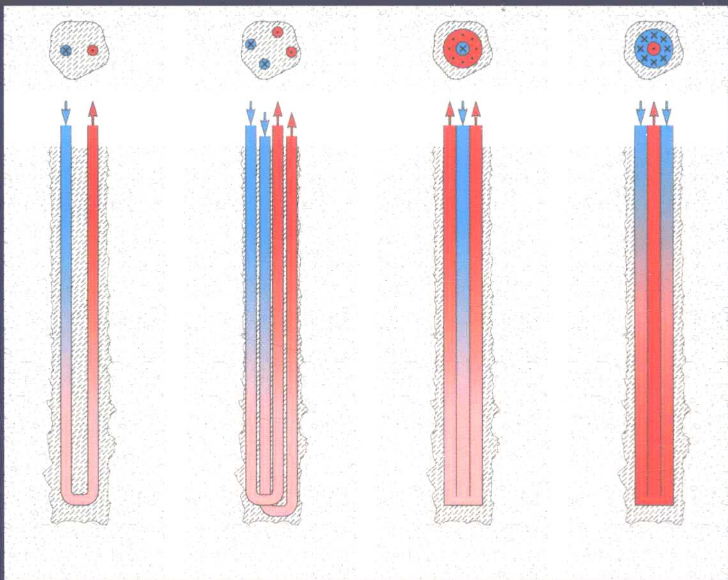
Shallow Geothermal Systems – Recommendations on Design, Construction, Operation and Monitoring



WILEY
Ernst & Sohn
A Wiley Brand

DGGV
German Geological Society

DGGT
Deutsche Gesellschaft für Geotechnik e. V.
German Geotechnical Society

Shallow Geothermal Systems – Recommendations on Design, Construction, Operation and Monitoring

Ernst & Sohn
A Wiley Brand

DGGV
German Geological Society

DGGT
Deutsche Gesellschaft
für Geotechnik e. V.
German Geotechnical Society

Deutsche Gesellschaft für Geotechnik e.V.
vertr. durch den Vorsitzenden
Herrn Dr.-Ing. Wolfgang Sondermann
Gutenbergstr. 43
45128 Essen
Germany

Deutsche Geologische Gesellschaft –
Geologische Vereinigung e.V.
vertr. durch den Vorsitzenden
Herrn Professor Dr. Jan Behrmann
Buchholzer Str. 98
30655 Hannover
Germany

Authors: Sass, I., Brehm, D., Coldewey, W. G., Dietrich, J., Klein, R., Kellner, T., Kirschbaum, B., Lehr, C., Marek, A., Mielke, P., Müller, L., Panteleit, B., Pohl, S., Porada, J., Schiessl, S., Wedewardt, M., Wesche, D.

Translated by Philipp Thrift, Hannover

Cover: Schematic drawings showing the arrangements of the different systems, Graphic: Sass & Mielke 2012

Library of Congress Card No.: applied for

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <http://dnb.d-nb.de>.

Coverdesign: DesignPur, Berlin
Typesetting: Thomson Digital, Noida, India
Printing and Binding:

Printed in the Federal Republic of Germany.
Printed on acid-free paper.

Print ISBN: 978-3-433-03140-7
ePDF ISBN: 978-3-433-60670-4
ePub ISBN: 978-3-433-60668-1
eMobi ISBN: 978-3-433-60669-8
oBook ISBN: 978-3-433-60667-4

Preface

The use of shallow geothermal energy has increased enormously over the past ten years. As the number of geothermal energy installations has risen, so has the number of technical developments in the field. There have been cases of damage in connection with the construction and operation of geothermal energy systems which have attracted much attention in the media. In particular, the cases of damage that have become public show that drilling to depths of several hundred metres is a technical activity that calls for responsible procedures in the sense of quality-assured design, construction and operation of the systems. Avoiding damage caused by shallow geothermal energy installations is a top priority for sustainable geothermal energy uses, especially when bodies of groundwater have to be protected against adverse effects. The recommendations in this book should be regarded as contributions to the quality-assured realisation of such systems. One of the aims of the Geothermal Energy Study Group at the specialist Hydrogeology Section of the German Geological Society (DGGV) and the Engineering Geology Section of both the German Geotechnical Society (DGGT) and the DGGV is to promote the widespread use of geothermal energy as an environment-friendly energy source while prioritising the protection of bodies of water. The authors as well as the DGGV and the DGGT have conceived these recommendations as advice and not as a set of technical regulations in the sense of a standard. Therefore, the recommendations of the Geothermal Energy Study Group include a number of textbook-like passages and much information on the legislation that affects approvals and permits. At the time of going to print, the preparation of a standard for shallow geothermal energy was not in sight; such a standard is, however, still regarded as essential.

