# Temperature and Thermal Properties (Detailed)

This module provides temperature and interpreted thermal properties data for the geological units at depth.

**Surface temperature**

The temperature of the ground determines the temperature gradient within the collector loops of the ground source heat pump. The UK Meteorological Office collects and archives climate temperature data. Monthly and annual long-term average datasets have been generated for the periods 1961-1990 and 1971-2000. Mean annual air temperatures at sea level in mainland UK varies from north to south from about 8 – 12 °C and the January - July mean air temperature swing for much of the UK is less than 15 °C. Mean annual air temperatures show a general decrease eastwards and northwards from highest values in the south-west of England. Mean annual air temperatures are mainly affected by position and elevation. Since the contribution to surface temperature from the heat conducted upwards from the sub-surface is very small, the mean annual ground surface temperature should be close to the mean annual air temperature although often shows a variation of ± 1 °C. Mean site temperature has been estimated using a model based on the 30-year station averages published by the UK Meteorological Office (UKMO) web site www.metoffice.gov.uk.

**Sub-surface temperatures**

Soil temperatures vary both diurnally and seasonally, the former variation fading out within a few 10s of cm and the latter at greater depths. At depths of about 15 m the temperature is approximately constant and equal to the mean annual air temperature. The temperature is transmitted down through the earth at a rate dependent on thermal diffusivity. Consequently the temperature in the near sub-surface has a progressive phase shift, i.e. at times of minimum air temperature ground temperatures are generally slightly higher and at times of maximum air temperatures ground temperatures are lower. Hence, at a depth of 3.5 m the minimum soil temperature is likely to be in the first two weeks of April and the maximum temperature about the end of October. The range of temperatures at 3.5 m depth is also likely to be about one quarter that at the surface. Soil temperatures at depth have been estimated using a soil diffusivity of 0.05 $m^2$ $day^{-1}$. Annual temperature swing is based on a model of the difference in mean January and July air temperatures derived from published UKMO long-term records.

At depths below about 15 m temperatures are affected by the small amount of heat conducted upwards from the sub-surface. In the UK this creates an increase of temperature with depth that has an average value of 2.6 °C per 100 m. This geothermal gradient will vary depending upon the nature of the rocks and their thermal properties. In addition moving groundwater can create warmer regions by transporting heat from depth, or cooler regions when cold water flows down from near the ground surface. Observed equilibrium temperature data for the UK indicate that some areas have stable ground temperatures of 15 °C at depths of 100 m. Conversely other regions show stable temperatures at 100 m depth of only 7 °C.

The mean observed equilibrium temperature for the UK at a depth of 100 m is close to 12 ±1.6 °C with a range of about 7-15 °C. Estimates of the temperatures at 100 and 200 m depths have been made from an estimate of the local heat flow and the thermal conductivity of the bedrock geology from the 1:250 000 scale geological map. It should be noted that anomalies caused by flowing groundwater are not included here.

**Estimated temperature parameters of the site**

| | |
|---|---|
| Mean annual air temperature | 10.1 °C |
| Mean annual temperature swing | 8.3 °C |
| Estimated mean soil temperature | 11.1 °C |
| Minimum annual soil temperature at 1 m | 5.6 °C |
| Maximum annual soil temperature at 1 m | 16.6 °C |
| Estimated temperature at 50 m depth | 12 °C |
| Estimated temperature at 100 m depth | 13 °C |
| Estimated temperature at 150 m depth | 13.9 °C |
| Estimated temperature at 200 m depth | 14.8 °C |

Soil temperatures at 1 m estimated using a soil diffusivity of 0.05 $m^2$ $day^{-1}$.
Annual temperature swing based on mean January and July air temperatures.

**Thermal properties**

The rate at which heat is exchanged between the collector loop of the ground source heat pump and the ground is determined mainly by the thermal properties of the earth. Thermal conductivity is the capacity of a material to conduct or transmit heat, whilst thermal diffusivity describes the rate at which heat is conducted through a medium. For a horizontal loop system in a shallow (1-2 m) trench then the properties of the superficial deposits are important, whilst for a vertical loop system it is the properties of the bedrock geology that are important.

