GHEtool calculation report

# Course 3.1 (Answers)

13/04/26

Licensed report by:

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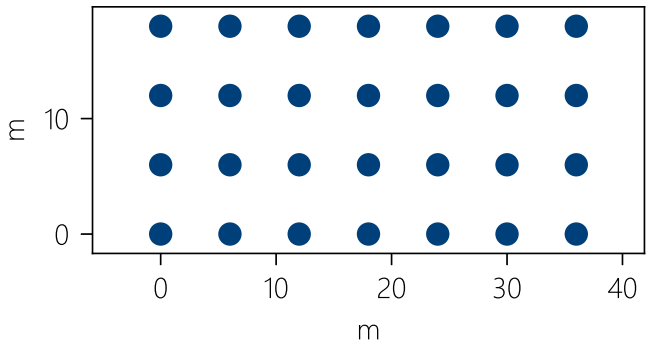
## 1.1 Structure of the report

First, in Chapter 2, a summary of all the simulations will be provided. Chapter 3 discusses the inputs that are consistent across all scenarios. In Chapter 4, the different simulation results are presented and discussed. Chapter 5 contains appendices with more detailed information.

## 2.1 Residential - monthly

### Input




Number of boreholes: 28

Average minimum borehole spacing: 6,0 m

Borehole depth (w.r.t. surface): 150,0 m

2 x U tube DN32 PN16

30,0 v/v% MPG @ 2,00 °C

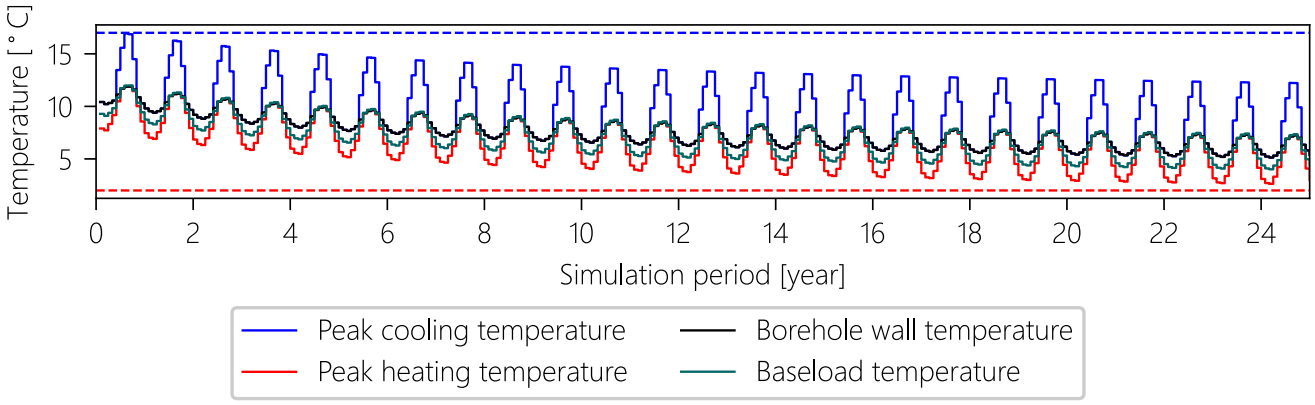
SCOP heating: 5,00; SEER cooling: 20,00; SCOP DHW: 3,00

| Building demand | Yearly load | Peak power |
|---|---|---|
| Heating demand | 120 310 kWh/y | 62,0 kW |
| Domestic hot water demand | 60 000 kWh/y | - |
| Cooling demand | 19 266 kWh/y | 77,0 kW |

### Results

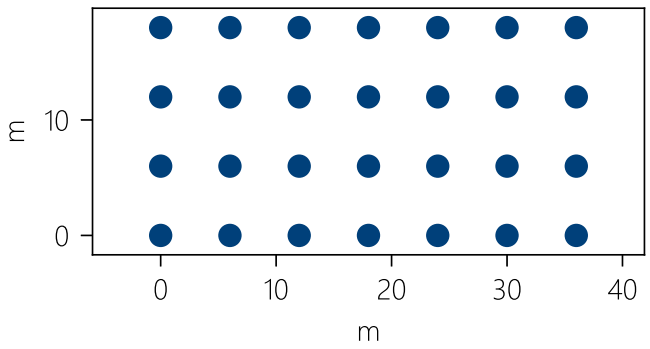
Effective borehole thermal resistance: 0,1694 m·K/W, Reynolds number: 694 (laminar)

Maximum average fluid temperature: 16,95 °C, Minimum average fluid temperature: 2,63 °C



## 2.2 Residential - hourly

### Input




Number of boreholes: 28

Average minimum borehole spacing: 6,0 m

Borehole depth (w.r.t. surface): 150,0 m

2 x U tube DN32 PN16

30,0 v/v% MPG @ 2,00 °C

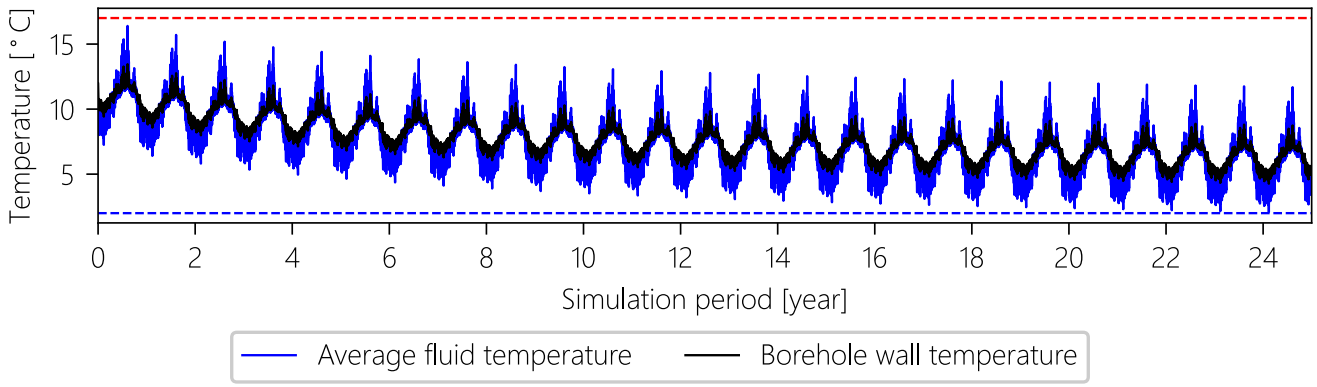
SCOP heating: 5,00; SEER cooling: 20,00; SCOP DHW: 3,00

| Building demand | Yearly load | Peak power |
|---|---|---|
| Heating demand | 120 310 kWh/y | 62,0 kW |
| Domestic hot water demand | 60 000 kWh/y | - |
| Cooling demand | 19 267 kWh/y | 77,3 kW |

### Results

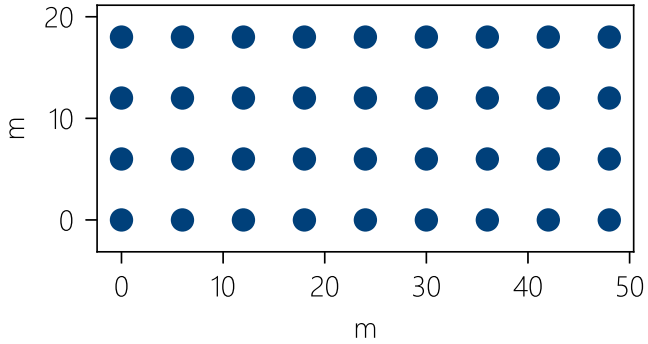
Effective borehole thermal resistance: 0,1694 m·K/W, Reynolds number: 694 (laminar)

Maximum average fluid temperature: 16,39 °C, Minimum average fluid temperature: 2,09 °C



## 2.3 Auditorium - monthly

### Input




Number of boreholes: 36

Average minimum borehole spacing: 6,0 m

Borehole depth (w.r.t. surface): 150,0 m

2 x U tube DN32 PN16

30,0 v/v% MPG @ 2,00 °C

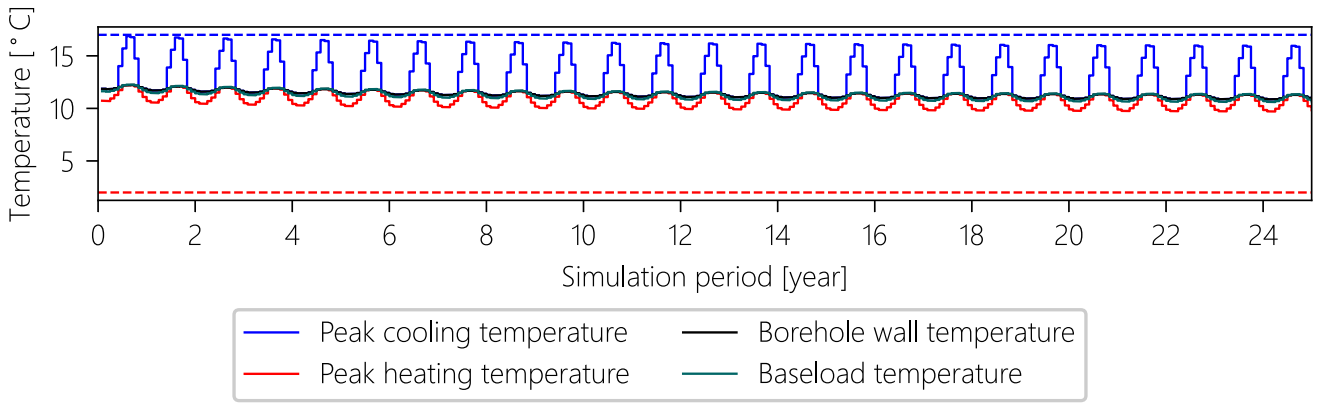
SCOP heating: 5,00; SEER cooling: 20,00

| Building demand | Yearly load | Peak power |
|---|---|---|
| Heating demand | 38 292 kWh/y | 32,0 kW |
| Cooling demand | 3 860 kWh/y | 90,0 kW |

### Results

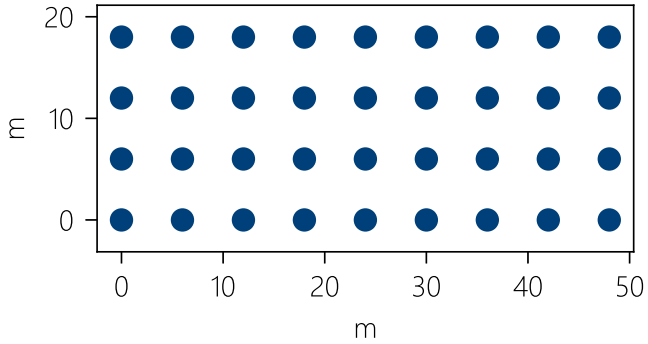
Effective borehole thermal resistance: 0,1694 m·K/W, Reynolds number: 694 (laminar)

Maximum average fluid temperature: 16,88 °C, Minimum average fluid temperature: 9,71 °C



## 2.4 Auditorium - hourly

### Input




Number of boreholes: 36

Average minimum borehole spacing: 6,0 m

Borehole depth (w.r.t. surface): 150,0 m

2 x U tube DN32 PN16

30,0 v/v% MPG @ 2,00 °C

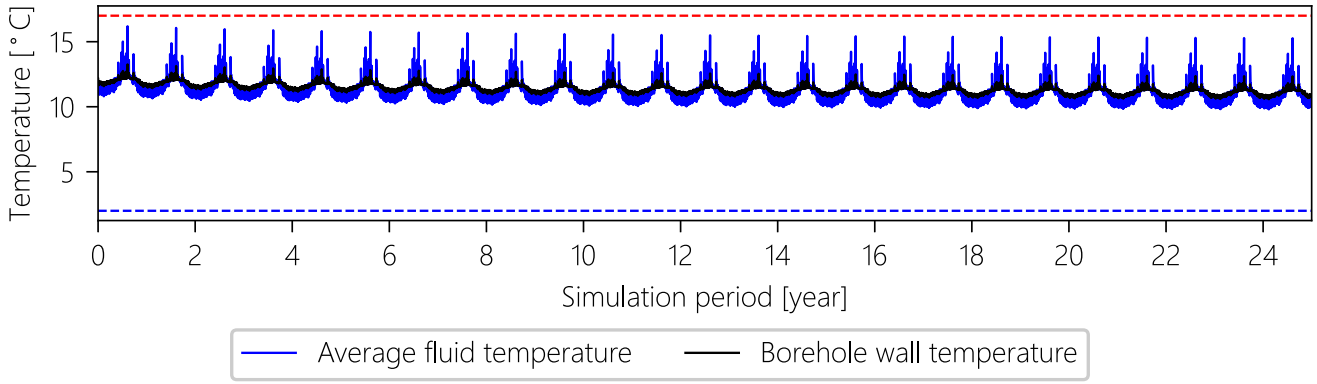
SCOP heating: 5,00; SEER cooling: 20,00

| Building demand | Yearly load | Peak power |
|---|---|---|
| Heating demand | 38 292 kWh/y | 32,5 kW |
| Cooling demand | 3 859 kWh/y | 90,2 kW |

### Results

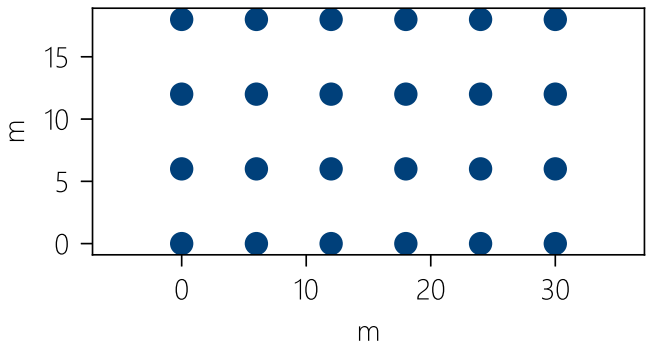
Effective borehole thermal resistance: 0,1694 m·K/W, Reynolds number: 694 (laminar)

Maximum average fluid temperature: 16,19 °C, Minimum average fluid temperature: 9,80 °C



## 2.5 Auditorium - hourly (smaller borefield)

### Input




Number of boreholes: 24

Average minimum borehole spacing: 6,0 m

Borehole depth (w.r.t. surface): 150,0 m

2 x U tube DN32 PN16

30,0 v/v% MPG @ 2,00 °C

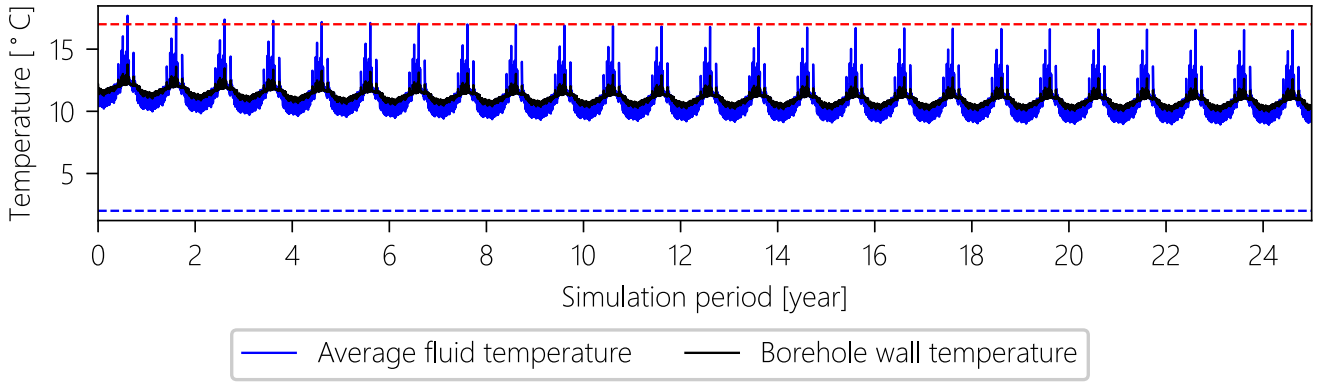
SCOP heating: 5,00; SEER cooling: 20,00

| Building demand | Yearly load | Peak power |
|---|---|---|
| Heating demand | 38 292 kWh/y | 32,5 kW |
| Cooling demand | 3 859 kWh/y | 90,2 kW |

### Results

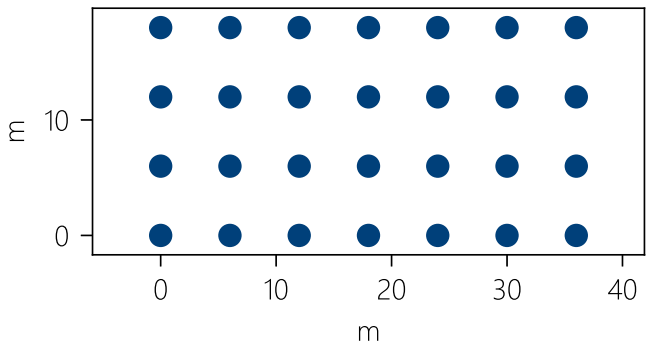
Effective borehole thermal resistance: 0,1514 m·K/W, Reynolds number: 1 041 (laminar)