The authors and their assistants in the study group are hydrogeologists, engineering geologists and engineers from design consultants, the construction industry, the building materials industry, authorities and universities. They drew up the recommendations over a number of years and all were well aware of the fact that some of the content could certainly trigger controversy in technical circles.

In order to guarantee the technical quality of the recommendations of the Geothermal Energy Study Group, the content was subjected to a peer review process. Prof. Dr. Ingrid Stober (Freiburg Regional Authority), Prof. Dr. Rolf Bracke (International Geothermal Center, Bochum) and Prof. Dr. Dmitry V. Rudakov (National Mining University, Dnipropetrovsk) undertook this important and demanding task, approaching it from different perspectives.

Their remarks and comments were carefully considered in the preparation of this current edition of the recommendations.

Besides the peer review process, the publishers made the recommendations publicly available on the Internet for three months. Anybody who was interested was invited to submit their remarks, comments and suggestions for improvements within those three months. The authors read and evaluated every single contribution received, which resulted in many improvements being made to the text and illustrations. We are very grateful to all who made contributions to the work of the study group in this way.

The authors of the recommendations are as follows:

Spokesman for the study group

Prof. Dr. rer. nat. Ingo Sass
Institute of Applied Geothermal Science & Technology
Technische Universität Darmstadt
Schnittspahnstr. 9
64287 Darmstadt

Deputy spokesman

Dr. rer. nat. Dirk Brehm
BGU, Bielefeld

Permanent members of the study group

Prof. Dr. rer. nat. Wilhelm Georg Coldewey
Institute of Geology & Palaeontology
Westfälische Wilhelms-Universität Münster

Dr. rer. nat. Jörg Dietrich
HeidelbergCement, Enningerloh

Dr. rer. nat. Rainer Klein
boden & grundwasser, Amtzell

Dipl.-Min. Torsten Kellner
Berlin

Dipl.-Ing. Dipl.-Geol. Bernd Kirschbaum
Federal Environment Agency, Dessau

Dipl.-Geol. Clemens Lehr
Geotechnisches Umweltbüro Lehr, Bad Nauheim

Dipl.-Geol. Adam Marek
Environment Department, Bielefeld

Dipl.-Ing. Philipp Mielke
Institute of Applied Geothermal Science & Technology
Technische Universität Darmstadt

Prof. Dr. rer. nat. Lutz Müller
Environmental Engineering Department
Ostwestfalen-Lippe University of Applied Sciences, Höxter

Dr. rer. nat. Björn Panteleit
Geological Services Agency for Bremen (GDfB)

Dipl.-Geol. Stefan Pohl
geo consult POHL, Bendorf

Dipl.-Geol. Joachim Porada
Porada GeoConsult GmbH & Co. KG, Harsefeld

Dipl.-Ing. Stefan Schiessl
TERRASOND GmbH & Co. KG, Günzburg

Dr. rer. nat. Marec Wedewardt
Senate Department for Urban Development & the Environment, Berlin

Dominik Wesche, MSc Geosciences
Institute of Geology & Palaeontology
Westfälische Wilhelms-Universität Münster

Prof. Dr. Ingo Sass
March 2016
Darmstadt

Acknowledgements

On behalf of the associations responsible for publishing the recommendations and the members of the DGGV/DGGT Geothermal Energy Study Group, we would like to thank all those dedicated people who contributed to and supported the preparation of this book. We are grateful to the following temporary members of the study group:

