

02.18 Geothermal potential: Specific conductivity and specific extraction capacity (Edition 2018)

Overview

General

In recent years, geothermal energy is being widely used in Berlin. Since 2004, the number of facilities using near-surface geothermal energy has risen from 132 to approximately 3,500, as of 2018 (Sept. 30th). This trend is continuing, and is an important factor in the energy mix for the future use of renewable energy sources.

Unlike most other renewable energy sources, such as wind, hydropower or solar power, geothermal energy is an energy form which is independent of the weather, of the time of day and of the season of the year; it is virtually always available.

The use of near-surface geothermal energy, which in Berlin means up to a maximum depth of 100 m, can draw on a wide spectrum of technological possibilities. All these procedures require heat pumps capable of increasing the relatively low temperatures of the subsoil or the groundwater at these depths, of between 8 and 11 °C, to a higher temperature level suitable for heating purposes, with the aid of mechanical or electrical energy.

While there are many other possible procedures, 93 % of the geothermal energy in Berlin is today obtained by means of closed-loop ground heat exchangers (see Figure 1). These are closed-loop plastic pipe systems installed in boreholes in which a water-brine mixture is circulated, which draws the heat from the surrounding groundwater-filled rocky soil. The depth of the heat exchanger is generally between 40 and 100 m, depending on the geological conditions and the technical specifications of the system.

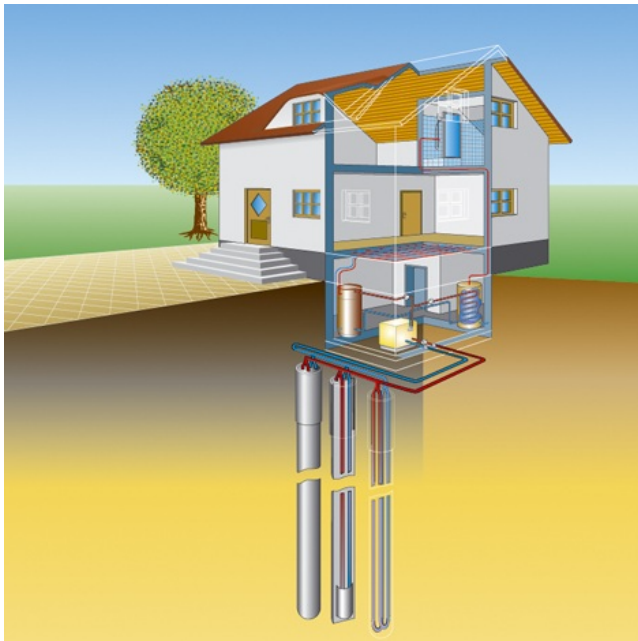


Fig 1: Closed-loop ground heat exchanger for a single-family home, source: Bundesverband Wärmepumpe (BWP) e. V.

In order to increase planning security of these borehole systems, we are here providing maps of the potentials of specific conductivity (Maps 02.18.1 - 02.18.4) and, specifically for single-family homes,

specific extraction capacities (Maps 02.18.5 - 02.18.12). The key geological and hydrological conditions necessary for this are provided herein.

Since the installation of geothermal portable facilities in the subsoil involves the potential risk of endangering the groundwater, strict legal hydrological requirements for the protection of the groundwater have been stipulated for the drilling procedure, the sealing of the borehole, the pressure tests, the documentation, etc., when installing such facilities. New research results, cases of damage, and the greatly increased numbers of ground heat exchangers have repeatedly underscored this danger.

Since Berlin gets almost 100 % of its drinking water from the groundwater, and almost all of that from within its own boundaries, especially strict requirements for the protection of the groundwater are stipulated in the permit procedure of the Water Authority, which is required for the installation of a closed-loop ground heat exchanger.

For more information please see Geothermal Guideline (in German only):

https://www.berlin.de/sen/uvk/_assets/umwelt/wasser-und-geologie/publikationen-und-merkblaetter/leitfaden_geothermie.pdf

Specific conductivity

The specific conductivity is the capacity of sub-surface rock to conduct heat. It is one of the most important quanta for the correct dimensioning of closed-loop ground heat exchangers. It is a measure for the speed with which the extracted heat can be replaced via the sub-surface rock and the groundwater.