**Thermal conductivity**

Thermal conductivity varies by a factor of more than two (1.5 - 3.5 W $m^{-1}$ $K^{-1}$) for the range of common rocks encountered at the surface. Superficial deposits and soils are complex aggregates of mineral and organic particles and so exhibit a wide range of thermal characteristics. The thermal conductivity of superficial deposits and soils will depend on the nature of the deposit, the bulk porosity of the soil and the degree of saturation. An approximate guide to the thermal conductivity of a superficial deposit can be made using a simple classification based on soil particle size and composition. Deposits containing silt or clay portions will have higher thermal conductivities than those of unsaturated clean granular sand. Clean sands have a low thermal conductivity when dry but a higher value when saturated. For sedimentary rocks the primary control on thermal conductivity is the lithology of the sedimentary rock, porosity, and the extent of saturation. Mudstones have thermal conductivities in the range 1.2-2.3 W $m^{-1}$ $K^{-1}$.

For chemical sediments and low porosity (<30%) shale, sandstone and siltstone the mean thermal conductivity is in the range 2.2-2.6 W $m^{-1}$ $K^{-1}$. Water has a thermal conductivity of 0.6 W $m^{-1}$ $K^{-1}$ and air a thermal conductivity of 0.0252 W $m^{-1}$ $K^{-1}$. A saturated quartz sandstone with 5% porosity might have a thermal conductivity of about 6.5 W $m^{-1}$ $K^{-1}$ but this would decrease to about 2.5 W $m^{-1}$ $K^{-1}$ if the rock had a porosity of 30%. Porosity is also the main influence on thermal conductivity of volcanic rocks. Low porosity tuffs, lavas and basalts may have values above 2 W $m^{-1}$ $K^{-1}$, but at 10% porosity with water saturation this might reduce to about 1.5 W $m^{-1}$ $K^{-1}$. For intrusive igneous rocks, which generally have a much lower porosity, the thermal conductivity variation is less. Intrusive rocks with low feldspar content (<60%), including granite, granodiorite, diorite, gabbro and many dykes, have a mean thermal conductivity of about 3.0 W $m^{-1}$ $K^{-1}$. For metamorphic rocks, porosity is often very low and thermal conductivity can be related to quartz content. The thermal conductivity of quartzites is high, typically above 5.5 W $m^{-1}$ $K^{-1}$. For schists, hornfels, quartz mica schists, serpentinites and marbles the mean thermal conductivity is about 2.9 W $m^{-1}$ $K^{-1}$.

**Thermal diffusivity**

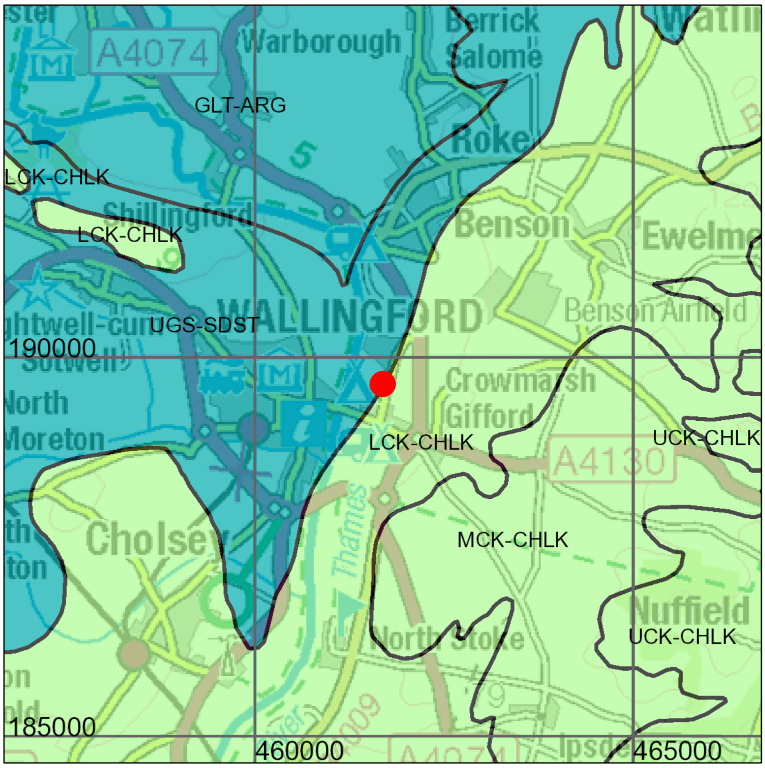
Typical rock thermal diffusivities range from about 0.065 $m^2$ $day^{-1}$ for clays to about 0.17 $m^2$ $day^{-1}$ for high conductivity rocks such quartzites. Many rocks have thermal diffusivities in the range 0.077–0.103 $m^2$ $day^{-1}$. Generally, thermal conductivity and specific heat are increased for saturated rocks and diffusivity is also enhanced.