Dipl.-Geol. Gisela Augustin, Hamburg
Dipl.-Ing. Arne Buss, Berlin
Dr. Verena Herrmann, GMP-Geotechnik GmbH, Würzburg
Dr. Claus Heske, International Geothermal Centre, Bochum
Dr. habil. Holger Knoke, IBES GmbH, Neustadt/Weinstraße
Prof. Dr. Martin Sauter, Göttingen University
Dipl.-Geol. Ingo Schäfer, Geological Department of North Rhine-Westphalia, Krefeld
Prof. Dr. Dietmar Schenk (dec.), Mainz University
Dipl.-Geol. Christian Spang, Dr. Spang Ingenieurgesellschaft für Bauwesen, Geologie und Umwelttechnik mbH, Witten
Dipl.-Geol. Andreas Terglane, HPC AG, Stuttgart

The tight schedule of working sessions and voting would not have been possible without the relentless organisation and support of Ms. Simone Ross-Krichbaum at TU Darmstadt. Dipl.-Ing. Sebastian Homuth, MSc, TU Darmstadt, took on the task of proofreading the manuscript, for which we are very thankful. Andreas Hofheinz, assistant at TU Darmstadt, proved to be especially dependable when it came to assembling texts, dealing with layout issues, integrating illustrations and typesetting equations for the study group.

We are also grateful to the boards and managers of the DGGV and DGGT and the members of their specialist sections for actively supporting the work of the Geothermal Energy Study Group.

On behalf of all the members of the study group and the DGGV and DGGT, the associations responsible for publishing the recommendations, we would like to thank Prof. Dr. Ingrid Stober, Freiburg, and Prof. Dr. Rolf Bracke, Bochum, for carrying out the highly demanding and very time-consuming peer review.

Preamble

The members of the Geothermal Energy Study Group, organised under the auspices of the specialist Hydrogeology (FH-DGGV) and Engineering Geology (FI-DGGV/DGGT) sections of the German Geological Society (DGGV) and the German Geotechnical Society (DGGT), are pleased that you are interested in the recommendations contained in *Shallow Geothermal Systems – Recommendations on Design, Construction, Operation and Monitoring*. These recommendations represent the results of the ongoing work of the Geothermal Energy Study Group (DGGT Working Group 4.11). The members of the study group are experts drawn from all areas involved with geothermal energy: industry, authorities, consulting, polytechnics and universities.

The publication of this book of recommendations is one of the main tasks of the study group. The recommendations are initially limited to shallow geothermal energy, but the intention is to consider aspects of deep geothermal energy as well. Furthermore, the recommendations are intended to form the technical foundation for basic and further training events aimed at the personnel of drilling contractors and based on standard DIN EN ISO 22475-1: 'Qualification in drilling boreholes for geothermal purposes and installing closed heat transfer systems (borehole heat exchangers)' (DGGT/DGGV, 2010).

The study group holds regular working sessions – about four to six times a year. One of the main tasks of the study group is the publication of advice and recommendations for the members of the specialist sections at the DGGV/DGGT and DGGV as well as others who are concerned with geothermal energy issues. The recommendations consider, in particular, the underground parts of the different geothermal energy systems. The most important aspects of the geothermal use of the ground are touched upon, although the focus is clearly on the most frequent types of application – borehole heat exchangers and well systems. Many special methods, techniques or combinations of methods are available on the market. The fact that those are not yet discussed in detail in these recommendations in no way implies that, for example, the various specialities represent ineffective or less suitable systems; it was merely decided to limit the recommendations to the most common systems in order not to exceed the scope of this book.

One specific aim of the recommendations is the quality-assured design, construction, operation and monitoring of shallow geothermal energy installations. The recommendations are intended to help guarantee the protection of bodies of groundwater without obstructing the further spread of heating and cooling systems based on geothermal energy. Avoiding damage to geothermal energy installations and damage caused by the construction and operation of such systems is central to the issues discussed. In the light of current projects, the book also includes a chapter on dealing with potential risks.

The use of shallow geothermal energy represents a significant, environment-friendly and also safe way of reducing the primary energy consumption of our society. Some 50–60% of the total energy consumption of the industrialised nations of Central Europe can be attributed to the operation of buildings. With virtually no restrictions on location, no direct emissions, the ability to cover the base load and economical operation, this is where geothermal energy can play a role.