The unit for measuring specific conductivity is watts per metre * Kelvin [W/mK]. The conductivity is a property specific to the type of rock, and depends on its mineral content, its porosity and its pore filling. Air is a poor conductor, so that dry sediments above the water table have low conductivity. Since water, on the other hand, has higher conductivity than air, the conductivity value of the water-saturated rock is considerably improved. For this reason, groundwater conditions are taken into account on the conductivity map.

Specific extraction capacity

The specific extraction is capacity, by contrast to specific conductivity, a quantum which depends on a large number of specific marginal conditions, especially the specific capacity of the rock in the subsoil to transport heat, but even more on the technical data of the ground heat exchanger, such as its number of operating hours, the interactive effect of neighbouring systems, the size of the borehole, the conductivity of the material pressed into it, etc.

The unit for measuring specific extraction capacity is watts per metre [W/m]. For heating systems with no hot water supply, 1800 operating hours per year [h/a] are estimated; for systems which do provide hot water, the figure is 2400 h/a (see below).

Groundwater flow

For ground heat exchangers, a high heat transport capacity of the subsoil is desirable, to ensure that the heat withdrawn from the subsoil is replaced from the surrounding soil as rapidly as possible. This heat replacement is provided both by the conductivity of the rock and by the very minimal groundwater flow. Since groundwater flow is difficult to ascertain, especially at great depths, and since this very low speed of groundwater flow moreover varies greatly, groundwater flow is disregarded in this calculation. Thus, the data on specific yield have been conservatively estimated, and can be viewed as a safety buffer for the sizing of the system. Moreover, the statements on specific extraction capacity apply only for the marginal conditions stated (see below).

Statistical Base

The database for the map is provided by approx. 14,950 bore holes with a depth of 40 m or more in the borehole database of the Working Group Geological Survey of the Senate Department for the Environment, Transport and Climate Protection, 1,900 interpretation profiles from geological cuts, data on rock specific conductivity and heat capacity, as well as the depth to groundwater of the main aquifer derived on the basis of the groundwater level measurement of May 2017 and the digital terrain altitude data.

Methodology

Based on the borehole database of the Working Group Geological Survey of the Senate Department for the Environment, Transport and Climate Protection, the approximately 250,000 strata obtained in the bore holes and the interpretation profiles were compiled and assigned to ten classes of rock with associated specific conductivities and specific heat capacities (Tab. 1).

Rock	Number of strata present	Conductivity λ [W / (m · K)] unsaturated	Conductivity λ [W / (m · K)] saturated	Heat capacity ² c [MJ/m ³ , K] unsaturated	Heat capacity ² c [MJ/m ³ , K] saturated
Landfill/ anthropogenic	4731	0.4	2.7	1.6	2.5
Soil	4115	2.1	2.8	2.25	2.25
Gyttja	2208	0.4 ²	0.4 ²	0.8	0.8
Peat/ peat gyttja	913	0.4 ²	0.4 ²	0.8	0.8
Sand	131766	0.4 ³	2.7 ³	1.6	2.5
Gravel	10117	0.4 ²	1.8 ²	1.45	2.4
Boulder clay	5825	2.9 ^{1,3}	2.9 ³	2.0	2.0
Glacial till	54097	2.9 ^{1,3}	2.9 ³	2.0	2.0
Clay/silt	32903	0.5 ³	1.5 ³	1.55	2.4
Brown coal	4263	0.4 ²	0.4 ²	0.8	0.8

¹ Moist soil; ² From VDI 4640 (2010); ³ From potential study, Module 1

Tab. 1: Classes of rock with associated specific conductivities and specific heat capacities

In order to determine the specific extraction capacity of the ten classes of rock, a model approach using the Earth Energy Designer (EED, Version 3.16) was used. The case calculated was that of the energy load of a single-family home, close to real conditions, with identical marginal conditions for each class of rock. Only the rock-specific parameters, conductivity and thermal capacity, were adapted. In that way, maximum heating yield for each class of rock, and from that, the specific extraction capacity, could be determined.