Maximum average fluid temperature: 17,69 °C, Minimum average fluid temperature: 8,92 °C



## 2.6 Residential - monthly (answer)

### Input




Number of boreholes: 28

Average minimum borehole spacing: 6,0 m

Borehole depth (w.r.t. surface): 150,0 m

2 x U tube DN32 PN16

30,0 v/v% MPG @ 2,00 °C

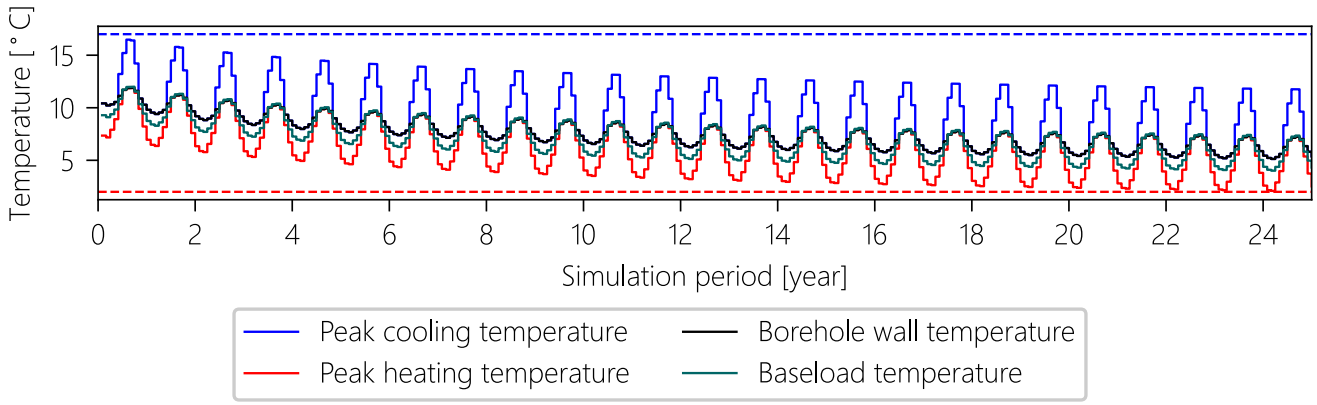
SCOP heating: 5,00; SEER cooling: 20,00; SCOP DHW: 3,00

| Building demand | Yearly load | Peak power |
|---|---|---|
| Heating demand | 120 310 kWh/y | 62,0 kW |
| Domestic hot water demand | 60 000 kWh/y | - |
| Cooling demand | 19 266 kWh/y | 77,0 kW |

### Results

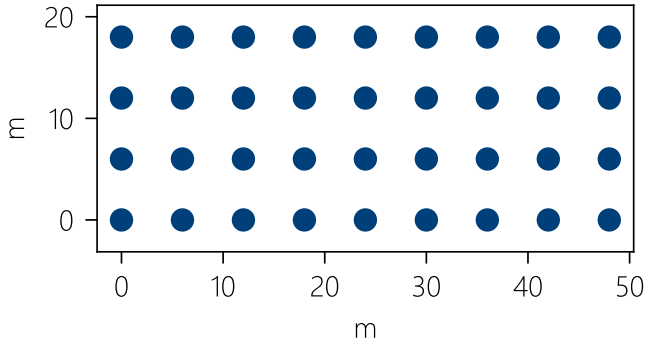
Effective borehole thermal resistance: 0,1694 m·K/W, Reynolds number: 694 (laminar)

Maximum average fluid temperature: 16,48 °C, Minimum average fluid temperature: 2,09 °C



## 2.7 Auditorium - monthly (answer)

### Input




Number of boreholes: 36

Average minimum borehole spacing: 6,0 m

Borehole depth (w.r.t. surface): 150,0 m

2 x U tube DN32 PN16

30,0 v/v% MPG @ 2,00 °C

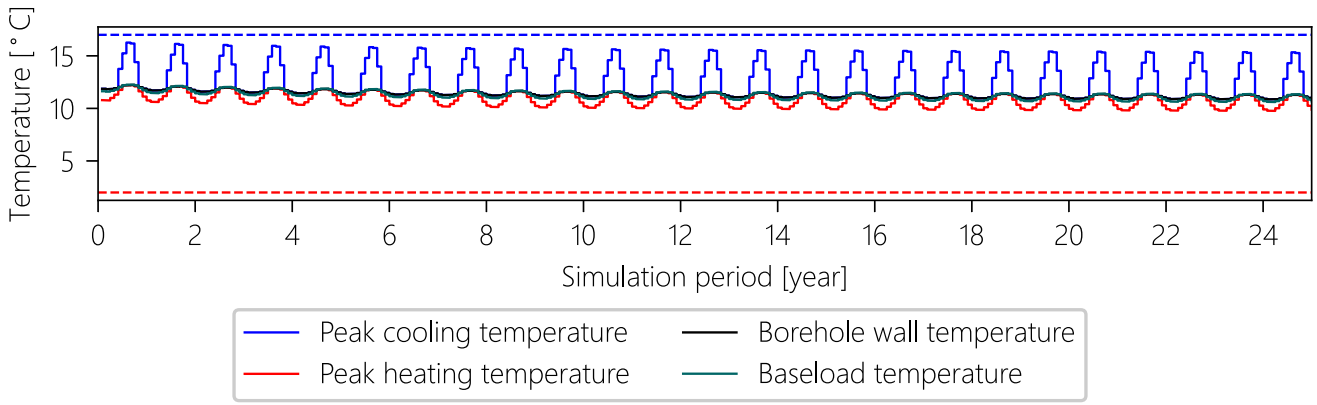
SCOP heating: 5,00; SEER cooling: 20,00

| Building demand | Yearly load | Peak power |
|---|---|---|
| Heating demand | 38 292 kWh/y | 32,0 kW |
| Cooling demand | 3 860 kWh/y | 90,0 kW |

### Results

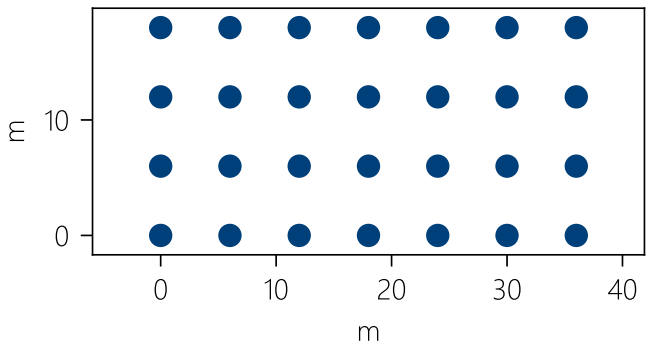
Effective borehole thermal resistance: 0,1694 m·K/W, Reynolds number: 694 (laminar)

Maximum average fluid temperature: 16,26 °C, Minimum average fluid temperature: 9,76 °C



## 2.8 Residential - monthly (answers 2.1)

### Input




Number of boreholes: 28

Average minimum borehole spacing: 6,0 m

Borehole depth (w.r.t. surface): 150,0 m

1 x U tube DN32 PN16

21,0 v/v% MPG

SCOP heating: 5,00; SEER cooling: 20,00; SCOP DHW: 3,00

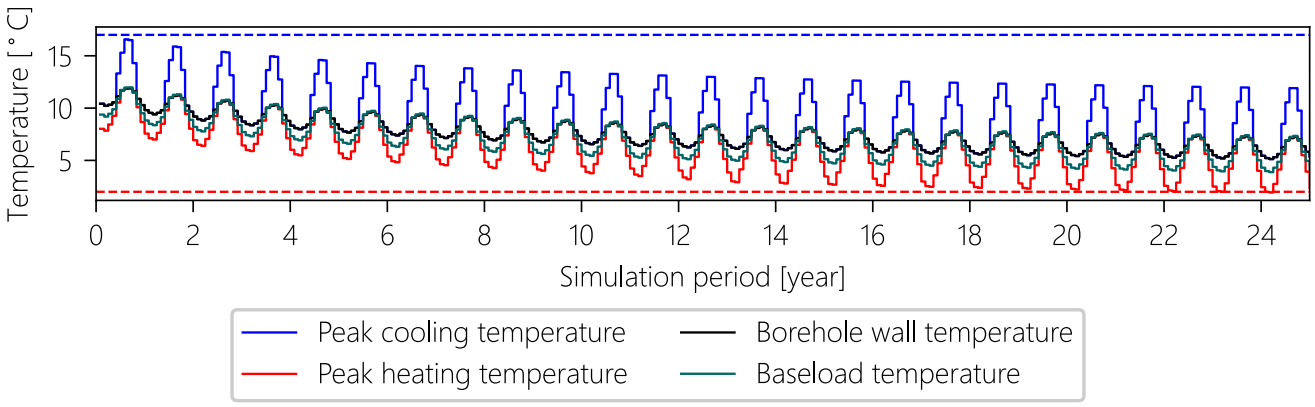
| Building demand | Yearly load | Peak power |
|---|---|---|
| Heating demand | 120 310 kWh/y | 62,0 kW |
| Domestic hot water demand | 60 000 kWh/y | - |
| Cooling demand | 19 266 kWh/y | 77,0 kW |

### Results

Effective borehole thermal resistance (extraction): 0,2287 m·K/W, Reynolds number: 2 197 (laminar)

Effective borehole thermal resistance (injection): 0,1500 m·K/W, Reynolds number: 3 919 (transient)

Maximum average fluid temperature: 16,58 °C, Minimum average fluid temperature: 1,93 °C



This section contains all the input data that is identical across all simulations. Input data that varies between scenarios is provided and discussed within the relevant scenario sections. The following subsections cover the following topics: general simulation settings, ground data, and efficiency data.

## 3.1 General simulation settings

The scenarios in this report have been simulated with a simulation period of 25 years, starting in January. The maximum and minimum average fluid temperatures were 2,00 °C and 17,00 °C respectively. The simulations were carried out with GHEtool Cloud v2.6.2.3.

## 3.2 Ground data

The ground is modelled as a single homogeneous layer with an average thermal conductivity of 2,00 W/(m·K) and a volumetric heat capacity of 2,40 MJ/($m^3$·K). This means that the ground properties are assumed to remain constant at all depths.

A ground temperature gradient is taken into account. Using a geothermal heat flux of 0,07 W/$m^2$, a ground surface temperature of 9,60 °C and the ground thermal conductivity, the average ground temperature can be calculated for each borehole depth. For example, the average ground temperature is 10,90 °C at 74 m and 12,21 °C at 149 m.

Please note that for all ground property calculations, both the borehole depth and the buried depth are taken into account. This means that the average ground properties, as seen by the borehole, are calculated from the buried depth down to the full borehole depth. The region above the buried depth is not considered.

## 3.3 Efficiency data

To calculate the resulting geothermal load, the heat pump is modelled to have a SCOP of 5,00 in heating and 3,00 for the production of domestic hot water. The cooling is modelled with an SEER of 20,00.

## 4.1 Residential - monthly

In the first subsection, the scenario-specific input parameters will be discussed. Afterwards, the simulation results are presented.

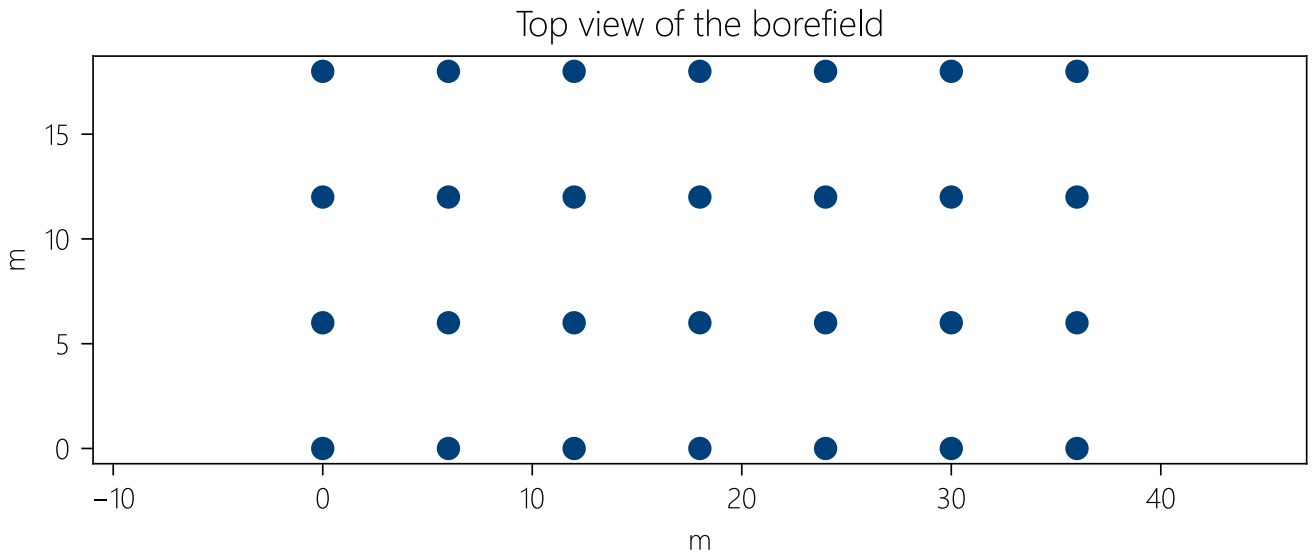
### 4.1.1 Input

#### Borefield configuration

The simulations were carried out with a borefield consisting of 28 boreholes, with an average buried depth of 1,00 m, an average borehole depth of 150,00 m and an average borehole length of 149,00 m. This results in a total borehole length of 4 172,00 m.

The minimum average borehole spacing is 6,00 m. This is defined as the average of the smallest distances between the centres of all pairs of boreholes in the borefield.

(The borehole depth is defined as the vertical distance between the ground surface and the deepest point of the borehole. The buried depth is the distance between the ground surface and the start of the borehole. The borehole length, sometimes called the 'active length' is the actual length of the heat exchanger measured along the borehole.)

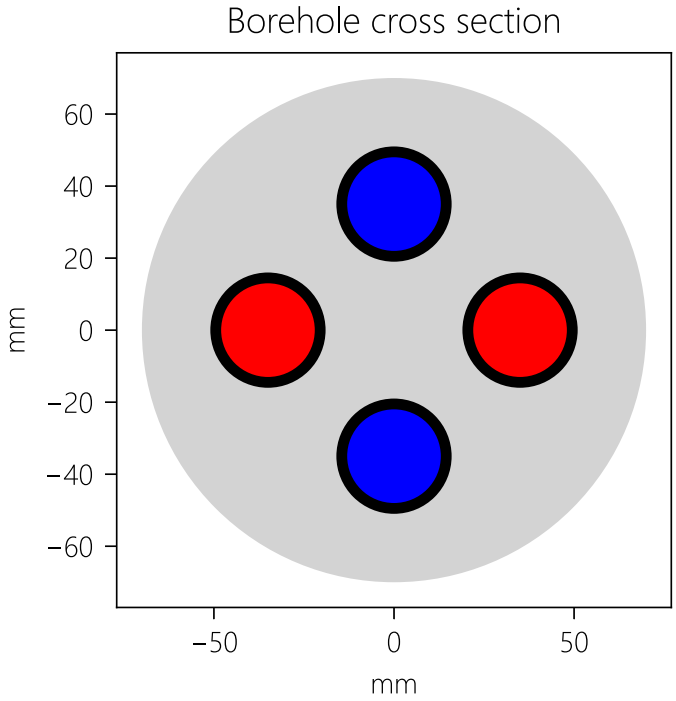


The coordinates of the different boreholes are given in the table below.

| x [m] | y [m] | Length [m] | Depth [m] | Buried depth [m] | Tilt [°] | Orientation [°] |
|---|---|---|---|---|---|---|
| 0,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

## Pipe data

Inside the borehole with a diameter of 140 mm, 2 DN32 PN16 U-tubes will be installed. The U-tubes have a thermal conductivity of 0,40 W/(m·K), and the pipe legs are positioned at a distance of 35 mm from the borehole center. The borehole will be grouted with a material that has a thermal conductivity of 1,50 W/(m·K).




### Fluid data

As a heat transfer fluid, MPG with 30,0 v/v% was selected, providing frost protection down to approximately -14 °C. The fluid properties were assumed to remain constant throughout the simulation period and were calculated at a reference temperature of 2,00 °C.

The fluid properties can be found in the table below.

| | |
|---|---|
| Thermal conductivity of the fluid | 0,42 W/(m·K) |
| Thermal capacity of the fluid | 3 781,04 J/(kg·K) |
| Dynamic viscosity | 7,0582 × $10^{-3}$ Pa·s |
| Density of the fluid | 1 032,94 kg/m³ |

The total flow rate through the borefield is 5,60 kg/s, corresponding to a flow of 0,20 kg/s per borehole in the system.

