10 YEARS VDI 4640 – GERMAN GUIDELINES FOR GROUND COUPLED HEAT PUMPS, UTES AND DIRECT THERMAL USE OF THE UNDERGROUND

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1. INTRODUCTION

Geothermal heat pumps experienced an enormous boom in the early 80'ies in Germany with about 22,000 heat pump units sold in 1980 (Figure 1). This was due to the second oil crisis and the significant increase of the energy costs when the price for crude oil increased from 7 US$/barrel in 1977 to 35 US$/barrel in 1981. But later on in the period from 1986 – 1998 the oil price leveled off in the range of 15 – 20 US$/barrel. Thus the demand for geothermal heat pumps dropped to less than 500 units sold in 1990. Not only the energy price was responsible for the collapse of this new technology but also the lack of experience of installers and serious quality problems.

Enormous effort by industry put in improvement of components and installation techniques combined with active marketing by utilities from then on resulted in a slow rally. This development experienced additional support through federal subsidies. To avoid in this situation a second slump VDI - The German Association of Engineers based on an initiative of a group of scientists decided to develop technical guidelines for the thermal use of the underground compiling environmental aspects, basic requirements of components and installation techniques.

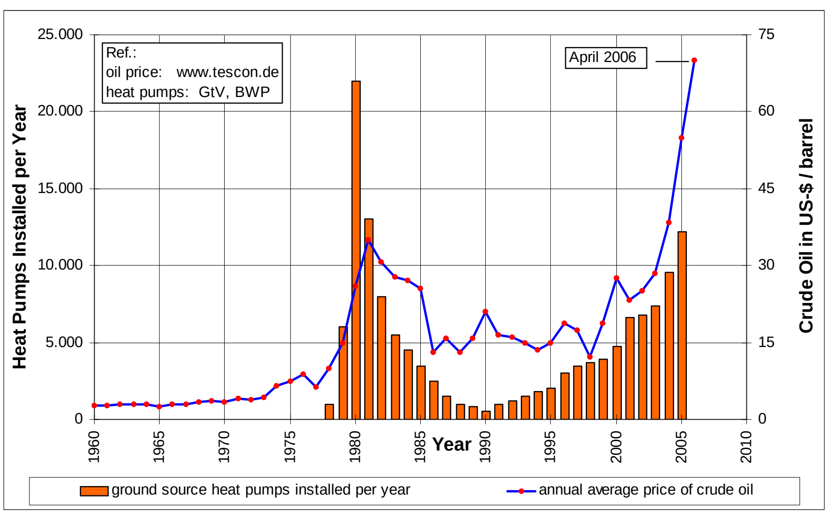

Figure 1: Annual sales number of ground source heat pumps in Germany and oil price development

2. GENERAL PRINCIPLES OF VDI GUIDELINES

VDI guidelines are generally recognised as engineering standards and have following objectives:

- describing current and future state-of-the-art developments,
- representing perspective working papers and decision support
- drawing up appraisal and evaluation criteria
- promoting the exchange of experience and the transfer of technology
- gaining a special legal recognition for example through adoption by laws, decrees and regulations or through inclusion in terms and conditions of business and contracts
- integrating in harmonised European and international rule making. They explain and supplement in a practical way national, European and international rules. They are also used as basis documents and as national perspective in the drawing up of European or international rules in harmonisation with the institutions responsible for these rules.

VDI guidelines are the result of honorary technical and scientific collective work. The experts come from the branches of business, science and administration. In terms of the composition of committees, whenever possible every eligible interested party is fairly represented. The committee members are appointed ad personam. Appointments apply up to 5 years but re-appointments are possible.

Before a guideline (white print) is published a VDI guideline draft (green print) is issued. The green print is published only in German; the white print on the other hand is published bilingually, in German and English. An opportunity to raise objections is given when a guideline draft (green print) is published. The period for objections is generally six months. Anyone can submit his opinion on a VDI guideline draft within the period of objection. The guideline committee considers all opinions submitted. If appropriate, an opportunity will be given to the opponent to present his objection to the committee. With the inclusion of any ratified objections the final version of the VDI guideline (white print) is drawn up and published.