Marginal conditions for the ascertainment of specific extraction capacity

1. Marginal conditions of the site/heating requirement:

- mean temperature of the earth's surface: 9°C
- arrangement of ground heat exchangers: 2 exchangers, 100 m in length each, 6 m apart
- borehole diameter: 180 mm
- volume flow per exchanger: 0.5 L/min (lower level of turbulence in fluid)
- ground heat exchanger: 0.07 m
- conductivity of the backfill: 1.5 W/(m·K)
- coolant: mono-ethylene glycol, 25%
- borehole resistance: corresponds to above design
- simulation period: 25 years
- annual coefficient of performance: 4.3 (subsidy guideline of the Federal Office of Economics and Export Control/ BAFA)
- minimum temperature marginal condition of fluid: 1.5°C

2. Marginal conditions of the groundwater/minimum soil temperature:

- groundwater flow: N/A
- subsoil temperature: constant at mean Berlin temperature (9°C)

3. Validity:

- Applicable only for small ground heat exchangers (two exchangers)
- For larger systems with more than two exchangers (even < 30 kW), corresponding reductions must be taken into account, since the interactive effect of the exchangers increases with their number.

Annual operating hours

The calculation of the extraction capacity refers to heating operations **without** hot water supply, with 1,800 operating hours per year for the heat pump (Maps 02.18.5-8); and for heating operations **with** hot water supply, with 2,400 operating hours per year for the heat pump (Maps 02.18.9-12).

The variations in annual heating load distribution are shown in Figures 2 and 3, for 1,800 and 2,400 operating hours, respectively. The share of hot water supply is constant, while the heating supply varies over the course of the year.