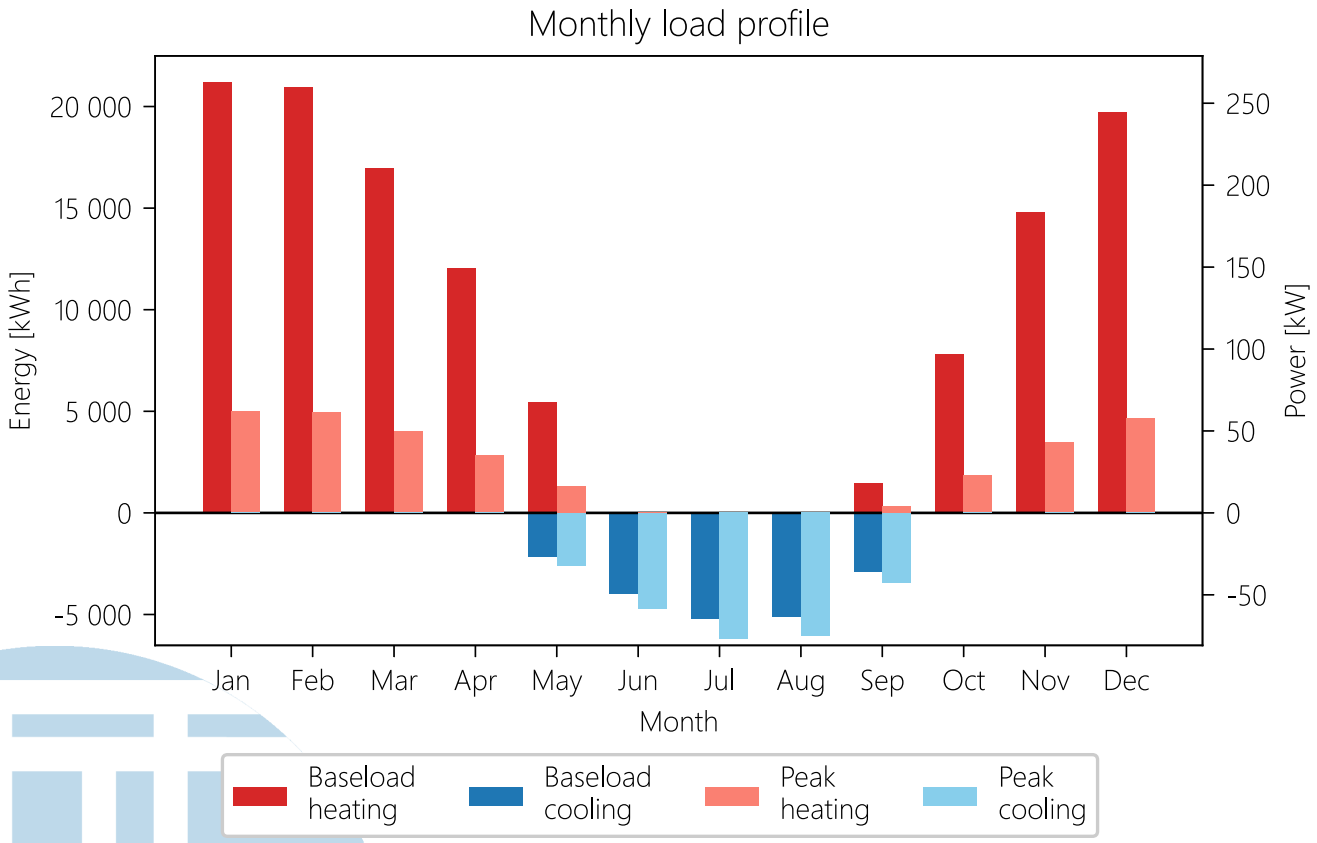
### Load data

For the simulation, a building load was used. This means that, in order to calculate the resulting extraction and injection loads for the ground, the efficiency of the heat pump will be taken into account. Below you can find a summary of the load.

| Building demand | Yearly load | Peak power |
|---|---|---|
| Heating demand | 120 310 kWh/y | 62,0 kW |
| Domestic hot water demand | 60 000 kWh/y | - |
| Cooling demand | 19 266 kWh/y | 77,0 kW |

The monthly distribution is given in the table below.

| Month | Baseload heating [kWh] | Baseload cooling [kWh] | Peak heating [kW] | Peak cooling [kW] |
|---|---|---|---|---|
| January | 21 175 | 0 | 62,0 | 0,0 |
| February | 20 934 | 0 | 61,4 | 0,0 |
| March | 16 964 | 0 | 49,7 | 0,0 |
| April | 12 031 | 0 | 35,1 | 0,0 |
| May | 5 414 | 2 158 | 16,4 | 32,0 |
| June | 0 | 3 950 | 0,0 | 58,2 |
| July | 0 | 5 202 | 0,0 | 77,0 |
| August | 0 | 5 086 | 0,0 | 75,2 |
| September | 1 444 | 2 871 | 4,1 | 42,3 |
| October | 7 820 | 0 | 22,8 | 0,0 |
| November | 14 798 | 0 | 43,3 | 0,0 |
| December | 19 731 | 0 | 57,9 | 0,0 |




The peak duration during heating is 8 hours, and for cooling it is 8 hours. The peak duration is defined as the longest runtime of the maximum heating/cooling power in a year. This value is typically higher with slow

emission systems (such as floor heating or concrete core activation) and lower for fast emission systems (such as air-based systems).

### 4.1.2 Results

#### Ground load

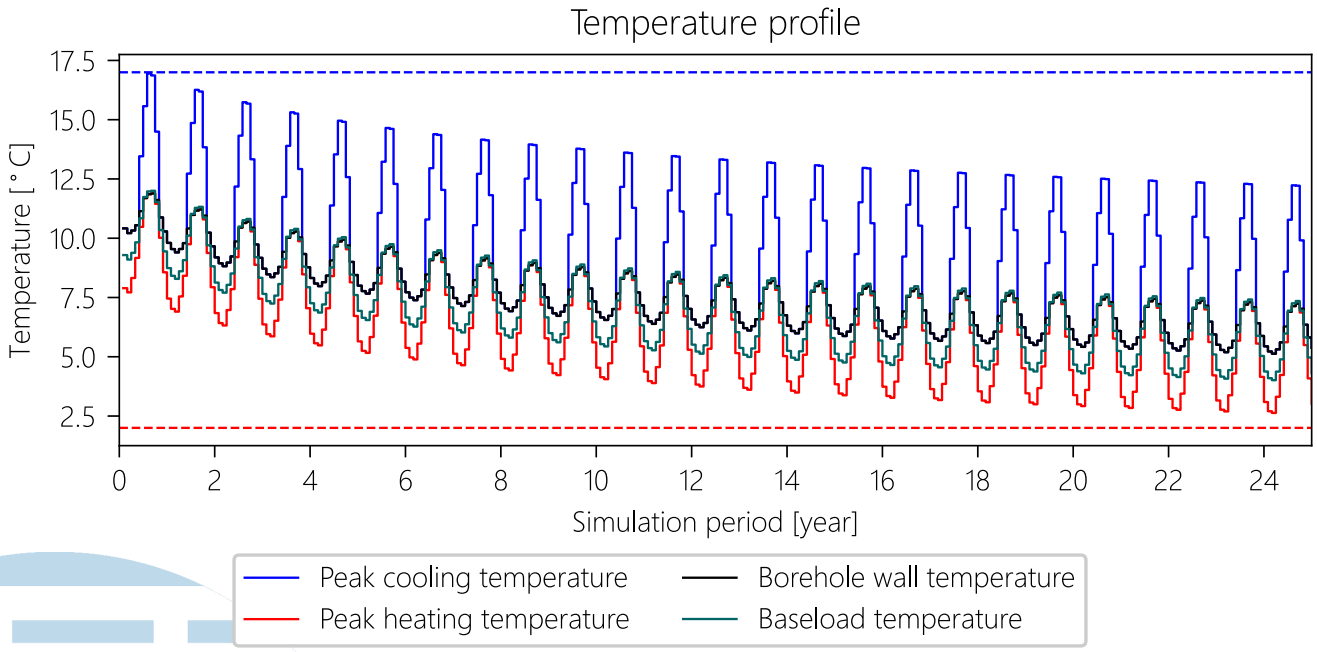
Because we are working with building loads (i.e. secondary loads), these must be converted into injection and extraction loads using the efficiency data. A summary of the resulting yearly ground load is given in the table below.

| Ground demand | Yearly load | Peak power |
|---|---|---|
| Extraction demand | 136 248 kWh/y | 49,6 kW |
| Injection demand | 20 229 kWh/y | 80,8 kW |

#### Temperature evolution of the borefield

Using the pipe, fluid and flow properties, the Reynolds number was calculated to be 694. This is a laminar regime, giving us an effective borehole thermal resistance of 0,1694 m·K/W.
This effective borehole thermal resistance is assumed to remain constant over the simulation period.

Below, the monthly simulation for the borefield is shown. For each month, three lines are displayed. The black line represents the borehole wall temperature, which is the temperature at the interface between the borehole and the ground. The other two lines, red and blue, show the average fluid temperature (between borehole inlet and outlet) during peak heating and peak cooling, respectively.
Since the simulation uses monthly resolution, both heating and cooling peaks can occur in the same month. Therefore, both fluid temperatures are always shown. The difference between the borehole wall temperature and the average fluid temperature is determined by the effective borehole thermal resistance.




The maximum and minimum average fluid temperature over the whole simulation period at peak power are 16,95 °C and 2,63 °C respectively. The minimum average fluid temperatures during the baseload are respectively 4,01 °C and 12,00 °C.

### Pressure drop

The pressure drop over a single borehole is 18,16 kPa during extration and 18,16 kPa during injection.

## 4.2 Residential - hourly

In the first subsection, the scenario-specific input parameters will be discussed. Afterwards, the simulation results are presented.

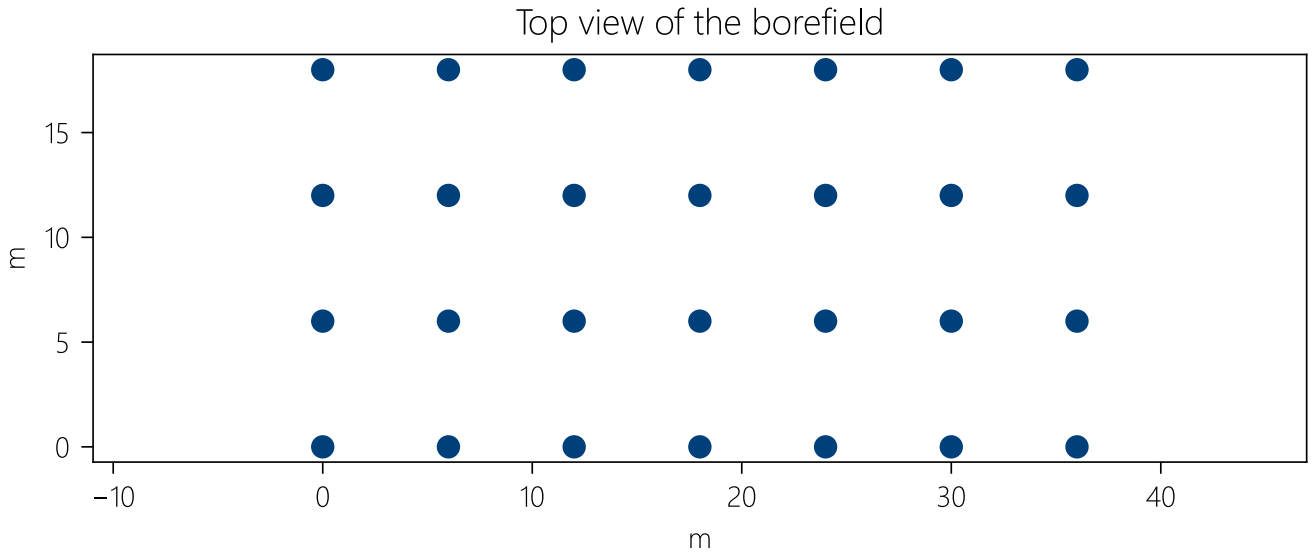
### 4.2.1 Input

#### Borefield configuration

The simulations were carried out with a borefield consisting of 28 boreholes, with an average buried depth of 1,00 m, an average borehole depth of 150,00 m and an average borehole length of 149,00 m. This results in a total borehole length of 4 172,00 m.

The minimum average borehole spacing is 6,00 m. This is defined as the average of the smallest distances between the centres of all pairs of boreholes in the borefield.

(The borehole depth is defined as the vertical distance between the ground surface and the deepest point of the borehole. The buried depth is the distance between the ground surface and the start of the borehole. The borehole length, sometimes called the 'active length' is the actual length of the heat exchanger measured along the borehole.)

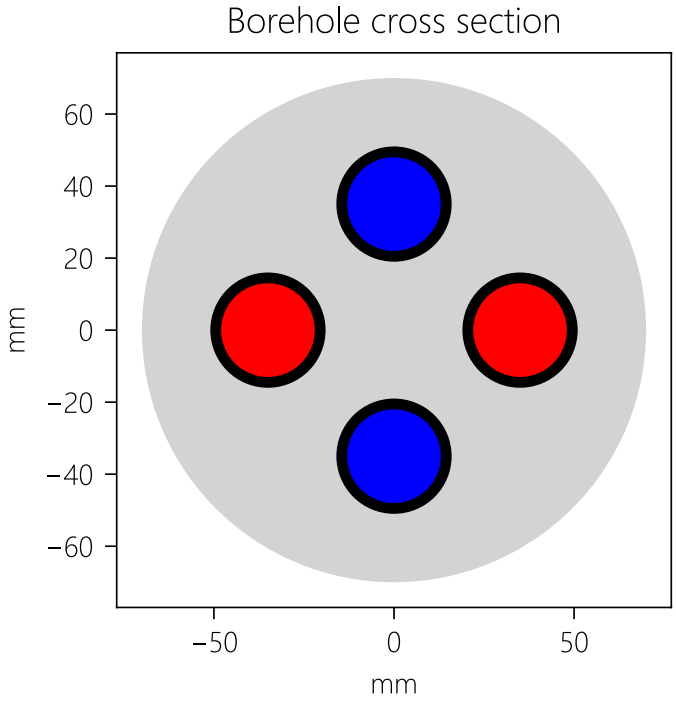


The coordinates of the different boreholes are given in the table below.

| x [m] | y [m] | Length [m] | Depth [m] | Buried depth [m] | Tilt [°] | Orientation [°] |
|---|---|---|---|---|---|---|
| 0,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

## Pipe data

Inside the borehole with a diameter of 140 mm, 2 DN32 PN16 U-tubes will be installed. The U-tubes have a thermal conductivity of 0,40 W/(m·K), and the pipe legs are positioned at a distance of 35 mm from the borehole center. The borehole will be grouted with a material that has a thermal conductivity of 1,50 W/(m·K).




### Fluid data

As a heat transfer fluid, MPG with 30,0 v/v% was selected, providing frost protection down to approximately -14 °C. The fluid properties were assumed to remain constant throughout the simulation period and were calculated at a reference temperature of 2,00 °C.

The fluid properties can be found in the table below.

