

[3] Fundamentals for evaluating the use of heat pumps in the view of water management

[4] Recommendations of LAWA for water-management requirements for BHE and horizontal GHE

[5] Water management aspects of planning for ground water heat pump systems