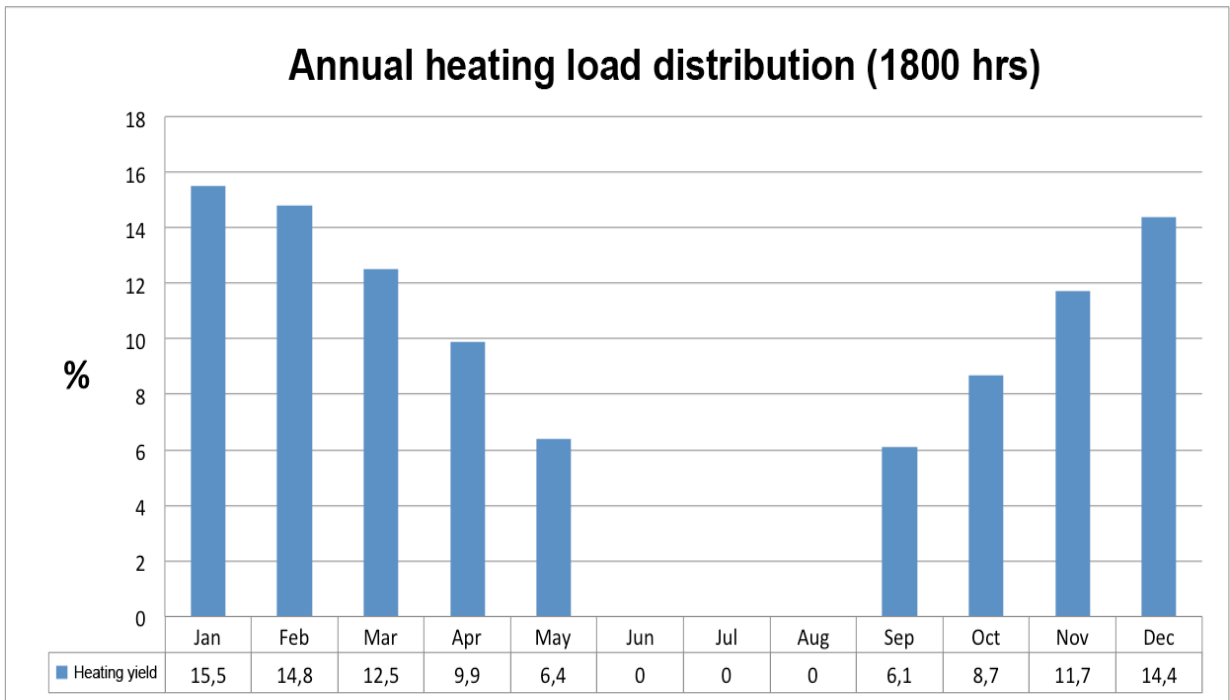


Fig. 2: Annual heating load distribution for 1,800 operating hours

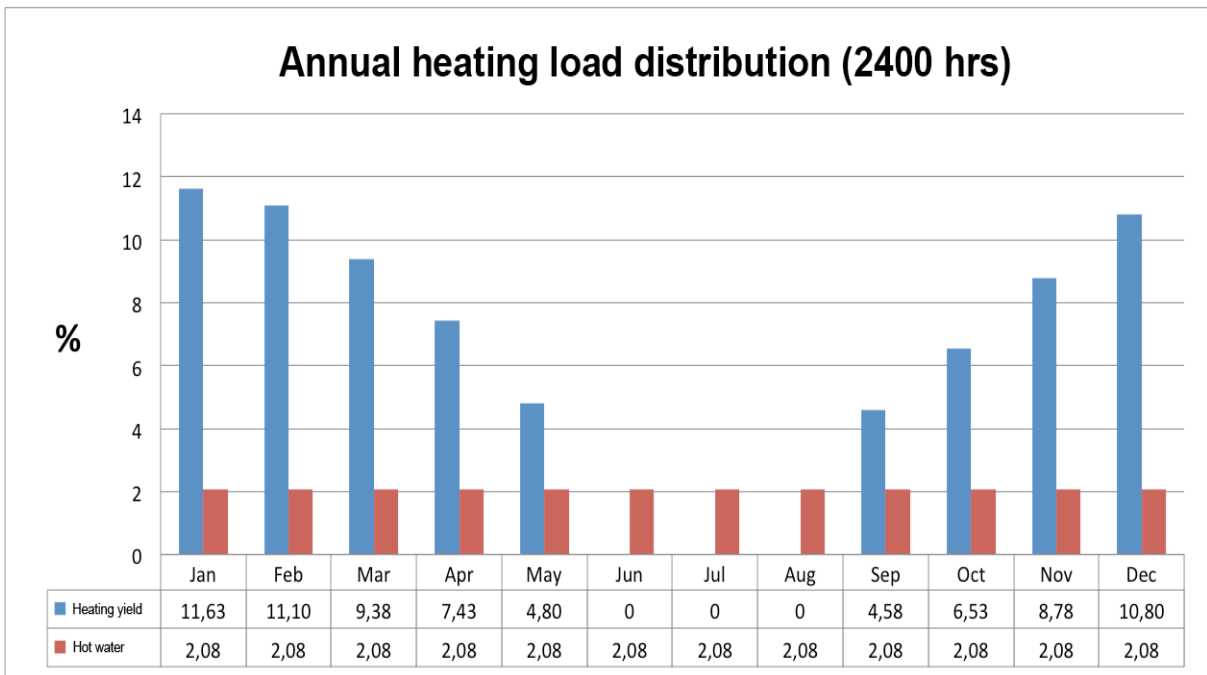


Fig. 3: Annual heating load distribution for 2,400 operating hours

The resulting specific extraction capacity for heating without a hot water supply (1,800 h/a) and with a hot water supply (2,400 h/a) for each class of rock, both in the saturated and the unsaturated areas, is shown in Tab. 2.

Rock	P 1800 h/a [W/m]	P 2400 h/a [W/m]	P 1800 h/a [W/m]	P 2400 h/a [W/m]
	unsaturated		saturated	
Landfill/anthropogenic	9.94	8.02	45.56	37.30
Soil	37.86	30.88	46.41	38.02
Gyttja	9.20	7.43	9.20	7.43
Peat/ peat gyttja	9.20	7.43	9.20	7.43
Sand	9.94	8.02	45.56	37.30
Gravel	9.82	7.94	34.01	27.75
Boulder clay	47.16	38.82	47.16	38.82
Glacial till	47.16	38.82	47.16	38.82
Clay/silt	11.91	9.63	29.84	24.22
Brown coal	9.20	7.43	9.20	7.43

Tab. 2: Specific extraction capacity of particular classes of rock

The mean specific conductivity and the mean specific extraction capacity for the entire borehole system has been calculated for selected depth segments (0 - 40 m, 0 - 60 m, 0 - 80 m and 0 - 100 m), by weighted averaging of the conduction and extraction capacity for each stratum.