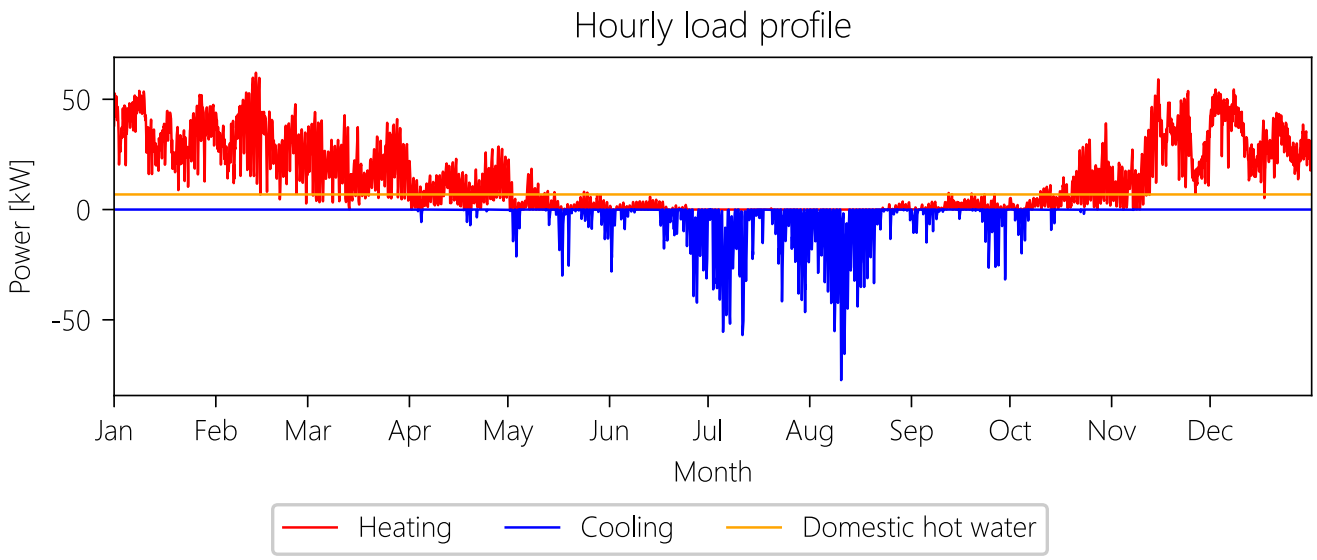
| | |
|---|---|
| Thermal conductivity of the fluid | 0,42 W/(m·K) |
| Thermal capacity of the fluid | 3 781,04 J/(kg·K) |
| Dynamic viscosity | 7,0582 × $10^{-3}$ Pa·s |
| Density of the fluid | 1 032,94 kg/m³ |

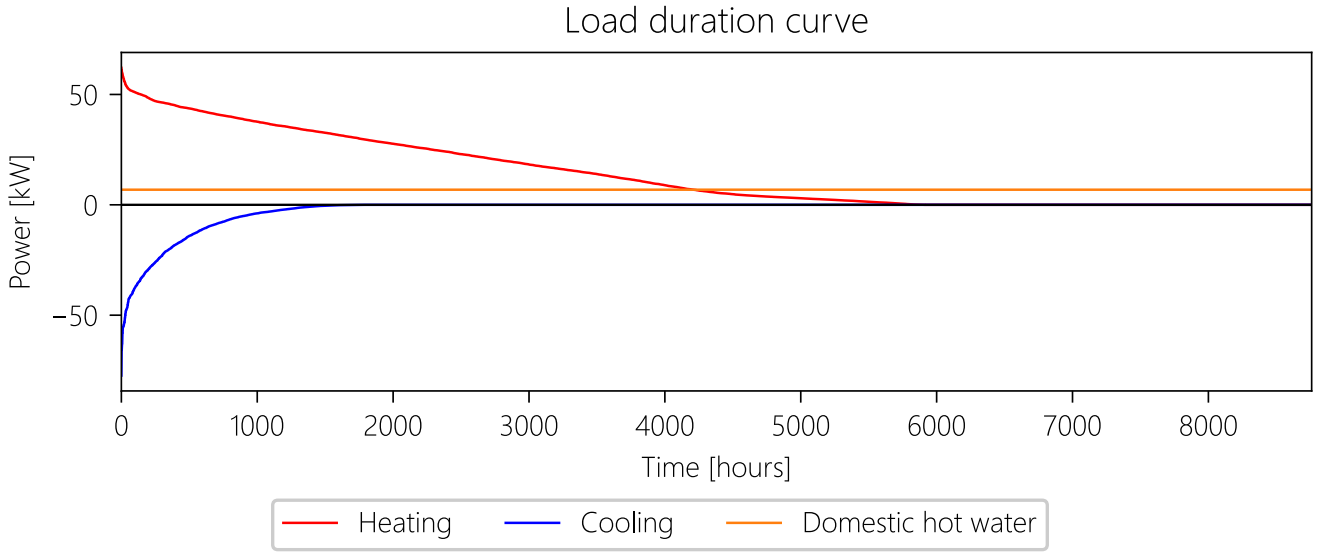
The total flow rate through the borefield is 5,60 kg/s, corresponding to a flow of 0,20 kg/s per borehole in the system.

### Load data

For the simulation, a building load was used. This means that, in order to calculate the resulting extraction and injection loads for the ground, the efficiency of the heat pump will be taken into account. Below you can find a summary of the load.

| Building demand | Yearly load | Peak power |
|---|---|---|
| Heating demand | 120 310 kWh/y | 62,0 kW |
| Domestic hot water demand | 60 000 kWh/y | - |
| Cooling demand | 19 267 kWh/y | 77,3 kW |




### 4.2.2 Results

#### Ground load

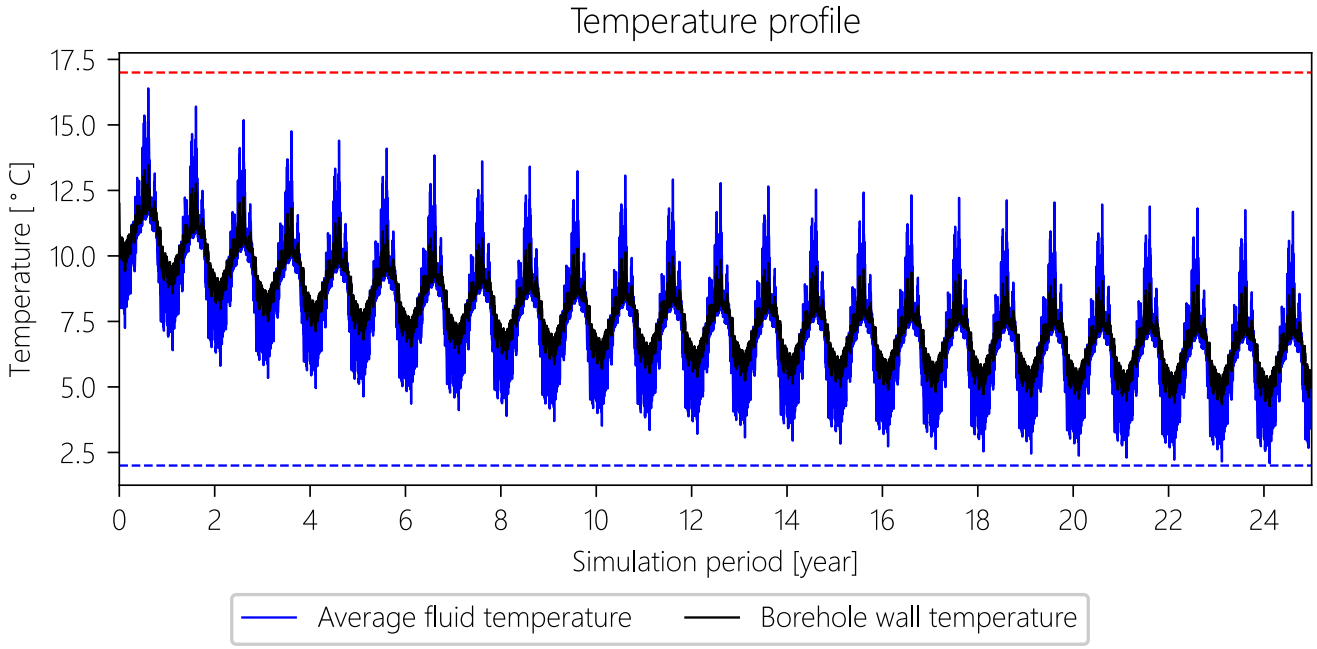
Because we are working with building loads (i.e. secondary loads), these must be converted into injection and extraction loads using the efficiency data. A summary of the resulting yearly ground load is given in the table below.

| Ground demand | Yearly load | Peak power |
|---|---|---|
| Extraction demand | 136 248 kWh/y | 54,2 kW |
| Injection demand | 20 230 kWh/y | 81,2 kW |

#### Temperature evolution of the borefield

Using the pipe, fluid and flow properties, the Reynolds number was calculated to be 694. This is a laminar regime, giving us an effective borehole thermal resistance of 0,1694 m·K/W.
This effective borehole thermal resistance is assumed to remain constant over the simulation period.

Below, the hourly simulation for the borefield is shown. The blue line represents the average fluid temperature between the inlet and outlet of the borehole at each hour of the simulation. The black line shows the borehole wall temperature, which is the interface between the borehole and the ground. The difference between both lines is determined by the effective borehole thermal resistance.




The maximum average fluid temperature over the whole simulation period is 16,39 °C, and the minimum average fluid temperature is 2,09 °C.

### Pressure drop

The pressure drop over a single borehole is 18,16 kPa during extration and 18,16 kPa during injection.

## 4.3 Auditorium - monthly

In the first subsection, the scenario-specific input parameters will be discussed. Afterwards, the simulation results are presented.

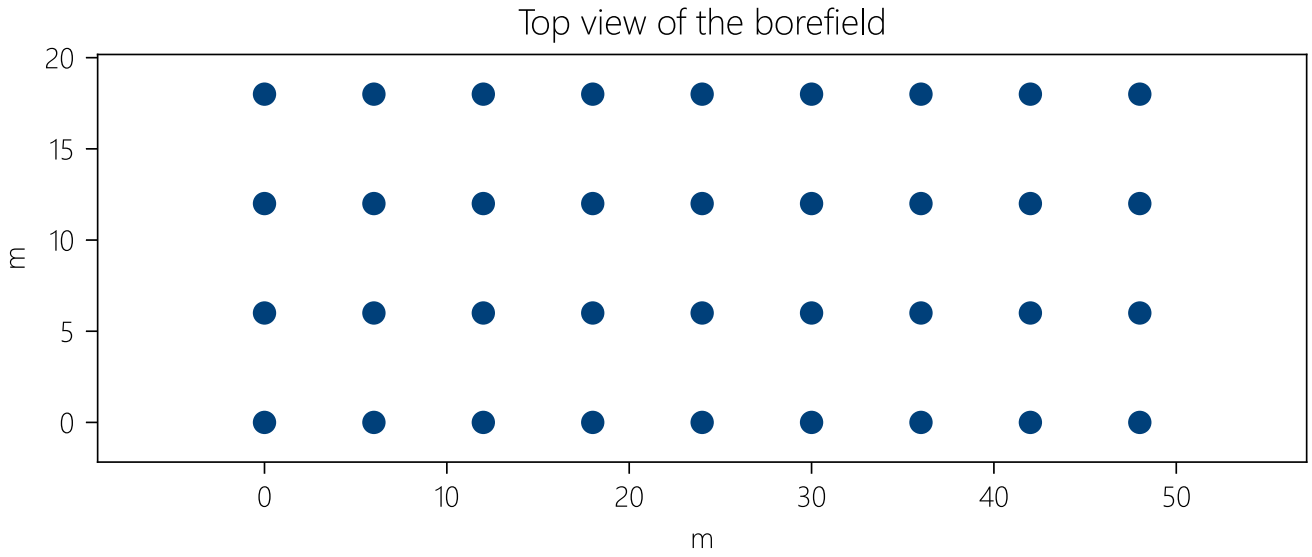
### 4.3.1 Input

#### Borefield configuration

The simulations were carried out with a borefield consisting of 36 boreholes, with an average buried depth of 1,00 m, an average borehole depth of 150,00 m and an average borehole length of 149,00 m. This results in a total borehole length of 5 364,00 m.

The minimum average borehole spacing is 6,00 m. This is defined as the average of the smallest distances between the centres of all pairs of boreholes in the borefield.

(The borehole depth is defined as the vertical distance between the ground surface and the deepest point of the borehole. The buried depth is the distance between the ground surface and the start of the borehole. The borehole length, sometimes called the 'active length' is the actual length of the heat exchanger measured along the borehole.)



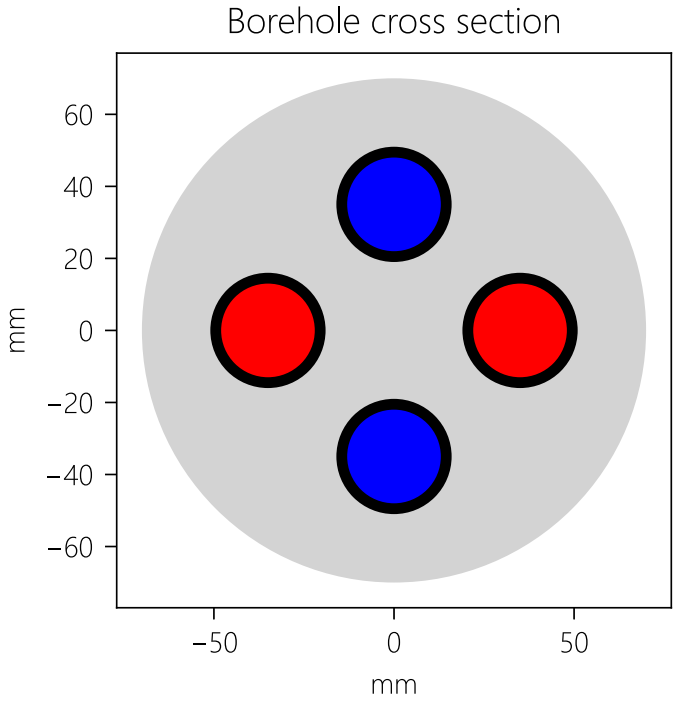
The coordinates of the different boreholes are given in the table below.

| x [m] | y [m] | Length [m] | Depth [m] | Buried depth [m] | Tilt [°] | Orientation [°] |
|---|---|---|---|---|---|---|
| 0,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 48,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

### Pipe data

Inside the borehole with a diameter of 140 mm, 2 DN32 PN16 U-tubes will be installed. The U-tubes have a thermal conductivity of 0,40 W/(m·K), and the pipe legs are positioned at a distance of 35 mm from the borehole center. The borehole will be grouted with a material that has a thermal conductivity of 1,50 W/(m·K).




### Fluid data

As a heat transfer fluid, MPG with 30,0 v/v% was selected, providing frost protection down to approximately -14 °C. The fluid properties were assumed to remain constant throughout the simulation period and were calculated at a reference temperature of 2,00 °C.

The fluid properties can be found in the table below.

| | |
|---|---|
| Thermal conductivity of the fluid | 0,42 W/(m·K) |
| Thermal capacity of the fluid | 3 781,04 J/(kg·K) |
| Dynamic viscosity | 7,0582 × $10^{-3}$ Pa·s |
| Density of the fluid | 1 032,94 kg/m³ |

The total flow rate through the borefield is 7,20 kg/s, corresponding to a flow of 0,20 kg/s per borehole in the system.

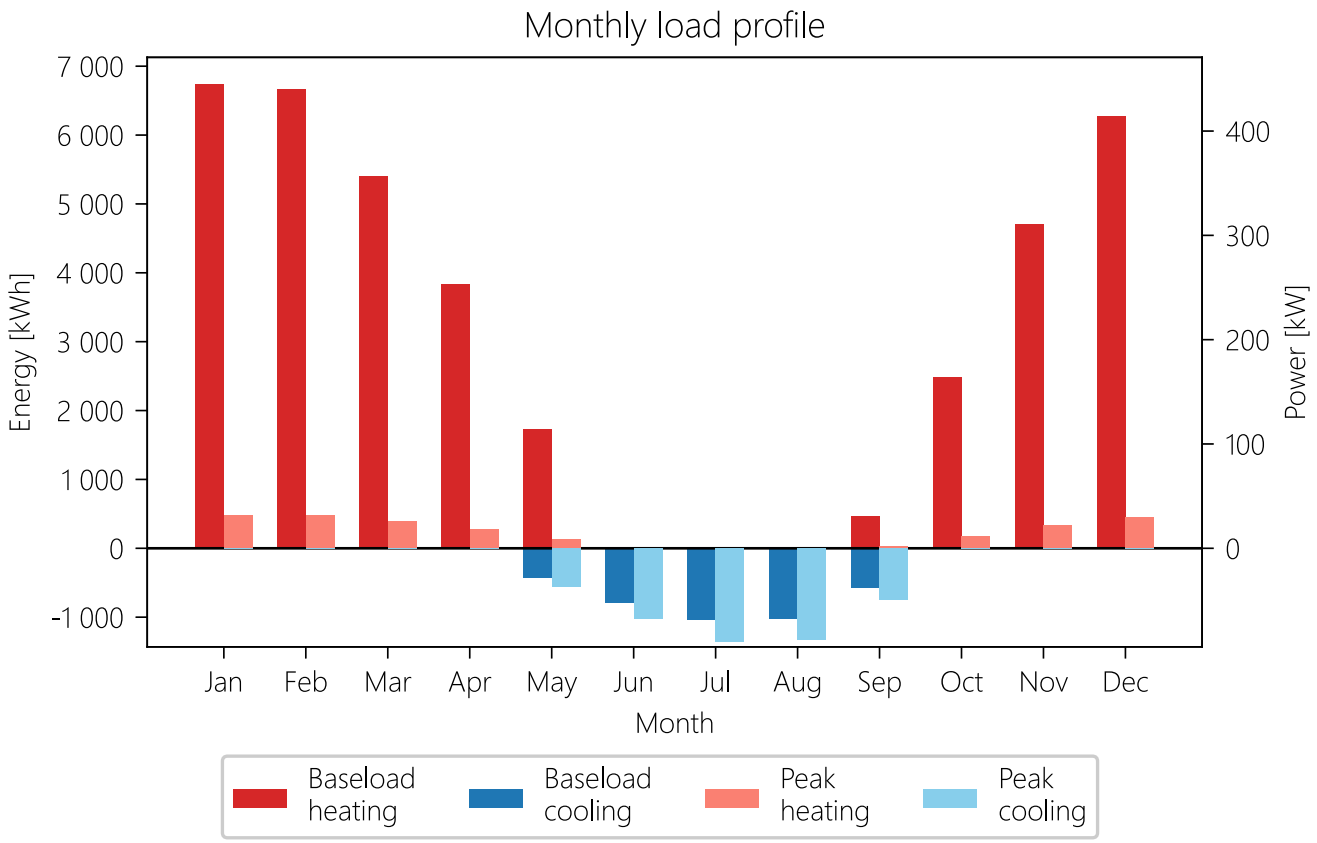
### Load data

For the simulation, a building load was used. This means that, in order to calculate the resulting extraction and injection loads for the ground, the efficiency of the heat pump will be taken into account. Below you can find a summary of the load.

| Building demand | Yearly load | Peak power |
|---|---|---|
| Heating demand | 38 292 kWh/y | 32,0 kW |
| Cooling demand | 3 860 kWh/y | 90,0 kW |

The monthly distribution is given in the table below.

| Month | Baseload heating [kWh] | Baseload cooling [kWh] | Peak heating [kW] | Peak cooling [kW] |
|---|---|---|---|---|
| January | 6 739 | 0 | 32,0 | 0,0 |
| February | 6 663 | 0 | 31,7 | 0,0 |
| March | 5 399 | 0 | 25,7 | 0,0 |
| April | 3 829 | 0 | 18,1 | 0,0 |
| May | 1 723 | 432 | 8,4 | 37,4 |
| June | 0 | 791 | 0,0 | 68,0 |
| July | 0 | 1 042 | 0,0 | 90,0 |
| August | 0 | 1 019 | 0,0 | 87,8 |
| September | 460 | 575 | 2,1 | 49,4 |
| October | 2 489 | 0 | 11,8 | 0,0 |
| November | 4 710 | 0 | 22,3 | 0,0 |
| December | 6 280 | 0 | 29,9 | 0,0 |




The peak duration during heating is 8 hours, and for cooling it is 8 hours. The peak duration is defined as the longest runtime of the maximum heating/cooling power in a year. This value is typically higher with slow emission systems (such as floor heating or concrete core activation) and lower for fast emission systems (such as air-based systems).