Notation

Symbol	Definition	Common unit
A	Area	m^2
A_f	net filter area	m^2
a_c	dimensionless critical well spacing	1
b_{wi}	capture zone width	m
C_a	heat capacity of an area	$W \cdot s \cdot K^{-1}$
C_p	heat capacity at constant pressure (isobar)	$W \cdot s \cdot K^{-1}$
C_V	heat capacity at constant volume (isochor)	$W \cdot s \cdot K^{-1}$
c_{mp}	molar heat capacity at constant pressure (isobar)	$W \cdot s \cdot mol^{-1} \cdot K^{-1}$
c_{mv}	molar heat capacity at constant volume (isochor)	$W \cdot s \cdot mol^{-1} \cdot K^{-1}$
c_{sp}	specific heat capacity	$W \cdot s \cdot kg^{-1} \cdot K^{-1}$
c_{spp}	specific heat capacity at constant pressure (= C_p/m)	$W \cdot s \cdot kg^{-1} \cdot K^{-1}$
c_{spv}	specific heat capacity at constant volume (= C_V/m)	$W \cdot s \cdot kg^{-1} \cdot K^{-1}$
d	diameter	m
d_{as}	diameter of annular space	m
d_b	borehole diameter	m
d_{fa}	filter mesh aperture	m
d_i	inside diameter (i.d.)	m
d_o	outside diameter (o.d.)	m
d_{pa}	particle size	m

Symbol	Definition	Common unit
d_{pu}	pump diameter	m
d_{spa}	diameter of BHE pipework with spacers	m
d_w	well pipe diameter	m
E_i	exponential integral	1
F	force	N
g	local gravitational acceleration	$m \cdot s^{-2}$
h_{aq}	thickness of aquifer[a)]	m
h_{aqo}	aquifer overburden	m
h_{gws}	thickness of groundwater-bearing stratum	m
I	hydraulic gradient (potential gradient)	1
i_z	depth increment	m
K	intrinsic permeability	m^2
k_f	hydraulic conductivity	$m \cdot s^{-1}$
k_{fr}	hydraulic conductivity of rock formation	$m \cdot s^{-1}$
l	characteristic length, travel distance	m
l_b	borehole depth	m
l_{bf}	characteristic length of body in flow	m
l_f	filter length	m
l_{he}	length of productive heat exchanger	m
l_z	vertical depth below ground level	m
m	mass	kg
n_{eff}	voids ratio effective for flow	$100\% = 1$
n_{fl}	proportion of voids filled with fluid	$100\% = 1$
n_{tot}	total porosity	$100\% = 1$

Symbol	Definition	Common unit
p	pressure	$Pa = N \cdot m^{-2}$
p	density	$kg \cdot m^{-3}$
Q	quantity of heat	$W \cdot s$
$\dot{Q}$	heat flow	W
$\dot{Q}_{ah}$	annual heating energy requirement	$kWh \cdot a^{-1}$
q_{sp}	specific heat flux	$W \cdot m^{-2}$
q_v	volumetric heat flux	$W \cdot m^{-3}$
r	measuring distance	m
r	distance of observation point from line source as mid-point	m
R_b	borehole thermal resistance	$k \cdot W^{-1}$
R_{beff}	effective borehole thermal resistance	$k \cdot W^{-1}$
R_c	thermal resistance of individual compartments	$k \cdot W^{-1}$
r_{dd}	radius of influence of groundwater drawdown	m
R_s	thermal resistance of skin zone	$k \cdot W^{-1}$
R_{th}	thermal resistance	$k \cdot W^{-1}$
R_{tr}	thermal transfer resistance	$k \cdot W^{-1}$
R_λ	thermal resistance	$k \cdot W^{-1}$
Ra_D	Darcy-modified Rayleigh number	1
Ra_{Dcrit}	critical Darcy-modified Rayleigh number	1
r_b	borehole radius	m
r_s	radius of skin zone	m
S_{ed}	extent of damage	currency
S_{pd}	probability of damage occurring	100% = 1