Since especially for the drafting of the map for the depth of 100 m, there were only 1,500 bore holes available, greater density was achieved using virtual drillings based on geological cuts at intervals of 500 m. The assignment of conductivities and of associated extraction capacities for these points was

carried out by means of average values for the petrographic properties of the surrounding rock. A total of approx. 1,900 additional virtual boreholes were thus used.

In order to draft the maps, the values for the specific conductivity and the specific extraction capacity calculated for all boreholes and virtual points were then interpolated by means of inverse distance weighting (IDW).

Map Description

These maps show the specific conductivity and the specific extraction capacity for the state of Berlin. The specific extraction capacity calculated referred to the average single-family home, and are differentiated between space heating only, with an estimated 1,800 annual operating hours (Maps 2.18.5 - 2.18.8), and space heating plus hot water supply, with an estimated 2,400 annual operating hours (Maps 2.18.9 - 2.18.12), and is valid only under the given boundary conditions, shown in chapter Methodology. Maps have been prepared for four established possible depth levels: 0 - 40 m, 0 - 60 m, 0 - 80 m and 0 - 100 m.

Based on these maps, an evaluation of the suitability of a site for use of geothermal energy is possible. In the simple case of a single-family home, extraction capacity can be directly determined; for other buildings, it can be calculated on the basis of specific conductivity (Maps 2.18.1 - 2.18.4).

This year's update of the geothermal map was implemented programmatically as 2015 using mapping rules of the petrography and genesis attributes of the bore hole database. This results in differences in individual cases to the 2010, 2012 and 2015 map edition.

The percentage distribution of the particular classes of specific conductivity present on the territory of Berlin shows that more than 40 % of the surfaces at all depths can be assigned to the class > 2.4 – 2.6 W/mK (Tab. 3).

Class [W/mK]	0 – 40 m	0 – 60 m	0 – 80 m	0 – 100 m
≤ 1.0	0.5	0.1	0.0	0.0
> 1.0 - 1.2	0.8	0.1	0.0	0.0
> 1.2 - 1.4	1.3	0.2	0.1	0.0
> 1.4 - 1.6	1.5	0.6	0.2	0.1
> 1.6 - 1.8	2.5	2.0	0.9	0.3
> 1.8 - 2.0	4.4	4.2	3.0	2.1
> 2.0 - 2.2	8.7	10.4	10.6	9.4
> 2.2 - 2.4	19.2	22.3	25.7	28.2
> 2.4 - 2.6	39.2	42.0	45.1	47.2
> 2.6 - 2.8	20.6	17.8	14.3	12.7
> 2.8	1.2	0.2	0.1	0.1

Tab. 3: Percentage distribution of particular classes of specific conductivity

The specific extraction capacity of the systems which provide only heating without hot water preparation (1,800 h/a) is shown in Tab. 4 to be relatively high (> 40 – 45 W/m) for all depths in over 50 % of areas.

Class [W/m]	0 – 40 m	0 – 60 m	0 – 80 m	0 – 100 m
≤ 25	2.6	0.3	0.1	0.0
> 25-30	2.7	1.5	0.6	0.3
> 30-35	6.3	6.2	5.2	4.0
> 35-40	20.1	26.6	30.8	34.0
> 40-45	60.5	60.8	60.5	58.9
> 45	7.8	4.6	2.8	2.8

Tab. 4: Percentage distribution of particular classes of specific extraction capacity for 1,800 operating hours

For systems with space heating and hot water supply (2,400 h/a), more than 50 % of the areas, at all depths, have a value of only >30 - 35 W/m (Tab. 4), while the > 35 - 40 W/m category accounts for only 20 to 30 % of the surfaces. A specific extraction capacity of greater than 40 W/m does not occur at all (Tab. 5).

Class [W/m]	0 – 40 m	0 - -60 m	0 – 80 m	0 – 100 m
≤ 25	5.7	2.0	0.8	0.3
> 25-30	9.8	10.7	9.1	7.7
> 30-35	50.7	55.2	63.0	68.0
> 35-40	33.8	32.0	27.1	24.0
> 40-45	0.0	0.0	0.0	0.0
> 45	0.0	0.0	0.0	0.0

Tab. 5: Percentage distribution of particular classes of specific extraction capacity for 2,400 operating hours

Representation of single boreholes

In addition to the surface depiction of specific conductivities and specific extraction capacities, it is possible to click onto a particular borehole schematically, and thus access a borehole-specific graphic. Here, a concrete borehole is shown in a greatly simplified and combined geological profile, with the groundwater level. Moreover, data on the specific conductivity and the specific extraction capacity for 1,800 operating hours (space heating without hot water supply), or for 2,400 operating hours (space heating with hot water supply) – depending on the map from which the access has been started – can be accessed (Fig. 4).