**Typical values of thermal conductivity and diffusivity for superficial deposits**

| Class | Thermal Conductivity W $m^{-1}$ $K^{-1}$ | Thermal diffusivity $m^2$ $day^{-1}$ |
|---|---|---|
| Sand (gravel) | 0.77 | 0.039 |
| Silt | 1.67 | 0.050 |
| Clay | 1.11 | 0.046 |
| Loam | 0.91 | 0.042 |
| Saturated sand | 2.50 | 0.079 |
| Saturated silt or clay | 1.67 | 0.056 |

W $m^{-1}$ $K^{-1}$ = Watts per Metre per Kelvin

## Thermal conductivity-diffusivity (based on 1:250 000 Bedrock Geology map)

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Scale: 1:100 000 (1cm = 1000 m)
**Search area indicated in red**

### *Key to Thermal conductivity-diffusivity:*

| Map colour | Computer Code | Geological unit | Composition | Thermal conductivity W $m^{-1}$ $K^{-1}$ | Thermal diffusivity $m^2$ $day^{-1}$ |
|---|---|---|---|---|---|
| | GLT-ARG | GAULT FORMATION | ARGILLACEOUS ROCKS, UNDIFFERENTIATED | 2.18 | 0.098 |
| | LCK-CHLK | LOWER CHALK FORMATION | CHALK | 1.67 | 0.0745 |
| | MCK-CHLK | MIDDLE CHALK FORMATION | CHALK | 1.67 | 0.0745 |
| | UCK-CHLK | UPPER CHALK FORMATION | CHALK | 1.67 | 0.0745 |
| | UGS-SDST | UPPER GREENSAND FORMATION | SANDSTONE | 2.59 | 0.111 |

This mapping is based on the BGS Digital Map of Great Britain at the 1:250 000 scale (DiGMapGB-250), so the linework and formation names displayed may differ to a certain extent from those shown in other modules that are based on 1:50 000 scale mapping.