### 4.3.2 Results

#### Ground load

Because we are working with building loads (i.e. secondary loads), these must be converted into injection and extraction loads using the efficiency data. A summary of the resulting yearly ground load is given in the table below.

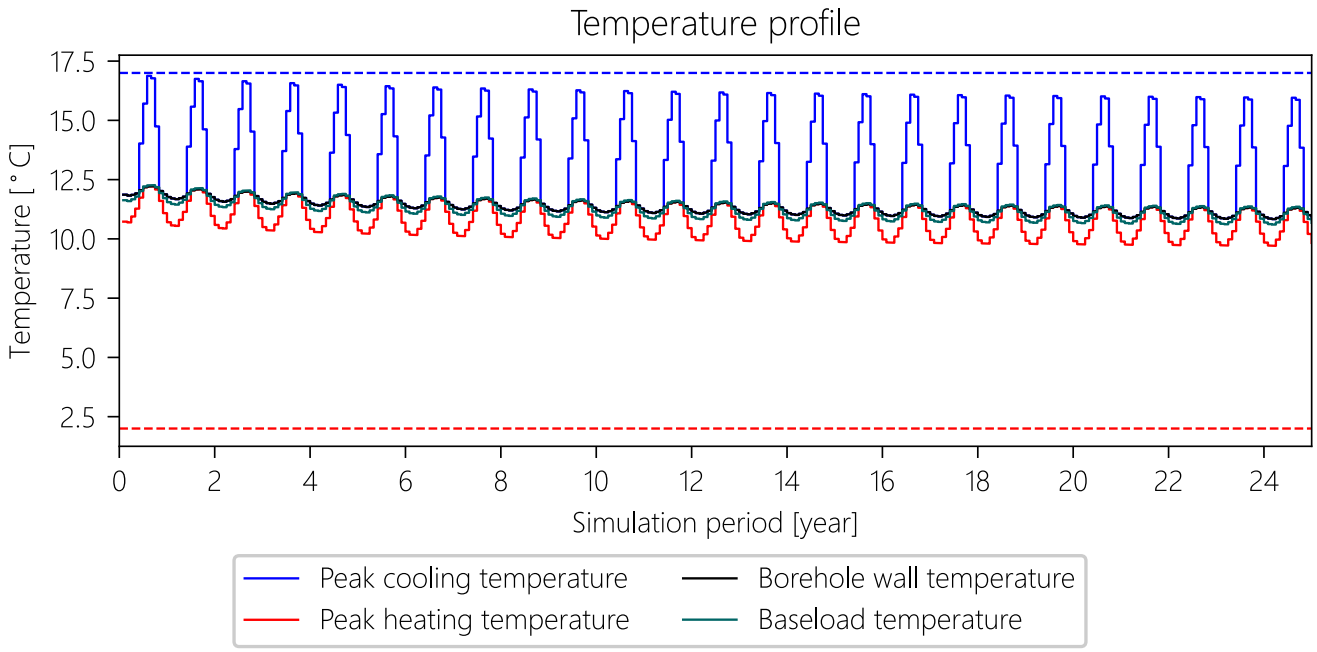
| Ground demand | Yearly load | Peak power |
|---|---|---|
| Extraction demand | 30 634 kWh/y | 25,6 kW |
| Injection demand | 4 053 kWh/y | 94,5 kW |

#### Temperature evolution of the borefield

Using the pipe, fluid and flow properties, the Reynolds number was calculated to be 694. This is a laminar regime, giving us an effective borehole thermal resistance of 0,1694 m·K/W.
This effective borehole thermal resistance is assumed to remain constant over the simulation period.

Below, the monthly simulation for the borefield is shown. For each month, three lines are displayed. The black line represents the borehole wall temperature, which is the temperature at the interface between the borehole and the ground. The other two lines, red and blue, show the average fluid temperature (between borehole inlet and outlet) during peak heating and peak cooling, respectively.
Since the simulation uses monthly resolution, both heating and cooling peaks can occur in the same month.

Therefore, both fluid temperatures are always shown. The difference between the borehole wall temperature and the average fluid temperature is determined by the effective borehole thermal resistance.




The maximum and minimum average fluid temperature over the whole simulation period at peak power are 16,88 °C and 9,71 °C respectively. The minimum average fluid temperatures during the baseload are respectively 10,60 °C and 12,27 °C.

### Pressure drop

The pressure drop over a single borehole is 18,16 kPa during extration and 18,16 kPa during injection.

## 4.4 Auditorium - hourly

In the first subsection, the scenario-specific input parameters will be discussed. Afterwards, the simulation results are presented.

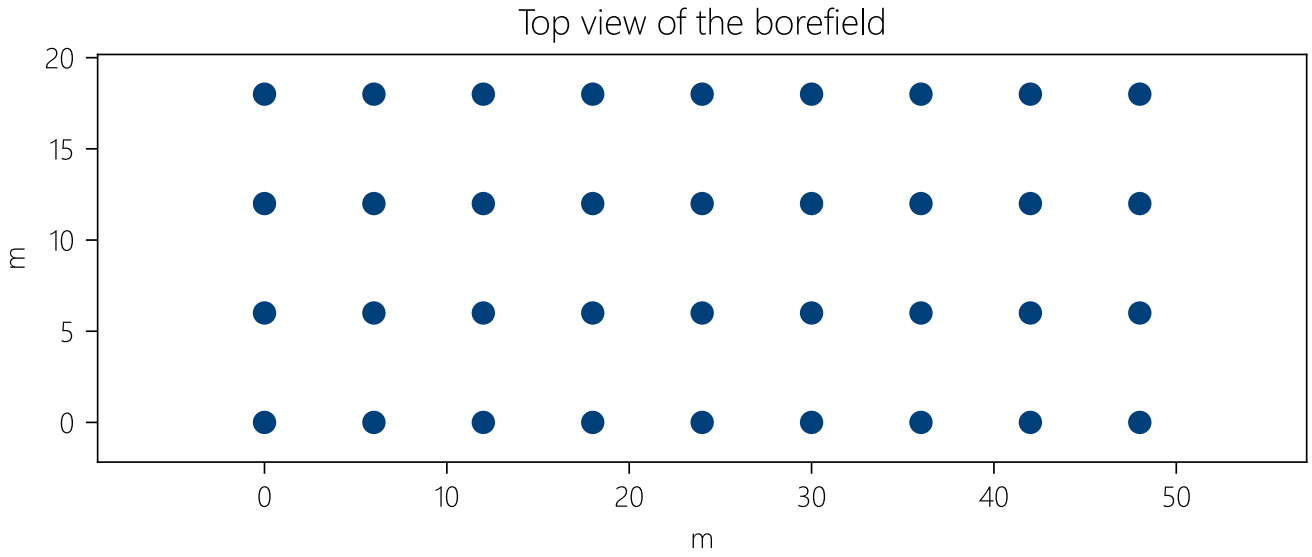
### 4.4.1 Input

#### Borefield configuration

The simulations were carried out with a borefield consisting of 36 boreholes, with an average buried depth of 1,00 m, an average borehole depth of 150,00 m and an average borehole length of 149,00 m. This results in a total borehole length of 5 364,00 m.

The minimum average borehole spacing is 6,00 m. This is defined as the average of the smallest distances between the centres of all pairs of boreholes in the borefield.

(The borehole depth is defined as the vertical distance between the ground surface and the deepest point of the borehole. The buried depth is the distance between the ground surface and the start of the borehole. The borehole length, sometimes called the 'active length' is the actual length of the heat exchanger measured along the borehole.)



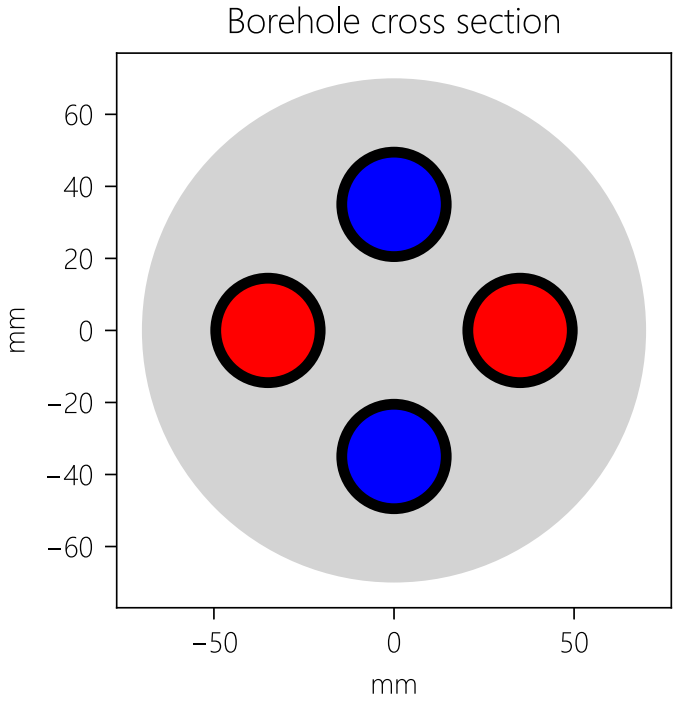
The coordinates of the different boreholes are given in the table below.

| x [m] | y [m] | Length [m] | Depth [m] | Buried depth [m] | Tilt [°] | Orientation [°] |
|---|---|---|---|---|---|---|
| 0,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 48,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

### Pipe data

Inside the borehole with a diameter of 140 mm, 2 DN32 PN16 U-tubes will be installed. The U-tubes have a thermal conductivity of 0,40 W/(m·K), and the pipe legs are positioned at a distance of 35 mm from the borehole center. The borehole will be grouted with a material that has a thermal conductivity of 1,50 W/(m·K).




### Fluid data

As a heat transfer fluid, MPG with 30,0 v/v% was selected, providing frost protection down to approximately -14 °C. The fluid properties were assumed to remain constant throughout the simulation period and were calculated at a reference temperature of 2,00 °C.

The fluid properties can be found in the table below.

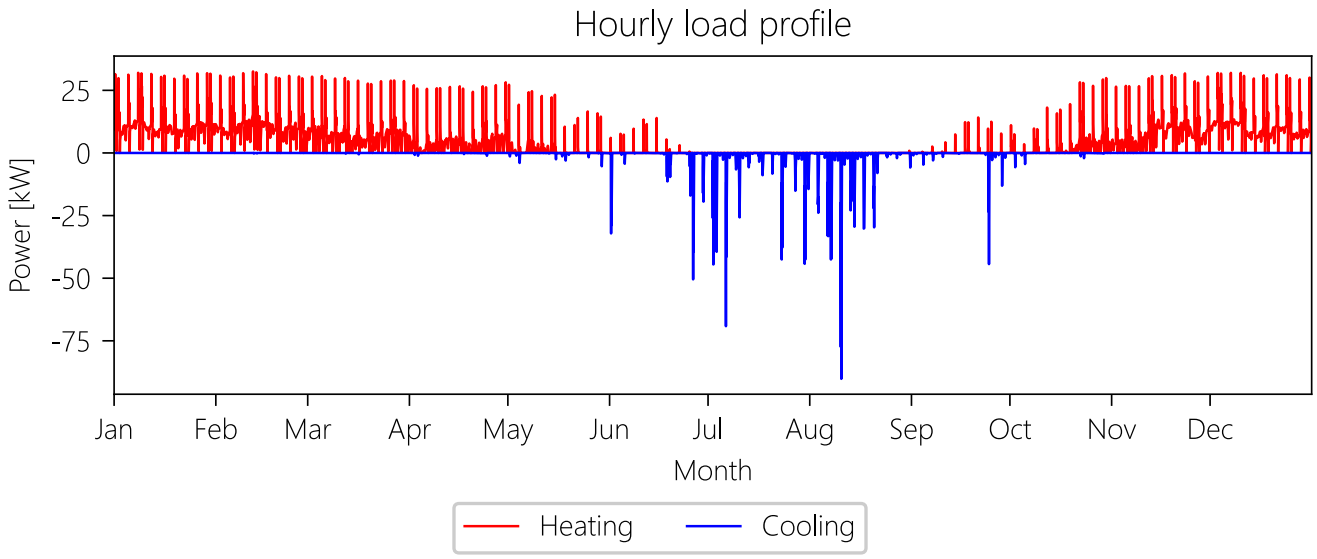
| | |
|---|---|
| Thermal conductivity of the fluid | 0,42 W/(m·K) |
| Thermal capacity of the fluid | 3 781,04 J/(kg·K) |
| Dynamic viscosity | 7,0582 × $10^{-3}$ Pa·s |
| Density of the fluid | 1 032,94 kg/m³ |

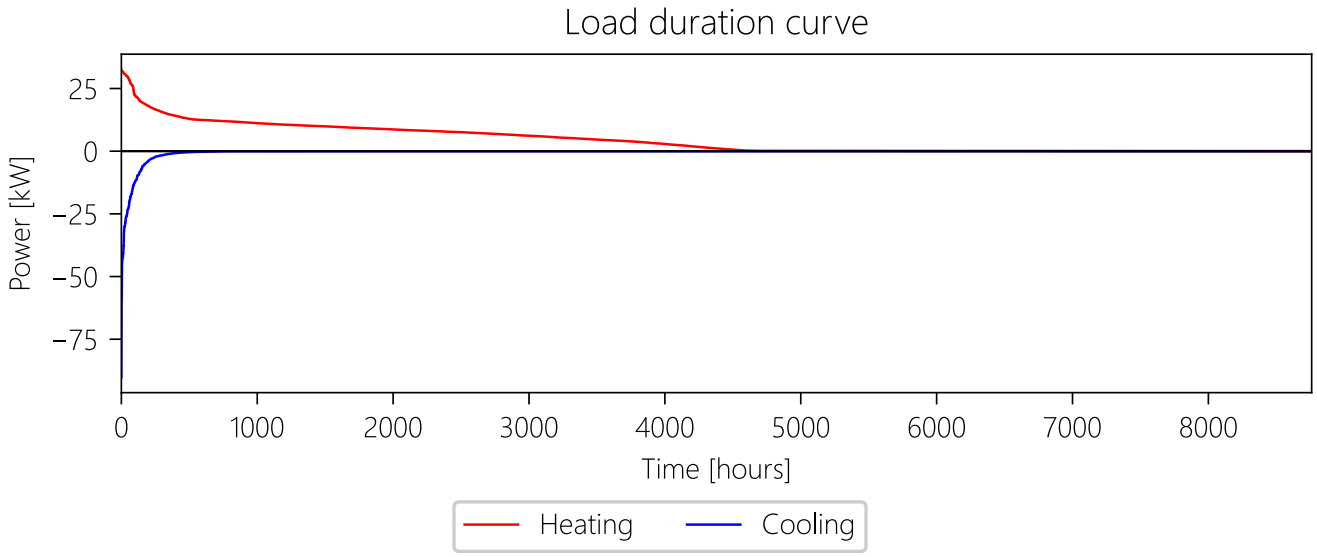
The total flow rate through the borefield is 7,20 kg/s, corresponding to a flow of 0,20 kg/s per borehole in the system.