VDI guidelines represent at the time of their adoption the state-of-the-art technology. Every 5 years after the publication of the white print every VDI guideline is checked whether it remains valid unchanged until further notice or it needs revising.

3. HISTORY

The guideline committee of the VDI 4640 consisting of representatives from universities, heat pump industry, drilling companies, design engineers, mining and water authorities started working with it's constitutional session at July 19 in 1995. The objectives are to describe the design and installation procedure of the different techniques of thermal use of the underground – heat extraction, heat injection and heat storage.

First draft (green print) of Part 1 – 'Fundamentals, Approvals, Environmental Aspects' and Part 2 – 'Ground Source Heat Pump Systems' were published in February 1998 and presented within a workshop in April 1998. The huge number of objections which were discussed in several sessions demonstrated the big interest and the exceptional demand for discussion of this subject. In this situation already the draft versions helped to improve design and installation of systems and are well accepted by the states legislation and authorities as a technical standard. The whiteprint of Part 1 was published in December 2000 and that of Part 2 in September 2001.

In 1998 the guideline committee started the work on part 3 titled 'Underground Thermal Energy Storage'. Based on the work and publications of the IEA ECES Annex VIII 'Implementing of Underground Thermal Energy Storage' the draft version of this part could already be published in March 2000, the final version (whiteprint) was released in December 2000. While ground source heat pumps show a fast growth underground storage started slowly as a niche market. In the last years combined heat and cold storage became very popular due to the increasing demand for cooling of office building as a result of the improved insulation standard, internal heat sources like computers and the popular glass architecture. Part 4 – 'Direct Use' published in September 2004 covers the direct use of groundwater e.g. for cooling or ground-air-heat-exchangers for preheating or precooling of ventilation air.

From the early beginning experts of neighboring countries like Switzerland, Austria and The Netherlands were integrated into the work on the one hand to include the experiences from these countries and on the other hand to work out a version which is easy to adapt to these countries within a European harmonization process.

Nowadays in practice the VDI 4640 is well recognized by authorities, consultancies, industry, drilling companies and installers which is proven by the great demand for the guidelines. In total almost 3400 copies were sold which proves that the VDI 4640 is one of the most popular guidelines of VDI-GET. Of special interest are Part 1 and 2 which deal with fundamentals, approvals, environmental issues and with ground source heat pump systems. The fast development of the market in the last years calls for a revision and update of these parts. It is planned to finish the actual revision during the year 2006 and to publish a new draft.

4. CONTENTS OF THE GUIDELINES

In part 1 an overall discussion of the fundamentals, the required approvals and the environmental aspects is presented and thus has to be seen in context with remaining parts 2 – 4. An overview of the contents of the different parts of the VDI 4640 guidelines is given in the following table:

Part 1 – ‘Fundamentals, Approvals, Environmental Aspects’

1 Scope
2 Abbreviations and definitions
3 Principles
  3.1 heat regime in the underground
  3.2 principles of system design
4 Approvals required
  4.1 water rights – procedure, fundamentals, heat pumps with groundwater wells, with horizontal loops, with borehole heat exchangers, underground thermal energy storage
  4.2 mining law – geothermal energy as licensed mineral resource, geothermal energy to a depth < 100 m, below 100 m
  4.3 approvals in Austria and Switzerland
5 Safety aspects of heat pumps
6 Site assessment
  6.1 above ground
  6.2 underground
7 Environmental aspects
  7.1 primary energy demand and CO_2-Emission
  7.2 influence of refrigerants
  7.3 potential influence of thermal use **–** on the underground and groundwater, on groundwater hydraulics and influences by antifreezes and refrigerants due leaks
8 Environmentally friendly materials for installation underground
  8.1 materials for wells, horizontal loops and borehole heat exchangers
  8.2 antifreeze in horizontal loops and borehole heat exchangers
  8.3 refrigerants in direct evaporation systems