Symbol	Definition	Common unit
S_{rd}	risk of damage	currency
T_{std}	standardized time	s
t	time	s
t_{min}	minimum time	s
T_0	critical soil temperature unaffected by air temperature	K
T_{abs}	absolute temperature	K
T_{bo}	temperature of a body	K
T_{cu}	temperature in area unaffected by convection	K
T_f	temperature of the fluid	K
T_{fin}	final temperature (equilibrium temperature)	K
T_m	mean fluid temperature	K, °C
T_r	temperature of rock formation	K
U	integration variable	1
V	volume	m^3
$\dot{V}$	flow rate	$m^3 \cdot s^{-1}$
$\dot{V}_{cw}$	capacity of one well	$m^3 \cdot s^{-1}$
$\dot{V}_w$	flow rate towards a well	$m^3 \cdot s^{-1}$
v_{av}	average linear groundwater velocity	$m \cdot s^{-1}$
ν	kinematic viscosity	$m^2 \cdot s^{-1}$
v_{crit}	critical flow velocity	$m \cdot s^{-1}$
v_D	Darcy velocity	$m \cdot s^{-1}$
v_{Du}	Darcy velocity of unaffected groundwater	$m \cdot s^{-1}$
v_{fl}	flow velocity	$m \cdot s^{-1}$

Symbol	Definition	Common unit
W	work, energy	$W \cdot s$
w	degree of water saturation	$100\% = 1$
x_{fl}	flow distance (leakage flow)	m
x, y, z	position coordinates	m
α	thermal diffusivity	$m^2 \cdot s^{-1}$
α_{bv}	angle of borehole deviation from vertical	°
α_{eff}	effective thermal diffusivity	$m^2 \cdot s^{-1}$
α_{fl}	angle of flow	°
β_a	seasonal performance factor (SPF)	1
γ	Euler–Mascheroni constant (0.57722)	1
γ_{lin}	coefficient of linear thermal expansion	K^{-1}
γ_{th}	coefficient of volumetric thermal expansion	K^{-1}
ΔQ	change in quantity of heat	$W \cdot s$
ΔT	temperature difference (absolute temperature)	K
ΔT_i	temperature difference between inflow water and natural groundwater (absolute temperature)	K
ΔT_r	temperature gradient in undisturbed rock formation	K
ΔT_z	vertical temperature gradient	$K \cdot m^{-1}$
Δz	deviation from vertical borehole axis	m^{-1}
$\Delta \upsilon$	change in kinematic viscosity, position- and time-dependent temperature change	1
δ	standard deviation	1
ε	coefficient of performance (COP)	1

Symbol	Definition	Common unit
ζ	primary energy ratio (PER)	1
ζ_a	annual heating energy ratio	1
η	dynamic viscosity	$Pa \cdot s$
θ	temperature gradient	$K \cdot m^{-1}$
ϑ	Celsius temperature	°C
κ	thermal transmittance (U-value)	$W \cdot m^{-2} \cdot K^{-1}$
λ	thermal conductivity	$W \cdot m^{-1} \cdot K^{-1}$
λ_{dr}	thermal conductivity of a dry soil	$W \cdot m^{-1} \cdot K^{-1}$
λ_{eff}	effective thermal conductivity	$W \cdot m^{-1} \cdot K^{-1}$
λ_{max}	maximum effective thermal conductivity	$W \cdot m^{-1} \cdot K^{-1}$
λ_{min}	minimum effective thermal conductivity	$W \cdot m^{-1} \cdot K^{-1}$
λ_{sat}	thermal conductivity of a saturated soil	$W \cdot m^{-1} \cdot K^{-1}$
λ_{sbo}	thermal conductivity of a solid body	$W \cdot m^{-1} \cdot K^{-1}$
λ_{vo}	thermal conductivity of the voids	$W \cdot m^{-1} \cdot K^{-1}$
ν_{crit}	critical viscosity	$m^2 \cdot s^{-1}$
ν_{fl}	kinematic viscosity of a fluid	$m^2 \cdot s^{-1}$
ϕ	slope of regression line for GRT measurements	1
ϕ	slope of regression line for straight line method for GRT assessment	1
ξ, ζ, Ψ	direction-dependent temperature function	1

a) see Glossary.