### Load data

For the simulation, a building load was used. This means that, in order to calculate the resulting extraction and injection loads for the ground, the efficiency of the heat pump will be taken into account. Below you can find a summary of the load.

| Building demand | Yearly load | Peak power |
|---|---|---|
| Heating demand | 38 292 kWh/y | 32,5 kW |
| Cooling demand | 3 859 kWh/y | 90,2 kW |




## 4.4.2 Results

### Ground load

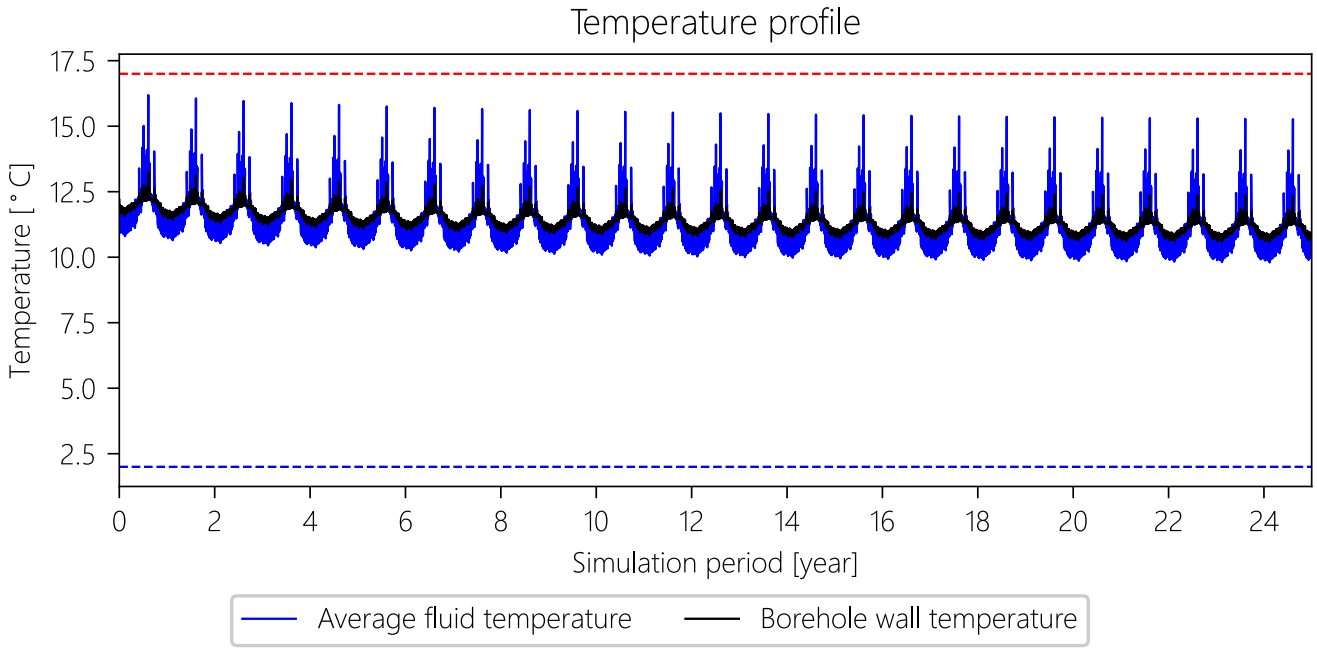
Because we are working with building loads (i.e. secondary loads), these must be converted into injection and extraction loads using the efficiency data. A summary of the resulting yearly ground load is given in the table below.

| Ground demand | Yearly load | Peak power |
|---|---|---|
| Extraction demand | 30 634 kWh/y | 26,0 kW |
| Injection demand | 4 052 kWh/y | 94,7 kW |

### Temperature evolution of the borefield

Using the pipe, fluid and flow properties, the Reynolds number was calculated to be 694. This is a laminar regime, giving us an effective borehole thermal resistance of 0,1694 m·K/W.
This effective borehole thermal resistance is assumed to remain constant over the simulation period.

Below, the hourly simulation for the borefield is shown. The blue line represents the average fluid temperature between the inlet and outlet of the borehole at each hour of the simulation. The black line shows the borehole wall temperature, which is the interface between the borehole and the ground. The difference between both lines is determined by the effective borehole thermal resistance.




The maximum average fluid temperature over the whole simulation period is 16,19 °C, and the minimum average fluid temperature is 9,80 °C.

### Pressure drop

The pressure drop over a single borehole is 18,16 kPa during extration and 18,16 kPa during injection.

## 4.5 Auditorium - hourly (smaller borefield)

In the first subsection, the scenario-specific input parameters will be discussed. Afterwards, the simulation results are presented.

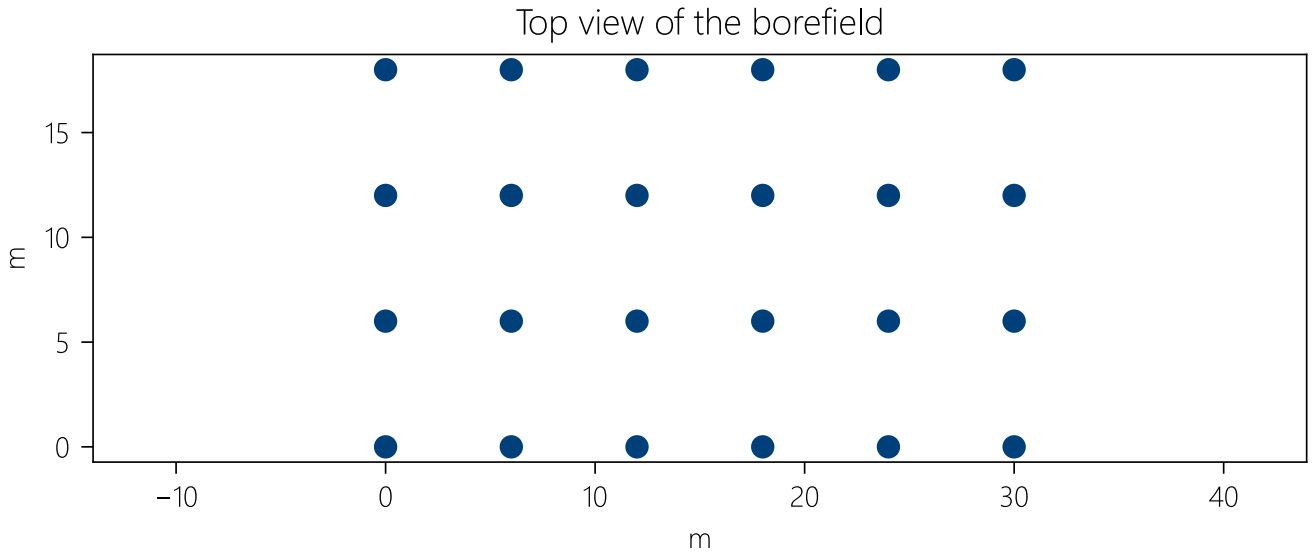
### 4.5.1 Input

#### Borefield configuration

The simulations were carried out with a borefield consisting of 24 boreholes, with an average buried depth of 1,00 m, an average borehole depth of 150,00 m and an average borehole length of 149,00 m. This results in a total borehole length of 3 576,00 m.

The minimum average borehole spacing is 6,00 m. This is defined as the average of the smallest distances between the centres of all pairs of boreholes in the borefield.

(The borehole depth is defined as the vertical distance between the ground surface and the deepest point of the borehole. The buried depth is the distance between the ground surface and the start of the borehole. The borehole length, sometimes called the 'active length' is the actual length of the heat exchanger measured along the borehole.)

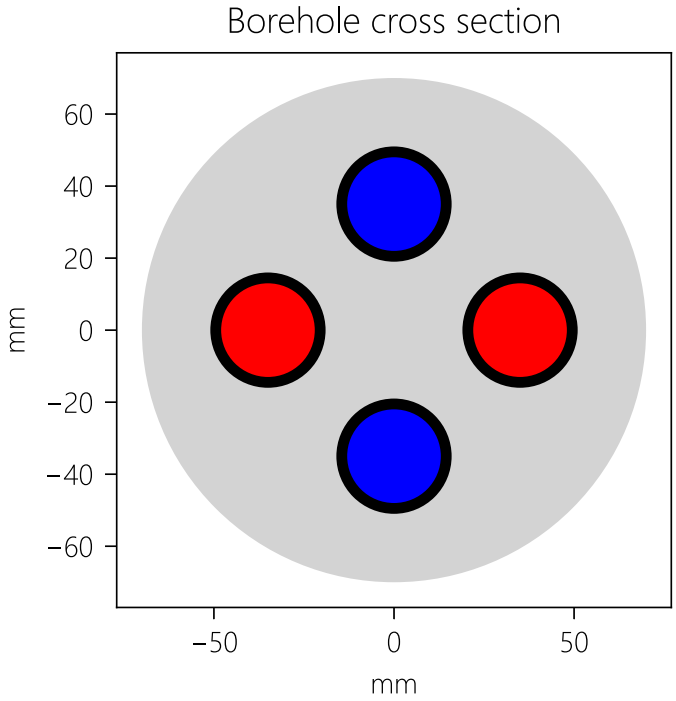


The coordinates of the different boreholes are given in the table below.

| x [m] | y [m] | Length [m] | Depth [m] | Buried depth [m] | Tilt [°] | Orientation [°] |
|---|---|---|---|---|---|---|
| 0,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

### Pipe data

Inside the borehole with a diameter of 140 mm, 2 DN32 PN16 U-tubes will be installed. The U-tubes have a thermal conductivity of 0,40 W/(m·K), and the pipe legs are positioned at a distance of 35 mm from the borehole center. The borehole will be grouted with a material that has a thermal conductivity of 1,50 W/(m·K).




### Fluid data

As a heat transfer fluid, MPG with 30,0 v/v% was selected, providing frost protection down to approximately -14 °C. The fluid properties were assumed to remain constant throughout the simulation period and were calculated at a reference temperature of 2,00 °C.

The fluid properties can be found in the table below.

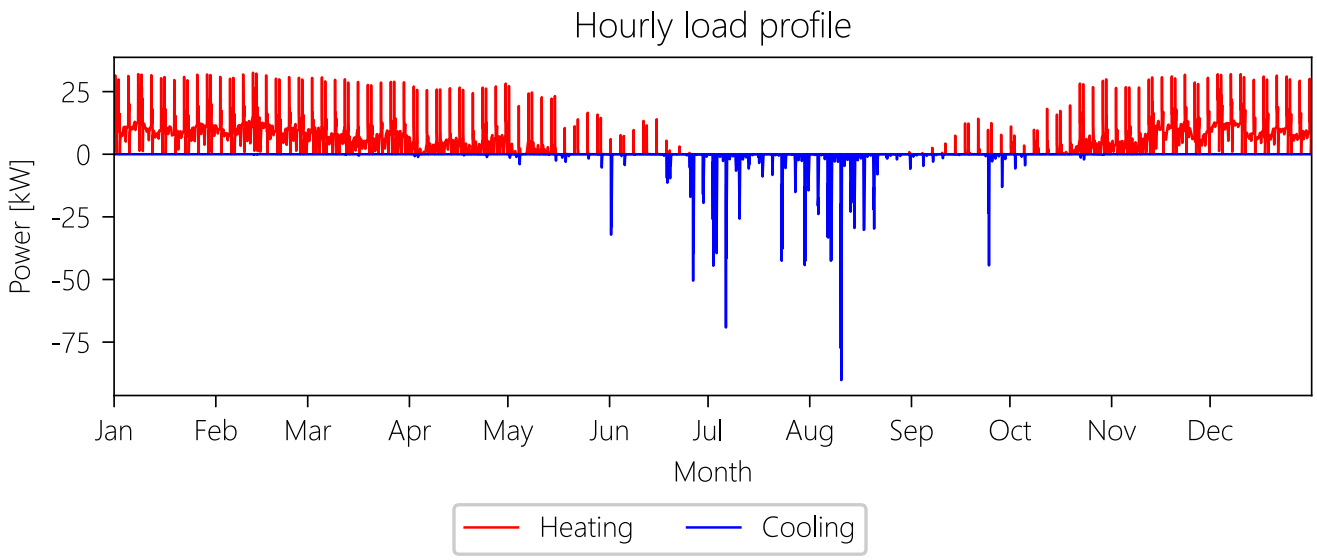
| | |
|---|---|
| Thermal conductivity of the fluid | 0,42 W/(m·K) |
| Thermal capacity of the fluid | 3 781,04 J/(kg·K) |
| Dynamic viscosity | 7,0582 × $10^{-3}$ Pa·s |
| Density of the fluid | 1 032,94 kg/m³ |

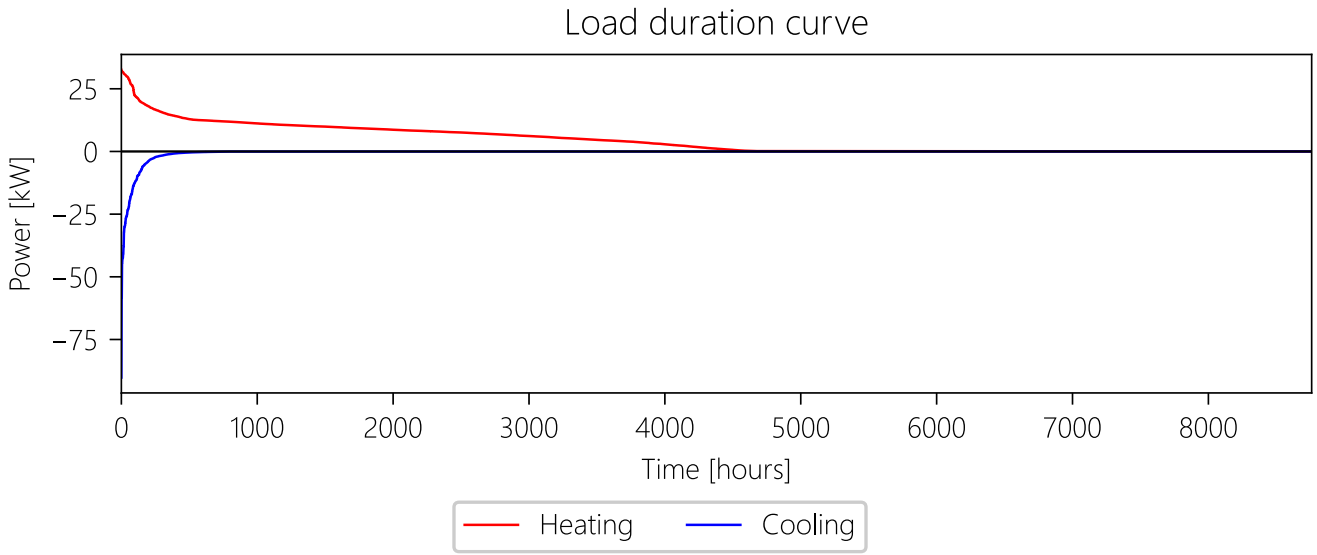
The total flow rate through the borefield is 7,20 kg/s, corresponding to a flow of 0,30 kg/s per borehole in the system.