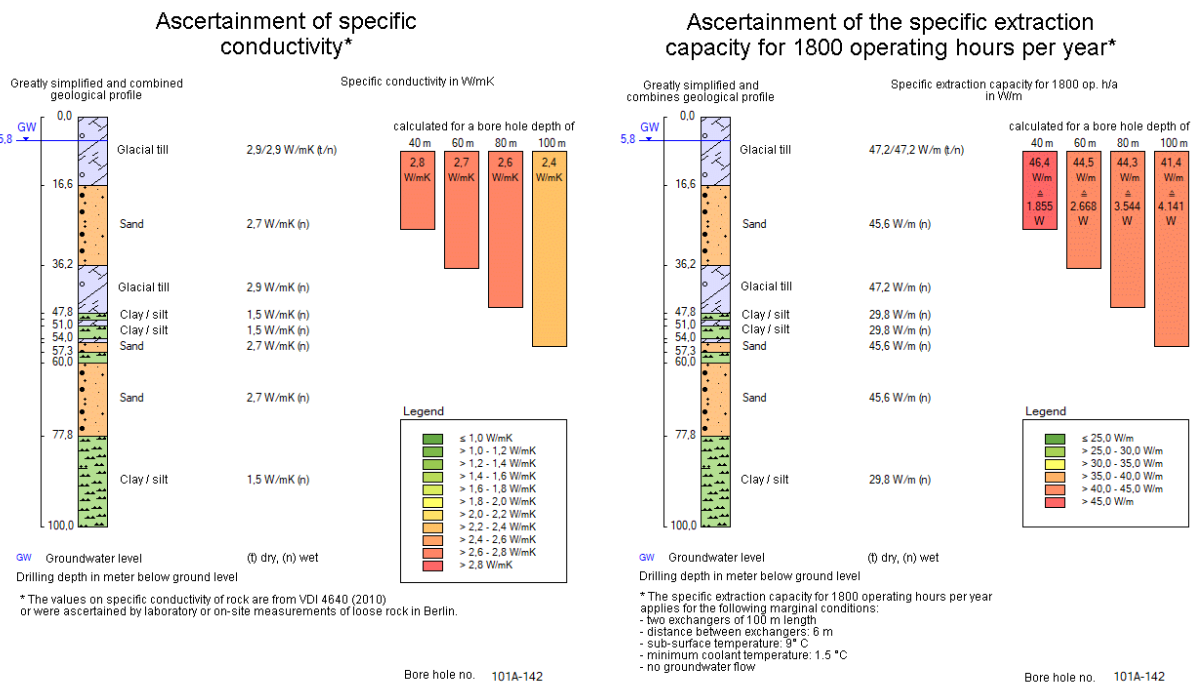


Fig. 4: Schematic description of borehole, with information on specific conductivity and specific extraction capacity

Restricted areas

In the State of Berlin, supplying drinking water to the population has priority over the thermal use of the subsoil. The use of geothermal energy is hence generally prohibited in certified water protection areas. These areas are cross-hatched in black on the maps.

The use of geothermal energy is restricted in areas with highly saline groundwater above the Holstein layers (aquifer 2). This is to prevent further deterioration of the situation in the main aquifer. These areas are cross-hatched in blue on the maps.

In certain areas of Berlin, the use of geothermal energy is also restricted to ensure groundwater protection. This includes areas with highly saline groundwater located below the Holstein layers (aquifers 3 and 4), areas with artesian confined groundwater or higher levels of Rupelian clay. These areas are hatched on the maps. Additional information can be obtained from the responsible authority. The maps on geothermal potentials serve as a reference guide only. Any change in the marginal conditions, such as the arrangement of the exchangers, the number of operating hours (see above), etc. could lead to deviations in the extraction capacity. Therefore, the maps should not be used as an exact basis for planning.

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