Important basics on the thermal regime underground, geological and physical principles as well as design rules are given. In a detailed list of rock materials physical properties like density, thermal conductivity and volumetric heat capacity are provided which are used for design procedures of horizontal loops and borehole heat exchangers in part 2. The chapter about approval procedures according to the water and mining law gives a brief overview on the level of the federal state. Additionally local regulations in each province have to be considered. The environmental aspects cover potential primary energy savings and the related reduction of CO_2-emissions as well as the environmental impact of refrigerants. Heat extraction or injection may influence neighboring use of the underground and has to be considered. This applies to all heat exchange techniques like groundwater extraction and injection, horizontal loops, borehole heat exchangers and heat/cold-storage. In case of groundwater heat pumps the hydraulic conditions have to be taken into account. Heat transfer fluid with hazardous antifreeze or refrigerants leaking from horizontal loops or borehole heat exchangers may have a severe environmental impact and has to be avoided absolutely.

Actually an update is under consideration to stay abreast of technical progress of the last years. It is planned to issue the green print of part 1 at the end of 2006.

Part 2 – 'Ground Source Heat Pump Systems'

1 Scope
2 Abbreviations
3 Use of groundwater with wells
  3.1 design – hydraulic parameters, hydro-chemical parameters
  3.2 installation – drilling and well construction, special components
4 Use of the shallow underground with horizontal loops
  4.1 design
  4.2 installation – loop depth and distance, earthworks, required material properties, pipe laying, pressure control, filling and de-aeration, commissioning
5 Use of the underground with borehole heat exchangers
  5.1 design – small systems < 30 kW, big systems > 30 kW
  5.2 installation – drilling, manufacturing and testing of borehole heat exchangers, installation and grouting, pipe laying, pressure control, filling and de-aeration, commissioning
6 Special features of direct evaporation heat pumps
  6.1 design
  6.2 installation – material requirements, installation, manifold, additional safety devices, filling
  6.3 commissioning
7 Characteristics of other heat sources
  7.1 foundation piles – design, prefabricated driven piles, in-situ concrete piles, connection of piles
  7.2 ground-coupled concrete elements
  7.3 compact horizontal loops – trench collectors, spiral collectors
  7.4 coaxial wells
  7.5 mines, tunnels
8 System integration
  8.1 manifolds
  8.2 fittings and pumps
  8.3 connecting pipes between manifolds and heat pump
  8.4 dimensioning of piping and pumps
9 Heating system
  9.1 heating system, buffer storage – panel heating, radiators and convectors, buffer storage
  9.2 control
  9.3 domestic hot water
10 Dismantling of ground source heat pump systems
  10.1 dismantling of the heat pump
  10.2 dismantling of the heat source – dismantling of groundwater wells, of horizontal loops, of borehole heat exchangers

This part of the VDI 4640 guidelines gives detailed descriptions of the design procedure and installation of the heat source for the three different types – groundwater wells, horizontal loops and borehole heat exchangers. The design part of groundwater wells includes not only considerations on hydraulic parameters of production and injection wells but also hydro-chemical aspects which are essential for long-term operation without problems. A table with specific extraction rates for different soils as a design tool for simple cases of horizontal loops is given. Large systems which are real exceptions because of the required space are not discussed. Small ground source heat pumps (< 30 kW) with borehole heat exchangers for heating only can be designed with specific extraction rates given in a table and a simple Nomogramm. For heating, cooling or combined heating and cooling with larger or complex systems more detailed calculations, system simulations up to very detailed numerical simulations are recommended.

In all three cases besides the heating power the annual heating energy has to be taken into account. Additionally temperature limits for heat extraction and/or injection are given which consider an acceptable environmental impact.