**Site specific thermal conductivity-diffusivity values based on the Borehole Prognosis**

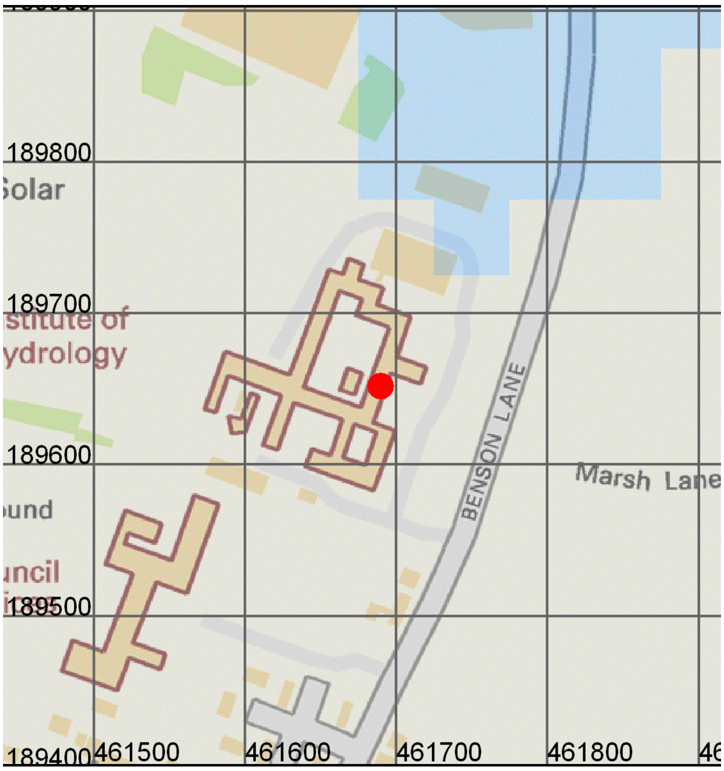
| **Unit** | **Thermal conductivity $W\ m^{-1}\ K^{-1}$** | **Thermal diffusivity $m^2\ day^{-1}$** | **Thickness in metres** |
|---|---|---|---|
| West Melbury Marly Chalk Formation | 1.67 | 0.0745 | Up to 2 m |
| Glauconitic Marl Member | 1.67 | 0.0745 | Up to 2 m |
| Upper Greensand Formation | 2.59 | 0.1110 | About 15 m |
| Gault Formation | 2.18 | 0.0980 | About 60 m |
| Lower Greensand Group | 2.59 | 0.1110 | Less than 8 m |
| Portland Formation | 2.1 | 0.0882 | Probably absent |
| Kimmeridge Clay Formation | 1.30 | 0.0509 | Up to 35 m |
| Corallian Group-limestone | 2.00 | 0.0783 | About 25 m |
| Corallian Group-sandstone | 2.23 | 0.0917 | |
| West Walton and Oxford Clay Formations | 1.30 | 0.0509 | Over 90 m |

A typical 150 m deep borehole would therefore penetrate 5 m of Northmoor Sand and Gravel Member (of which the basal 3 m would be saturated), 1 m of West Melbury Marly Chalk Formation, 2 m of Glauconitic Marl Member, 15 m of Upper Greensand Formation, 60 m of Gault Formation, 6 m of Lower Greensand Group, 35 m of Kimmeridge Clay Formation, 15 m of Corallian Group limestone, 10 m of Corallian Group sandstone and 1 m of West Walton and Oxford Clay Formations. It will have an average thermal conductivity of 1.85 $W\ m^{-1}\ K^{-1}$ and average thermal diffusivity of 0.0845 $m^2\ day^{-1}$.

Most ground source heat pump design techniques are based on the assumption that the heat will be dissipated by conduction. If heat advection due to groundwater flow is significant at a site it is likely that this will have a beneficial effect. The significance of advection is controlled by the hydraulic gradient, the hydraulic conductivity and the thermal conductivity of the saturated rock. In most aquifers advection will be significant except where the groundwater gradient is low; e.g. in coastal plains or confined conditions. At this site, the hydraulic gradient is generally low, but advection due to groundwater flow may improve heat transfer in the Northmoor Sand and Gravel Member and Upper Greensand Formation.

## Superficial thickness

The following map is derived from a mathematical model of the thickness of Superficial Deposits produced by analysing information from approximately 600 000 borehole logs held in the BGS archives. It also uses the digital data on the extent of Superficial Deposits. As a model, the map is a guide only and may differ from the value for superficial deposits thickness given in the borehole prognosis above, but it indicates where thin superficial deposits are likely. In general, depending on the hardness of the bedrock, horizontal collector loops will be easier to install within superficial deposits.




| | Expected Minimum Thickness (m) |
|---|---|
| red | 100 |
| orange | 70 |
| light orange | 50 |
| yellow | 40 |
| yellow-green | 30 |
| green | 20 |
| turquoise | 10 |
| blue | 5 |
| grey | Thickness unknown, but > 1m |
| white | No mapped superficial deposits |

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Scale: 1:5 000 (1cm = 50 m)
**Search area indicated in red**