### Load data

For the simulation, a building load was used. This means that, in order to calculate the resulting extraction and injection loads for the ground, the efficiency of the heat pump will be taken into account. Below you can find a summary of the load.

| Building demand | Yearly load | Peak power |
|---|---|---|
| Heating demand | 38 292 kWh/y | 32,5 kW |
| Cooling demand | 3 859 kWh/y | 90,2 kW |




## 4.5.2 Results

### Ground load

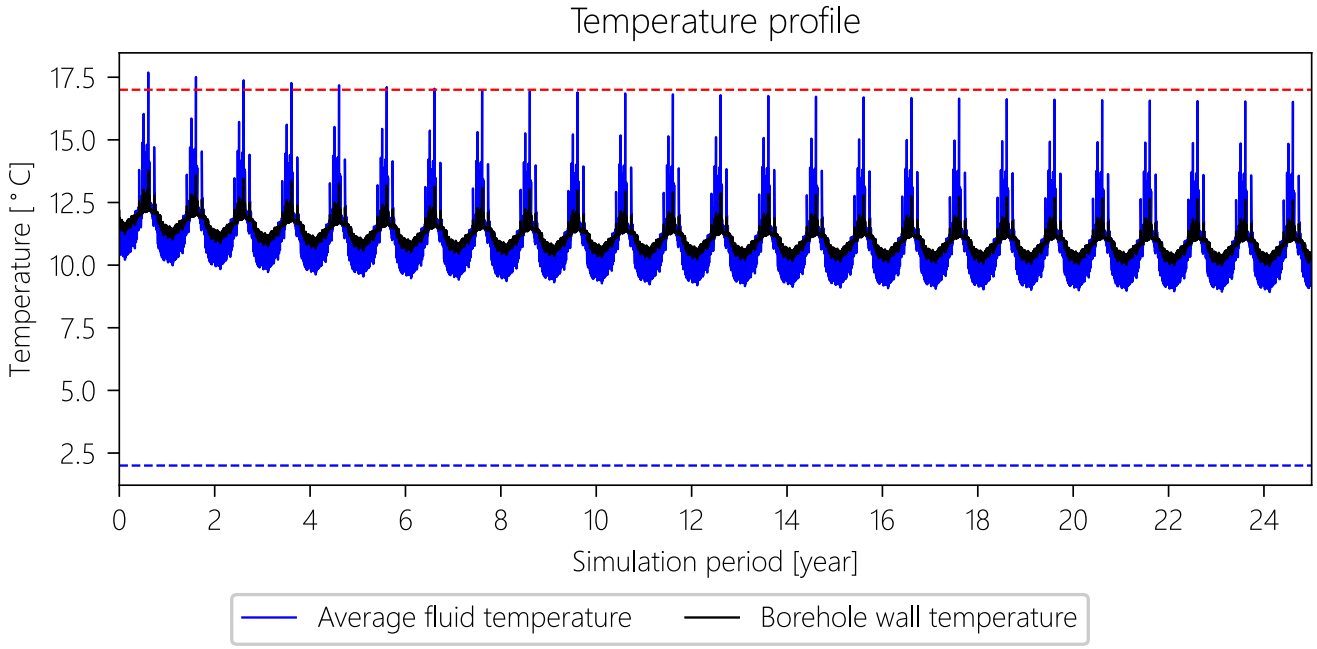
Because we are working with building loads (i.e. secondary loads), these must be converted into injection and extraction loads using the efficiency data. A summary of the resulting yearly ground load is given in the table below.

| Ground demand | Yearly load | Peak power |
|---|---|---|
| Extraction demand | 30 634 kWh/y | 26,0 kW |
| Injection demand | 4 052 kWh/y | 94,7 kW |

### Temperature evolution of the borefield

Using the pipe, fluid and flow properties, the Reynolds number was calculated to be 1 041. This is a laminar regime, giving us an effective borehole thermal resistance of 0,1514 m·K/W.
This effective borehole thermal resistance is assumed to remain constant over the simulation period.

Below, the hourly simulation for the borefield is shown. The blue line represents the average fluid temperature between the inlet and outlet of the borehole at each hour of the simulation. The black line shows the borehole wall temperature, which is the interface between the borehole and the ground. The difference between both lines is determined by the effective borehole thermal resistance.




The maximum average fluid temperature over the whole simulation period is 17,69 °C, and the minimum average fluid temperature is 8,92 °C.

### Pressure drop

The pressure drop over a single borehole is 27,24 kPa during extration and 27,24 kPa during injection.

## 4.6 Residential - monthly (answer)

In the first subsection, the scenario-specific input parameters will be discussed. Afterwards, the simulation results are presented.

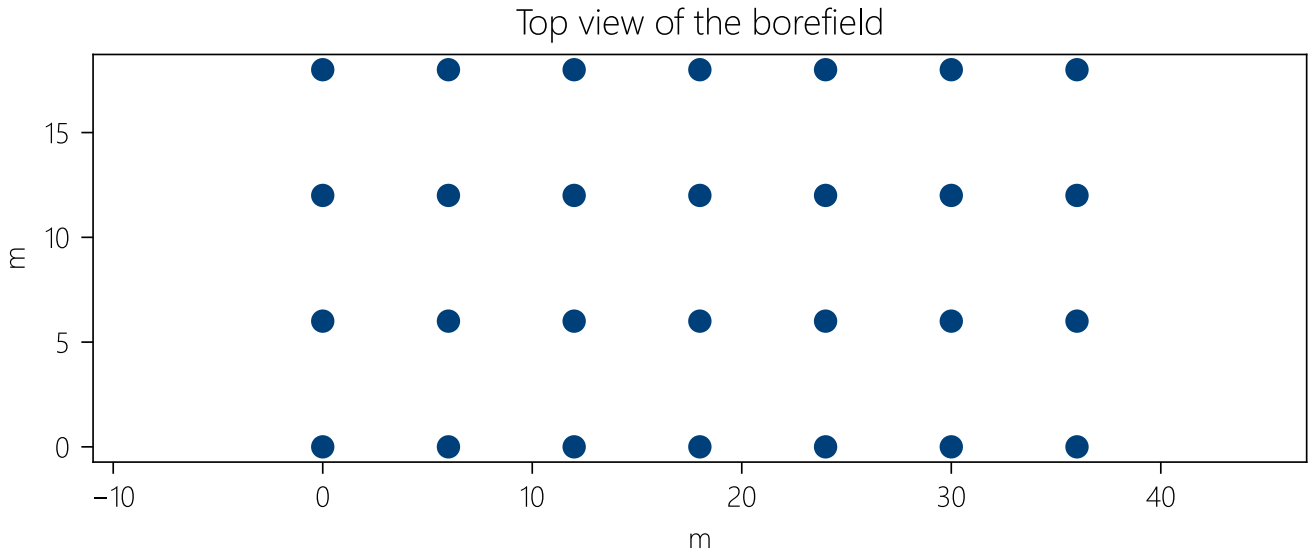
### 4.6.1 Input

#### Borefield configuration

The simulations were carried out with a borefield consisting of 28 boreholes, with an average buried depth of 1,00 m, an average borehole depth of 150,00 m and an average borehole length of 149,00 m. This results in a total borehole length of 4 172,00 m.

The minimum average borehole spacing is 6,00 m. This is defined as the average of the smallest distances between the centres of all pairs of boreholes in the borefield.

(The borehole depth is defined as the vertical distance between the ground surface and the deepest point of the borehole. The buried depth is the distance between the ground surface and the start of the borehole. The borehole length, sometimes called the 'active length' is the actual length of the heat exchanger measured along the borehole.)

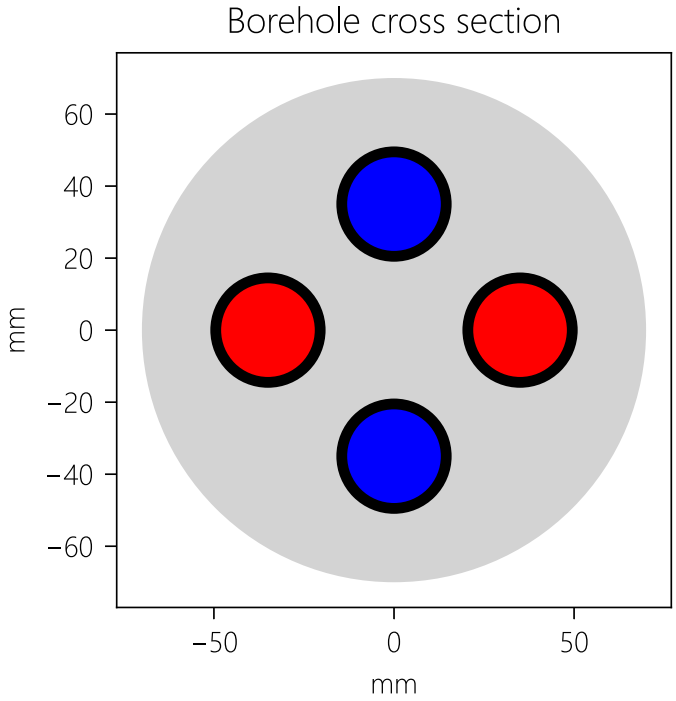


The coordinates of the different boreholes are given in the table below.

| x [m] | y [m] | Length [m] | Depth [m] | Buried depth [m] | Tilt [°] | Orientation [°] |
|---|---|---|---|---|---|---|
| 0,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

## Pipe data

Inside the borehole with a diameter of 140 mm, 2 DN32 PN16 U-tubes will be installed. The U-tubes have a thermal conductivity of 0,40 W/(m·K), and the pipe legs are positioned at a distance of 35 mm from the borehole center. The borehole will be grouted with a material that has a thermal conductivity of 1,50 W/(m·K).




### Fluid data

As a heat transfer fluid, MPG with 30,0 v/v% was selected, providing frost protection down to approximately -14 °C. The fluid properties were assumed to remain constant throughout the simulation period and were calculated at a reference temperature of 2,00 °C.

The fluid properties can be found in the table below.

| | |
|---|---|
| Thermal conductivity of the fluid | 0,42 W/(m·K) |
| Thermal capacity of the fluid | 3 781,04 J/(kg·K) |
| Dynamic viscosity | 7,0582 × $10^{-3}$ Pa·s |
| Density of the fluid | 1 032,94 kg/m³ |

The total flow rate through the borefield is 5,60 kg/s, corresponding to a flow of 0,20 kg/s per borehole in the system.

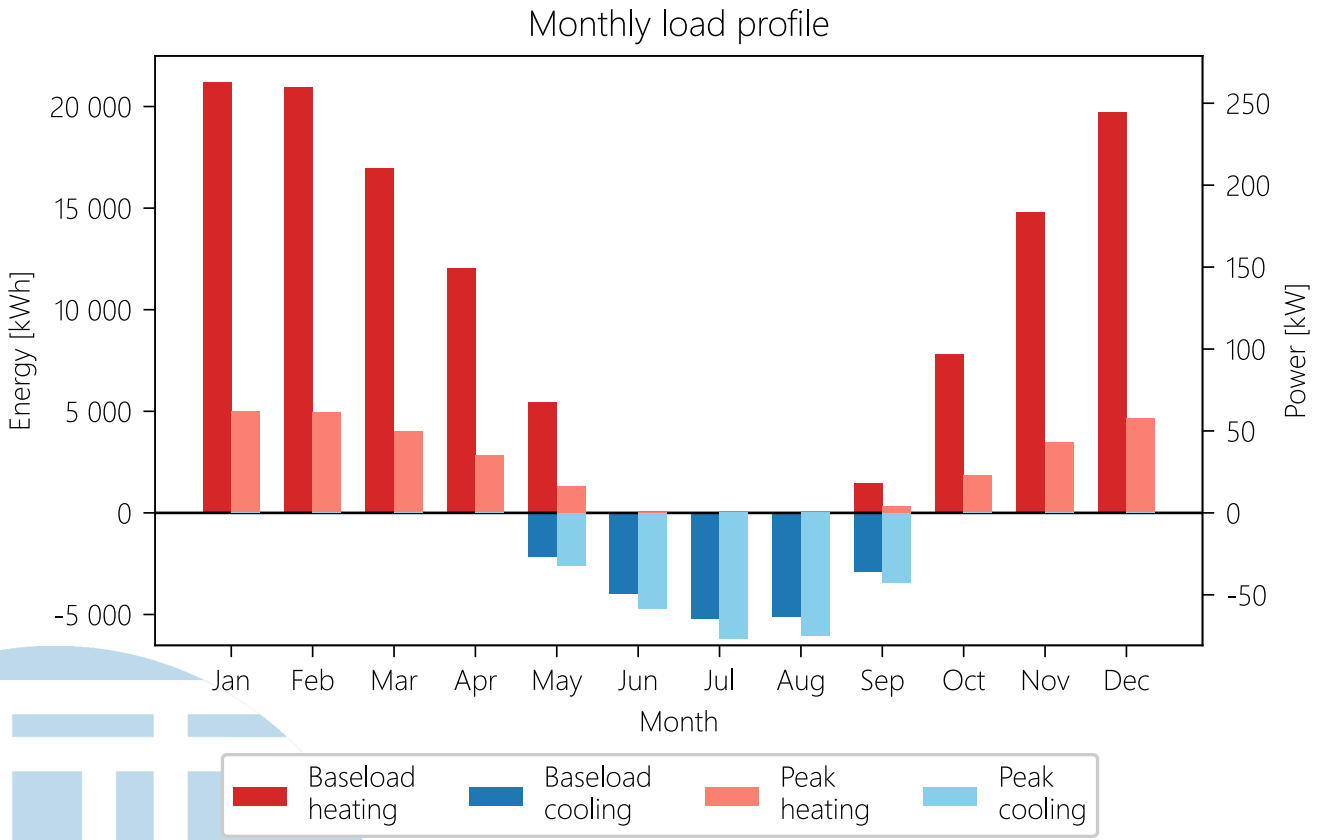
### Load data

For the simulation, a building load was used. This means that, in order to calculate the resulting extraction and injection loads for the ground, the efficiency of the heat pump will be taken into account. Below you can find a summary of the load.

| Building demand | Yearly load | Peak power |
|---|---|---|
| Heating demand | 120 310 kWh/y | 62,0 kW |
| Domestic hot water demand | 60 000 kWh/y | - |
| Cooling demand | 19 266 kWh/y | 77,0 kW |

The monthly distribution is given in the table below.

| Month | Baseload heating [kWh] | Baseload cooling [kWh] | Peak heating [kW] | Peak cooling [kW] |
|---|---|---|---|---|
| January | 21 175 | 0 | 62,0 | 0,0 |
| February | 20 934 | 0 | 61,4 | 0,0 |
| March | 16 964 | 0 | 49,7 | 0,0 |
| April | 12 031 | 0 | 35,1 | 0,0 |
| May | 5 414 | 2 158 | 16,4 | 32,0 |
| June | 0 | 3 950 | 0,0 | 58,2 |
| July | 0 | 5 202 | 0,0 | 77,0 |
| August | 0 | 5 086 | 0,0 | 75,2 |
| September | 1 444 | 2 871 | 4,1 | 42,3 |
| October | 7 820 | 0 | 22,8 | 0,0 |
| November | 14 798 | 0 | 43,3 | 0,0 |
| December | 19 731 | 0 | 57,9 | 0,0 |




The peak duration during heating is 115 hours, and for cooling it is 4 hours. The peak duration is defined as the longest runtime of the maximum heating/cooling power in a year. This value is typically higher with slow

emission systems (such as floor heating or concrete core activation) and lower for fast emission systems (such as air-based systems).

## 4.6.2 Results

### Ground load

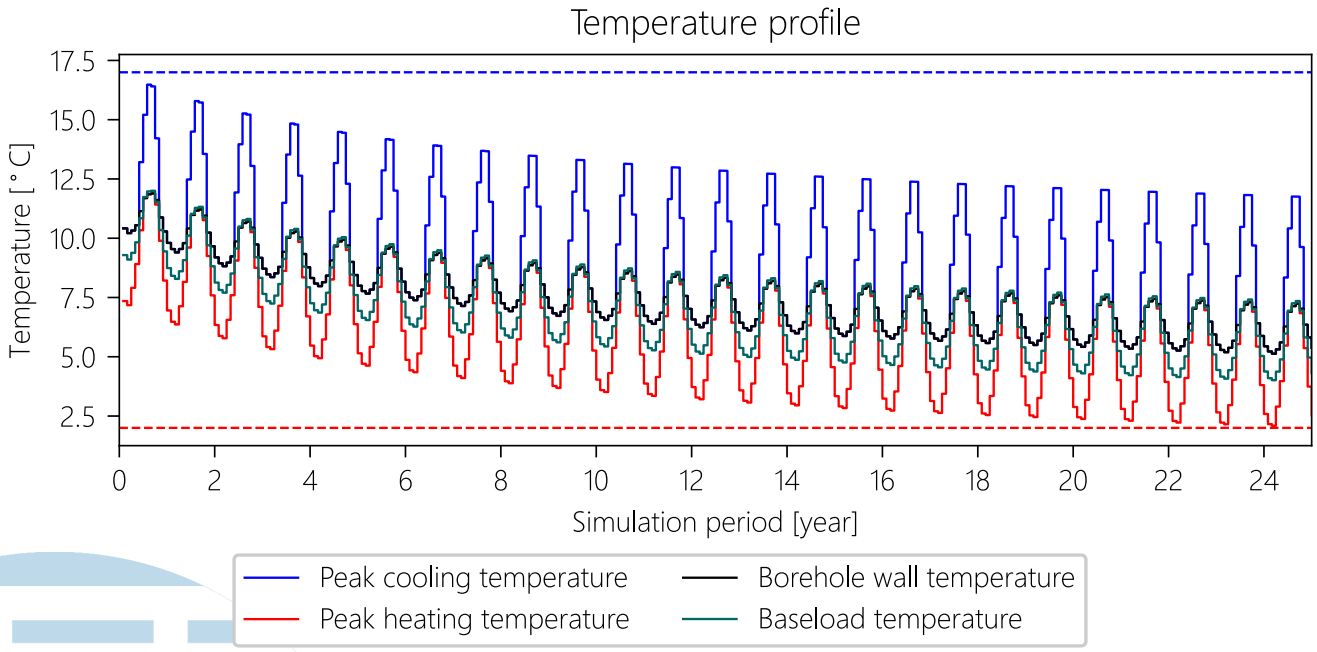
Because we are working with building loads (i.e. secondary loads), these must be converted into injection and extraction loads using the efficiency data. A summary of the resulting yearly ground load is given in the table below.

| Ground demand | Yearly load | Peak power |
|---|---|---|
| Extraction demand | 136 248 kWh/y | 49,6 kW |
| Injection demand | 20 229 kWh/y | 80,8 kW |

### Temperature evolution of the borefield

Using the pipe, fluid and flow properties, the Reynolds number was calculated to be 694. This is a laminar regime, giving us an effective borehole thermal resistance of 0,1694 m·K/W.
This effective borehole thermal resistance is assumed to remain constant over the simulation period.