The installation parts of the three ground source types cover many details like drilling, well construction, earthwork, materials and components, installation of underground parts, grouting of boreholes, pressure test of components and system, pipe laying, filling and de-aeration as well as commissioning. Especially in the case of borehole heat exchangers many details are described to insure correct installation, long life-expectancy and environmentally compatible operation. Special features of direct evaporation heat pump systems regarding design, materials, installation, additional safety devices, filling and commissioning are discussed in a separate chapter.

Throughout the years various other constructions of heat source e.g. foundation piles, ground coupled concrete slabs, etc.) were introduced in the market of which thermally activated foundation piles are the most popular ones. In some locations water from old mines or large railway or road tunnel are considered. In this regard the guideline describe the application to help the promotion of such expedient concepts.

Finally remarks on special requirements regarding system integration and the heating system were added. If the ground source heat pumps are shut down permanently the underground system parts have to be dismantled properly to eliminate any possibility of contamination of groundwater or collapse of damaged wells.

This part of the guideline relevant for the majority of systems installed throughout the last years in Germany helped significantly to improve the technical standard of ground source heat pumps from the point of view of the building owner, the licensing authorities and the other involved parties like drilling companies or installers. The growing market initiated the development of new components and installation techniques but provided also experiences from installed systems in positive or negative sense which demand a revision in regular time intervals. Actually this part 2 of the guidelines is revised too and a draft version is expected to be published early 2007.

Part 3 – 'Underground Thermal Energy Storage - UTES'

1 Scope
2 Abbreviations, symbols and indices
3 General
   3.1 definitions of terms
   3.2 special environmental aspects of UTES
   3.3 choice of materials for higher temperatures
4 Incorporation into an energy supply system
   4.1 energy balance
   4.2 temperature levels
   4.3 utilization ratio of the storage system
   4.4 uses – storage of cold and/or of low temperature heat without a heat pump, storage of cold and/or of low temperature heat with a heat pump, solar energy and heat storage, heat and power co-generation plant coupled with heat storage, complex energy supply systems utilizing and storing waste heat, further system variants of underground thermal energy storage
5 Aquifer storage
   5.1 description of system
   5.2 natural site requirements
   5.3 site exploration – collecting parameters, interpretation of parameters and design of system layout
   5.4 design of wells
   5.5 some special aspects relating to the licensing of aquifer storage
   5.6 possible operating problems arising from the chemical composition of the ground water – precipitation of calcium carbonate in high-temperature heat storage systems, precipitation of iron and manganese, degassing phenomena, contaminated sites
6 Storage systems using borehole heat exchangers (BHE)
   6.1 general
   6.2 geometry of the storage system
   6.3 layout – general procedure, rough layout, numerical simulation

6.4 construction – boreholes, borehole heat exchanger materials, heat transfer medium and antifreeze, installation and grouting of borehole heat exchangers, hydraulic circuit layout

7 Other underground thermal storage systems
7.1 cavern storage
7.2 abandoned mines
7.3 near-natural underground thermal energy storage systems – fundamental structural principle, gravel-water thermal energy storage system, soil-water thermal energy storage system

Generally thermal energy storage is used to compensate for any difference in thermal performance of the energy supply and the demand or to bridge the time between supply and demand. The first case is the typical buffer storage with a high charging/discharging capacity but a relatively short storage period while the purpose of the second one is to store a high amount of energy for a long time period. UTES allows building of large storage capacities for long-term storage relatively cheap. UTES is suitable for heat, cold or combined heat and cold storage in various energy supply systems. Although UTES has numerous applications and possibilities of system integration there is not yet a real market penetration.

The different operating modes of aquifer storages are described and illustrated to show the flexibility to match the various hydro-geological site conditions. Intensive site investigation is the basis for a reliable design which requires simulation of the chemical, thermal and hydrodynamic behavior of the aquifer storage. Besides these design calculations recommendations regarding well construction and peculiarities of the approval procedure are given. Water chemistry an essential problem of aquifer storage is discussed to some extend.

Storage systems using borehole heat exchangers typically installed in unsaturated ground can be used for long-term storage of heat, cold or combined heat and cold. The design requires like that of aquifer stores an intensive site investigation and thorough simulation preferably not only for the store itself but for the whole system. Special construction aspects exceeding the recommendations of part 2 top this chapter off.

Finally the part 3 of VDI 4640 gives a brief overview of other storage systems which have been used in some places like rock caverns in Scandinavia or shut off mines which are filled with water. Another type is the so-called gravel-water pit which uses a mixture of gravel or soil and water as storage material filled into an artificial pit sealed with a rubber or plastic liner. Although this store is not directly using the underground, ground materials like gravel or soil together with water form the storage material. Such systems can be considered as semi-natural.

Part 4 – 'Direct Uses'

1 Scope
2 Abbreviations and definitions
2.1 abbreviations
2.2 symbols and subscripts
2.3 definitions for earth-air heat exchangers
3 Direct thermal use of ground water
3.1 system description
3.2 environmental influence and special aspects relating to water management and water legislation – environmental effects, water management objectives, water legislation aspects
3.3 Design – hydraulic parameters, hydro-chemical parameters, installation, dismantling
4 Direct thermal use of the underground with borehole heat exchangers, energy piles, etc.
4.1 system description
4.2 environmental aspects and questions relating to water legislation
4.3 construction and installation including dismantling
5 Air heating or cooling in the underground
5.1 description of system
5.2 environmental aspects
5.3 air hygiene
5.4 design – fundamentals of design, design of small plants for residential buildings with flow rates up to 1000 m³/h, design of large plants for flow rates over 1000 m³/h

5.5 installation, selection of materials, dismantling
5.6 control strategy
5.7 economic efficiency – economic calculations, operational costs, capital costs and investment costs, maintenance costs

Direct use of the underground considers in the guideline only systems without heat pumps. Since such systems only consist of wells, pumps and heat exchangers they are technically simple and thus of economic interest. Typical applications are preheating or cooling of ventilation air but also direct cooling of technical processes. The environmental and legal aspects are similar to those described in part 2 groundwater heat pumps. For borehole heat exchangers or energy piles comparable applications are conceivable.

The earth-air heat exchanger consists of piping system similar to horizontal ground loops but with air as heat transport fluid. Such systems are typically used for preheating or cooling of ventilation air. Part 4 of the guidelines gives besides the system description and environmental aspect recommendations according hygienic aspects of the air. In chapter 5.4 an extensive description of the design procedure is given distinguishing between small systems for residential buildings with flow rates up to 1000 m^3/h and large systems for higher flow rates. Piping materials have to meet hygienic requirements of air ducts but also corrosion aspects have to be considered. This part is topped off with economical considerations on earth-air heat exchangers.

5. CONCLUSION

The VDI 4640 guideline 'Thermal Use of the Underground' was developed after a collapse of the market for ground source heat pumps in a phase of slow recovery. The goal was to compile environmental aspects, basic requirements of components and installation techniques in the compact form of a guideline which are legally binding. The VDI 4640 covers a wide field of application ranging from fundamentals and ground source heat pumps via underground thermal energy storage to direct use of the underground. Therefore it is composed of four parts.

Within two years the first draft could be published initiating an extensive discussion which was on the other hand a sign for the importance of this work. This is also documented by the relatively high number of copies sold.

Part 1 and 2 ('Fundamentals, Approvals, Environmental Aspects' and 'Ground Source Heat Pump Systems'**)** should ensure high quality of components and construction of ground source heat pump systems to the advantage of the user but also to the advantage of the environment. Therefore it was well recognized by the licensing authorities too. Part 3 and 4 ('Underground Thermal Energy Storage - UTES' and 'Direct Uses') is dealing with a subject that has not yet penetrated the market in the same way as ground source heat pumps. Nevertheless UTES has a high potential in terms of energy conservation and efficient use of energy and experienced an acceptable growth of combined heat and cold storage.

The fast development and improvement in knowledge and technology requires an update of the actual versions of part 1 and 2. A green print of the revised version is expected to be published to the end of 2006.

ACKNOWLEDGMENTS

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