Below, the monthly simulation for the borefield is shown. For each month, three lines are displayed. The black line represents the borehole wall temperature, which is the temperature at the interface between the borehole and the ground. The other two lines, red and blue, show the average fluid temperature (between borehole inlet and outlet) during peak heating and peak cooling, respectively.
Since the simulation uses monthly resolution, both heating and cooling peaks can occur in the same month. Therefore, both fluid temperatures are always shown. The difference between the borehole wall temperature and the average fluid temperature is determined by the effective borehole thermal resistance.




The maximum and minimum average fluid temperature over the whole simulation period at peak power are 16,48 °C and 2,09 °C respectively. The minimum average fluid temperatures during the baseload are respectively 4,01 °C and 12,00 °C.

### Pressure drop

The pressure drop over a single borehole is 18,16 kPa during extration and 18,16 kPa during injection.

## 4.7 Auditorium - monthly (answer)

In the first subsection, the scenario-specific input parameters will be discussed. Afterwards, the simulation results are presented.

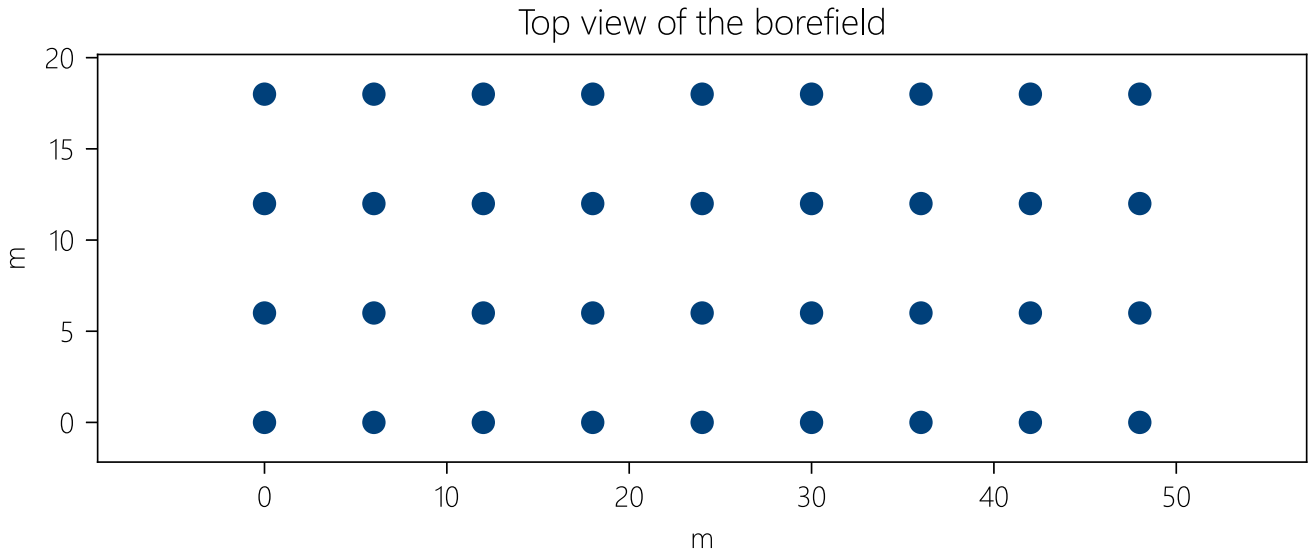
### 4.7.1 Input

#### Borefield configuration

The simulations were carried out with a borefield consisting of 36 boreholes, with an average buried depth of 1,00 m, an average borehole depth of 150,00 m and an average borehole length of 149,00 m. This results in a total borehole length of 5 364,00 m.

The minimum average borehole spacing is 6,00 m. This is defined as the average of the smallest distances between the centres of all pairs of boreholes in the borefield.

(The borehole depth is defined as the vertical distance between the ground surface and the deepest point of the borehole. The buried depth is the distance between the ground surface and the start of the borehole. The borehole length, sometimes called the 'active length' is the actual length of the heat exchanger measured along the borehole.)



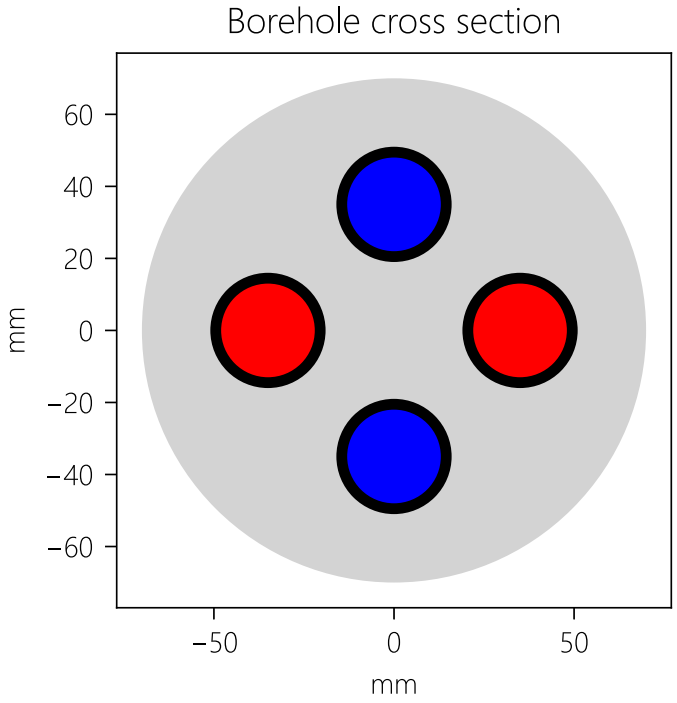
The coordinates of the different boreholes are given in the table below.

| x [m] | y [m] | Length [m] | Depth [m] | Buried depth [m] | Tilt [°] | Orientation [°] |
|---|---|---|---|---|---|---|
| 0,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 48,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

### Pipe data

Inside the borehole with a diameter of 140 mm, 2 DN32 PN16 U-tubes will be installed. The U-tubes have a thermal conductivity of 0,40 W/(m·K), and the pipe legs are positioned at a distance of 35 mm from the borehole center. The borehole will be grouted with a material that has a thermal conductivity of 1,50 W/(m·K).




### Fluid data

As a heat transfer fluid, MPG with 30,0 v/v% was selected, providing frost protection down to approximately -14 °C. The fluid properties were assumed to remain constant throughout the simulation period and were calculated at a reference temperature of 2,00 °C.

The fluid properties can be found in the table below.

| | |
|---|---|
| Thermal conductivity of the fluid | 0,42 W/(m·K) |
| Thermal capacity of the fluid | 3 781,04 J/(kg·K) |
| Dynamic viscosity | 7,0582 × $10^{-3}$ Pa·s |
| Density of the fluid | 1 032,94 kg/m³ |

The total flow rate through the borefield is 7,20 kg/s, corresponding to a flow of 0,20 kg/s per borehole in the system.

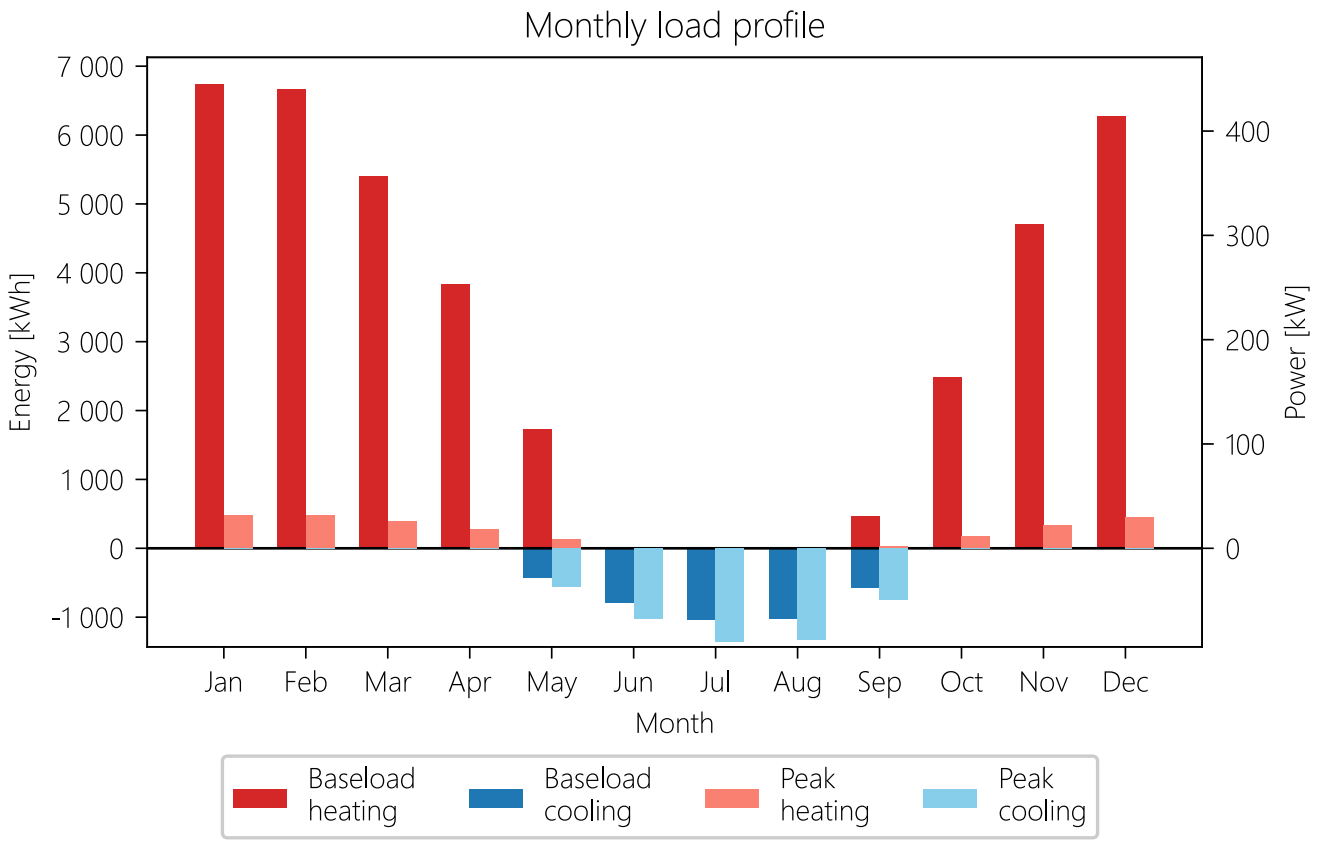
### Load data

For the simulation, a building load was used. This means that, in order to calculate the resulting extraction and injection loads for the ground, the efficiency of the heat pump will be taken into account. Below you can find a summary of the load.

| Building demand | Yearly load | Peak power |
|---|---|---|
| Heating demand | 38 292 kWh/y | 32,0 kW |
| Cooling demand | 3 860 kWh/y | 90,0 kW |

The monthly distribution is given in the table below.

| Month | Baseload heating [kWh] | Baseload cooling [kWh] | Peak heating [kW] | Peak cooling [kW] |
|---|---|---|---|---|
| January | 6 739 | 0 | 32,0 | 0,0 |
| February | 6 663 | 0 | 31,7 | 0,0 |
| March | 5 399 | 0 | 25,7 | 0,0 |
| April | 3 829 | 0 | 18,1 | 0,0 |
| May | 1 723 | 432 | 8,4 | 37,4 |
| June | 0 | 791 | 0,0 | 68,0 |
| July | 0 | 1 042 | 0,0 | 90,0 |
| August | 0 | 1 019 | 0,0 | 87,8 |
| September | 460 | 575 | 2,1 | 49,4 |
| October | 2 489 | 0 | 11,8 | 0,0 |
| November | 4 710 | 0 | 22,3 | 0,0 |
| December | 6 280 | 0 | 29,9 | 0,0 |




The peak duration during heating is 5 hours, and for cooling it is 3 hours. The peak duration is defined as the longest runtime of the maximum heating/cooling power in a year. This value is typically higher with slow emission systems (such as floor heating or concrete core activation) and lower for fast emission systems (such as air-based systems).

## 4.7.2 Results

### Ground load

Because we are working with building loads (i.e. secondary loads), these must be converted into injection and extraction loads using the efficiency data. A summary of the resulting yearly ground load is given in the table below.

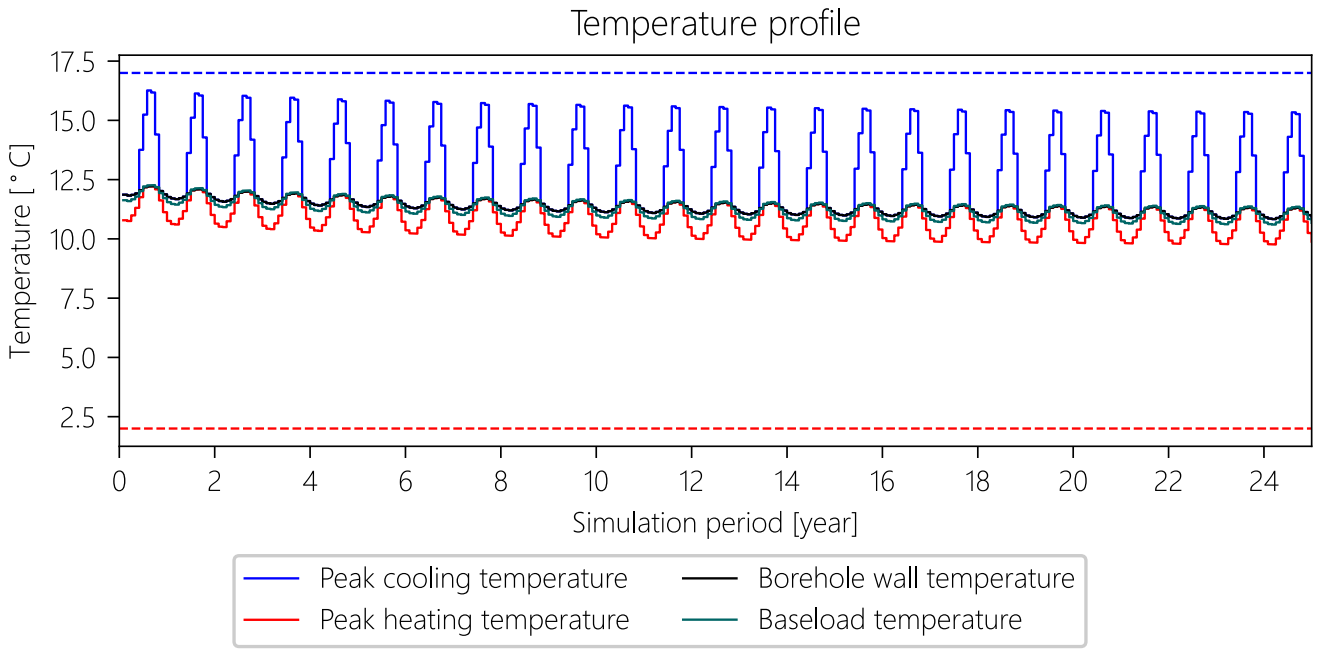
| Ground demand | Yearly load | Peak power |
|---|---|---|
| Extraction demand | 30 634 kWh/y | 25,6 kW |
| Injection demand | 4 053 kWh/y | 94,5 kW |

### Temperature evolution of the borefield

Using the pipe, fluid and flow properties, the Reynolds number was calculated to be 694. This is a laminar regime, giving us an effective borehole thermal resistance of 0,1694 m·K/W.
This effective borehole thermal resistance is assumed to remain constant over the simulation period.

Below, the monthly simulation for the borefield is shown. For each month, three lines are displayed. The black line represents the borehole wall temperature, which is the temperature at the interface between the borehole and the ground. The other two lines, red and blue, show the average fluid temperature (between borehole inlet and outlet) during peak heating and peak cooling, respectively.
Since the simulation uses monthly resolution, both heating and cooling peaks can occur in the same month.

Therefore, both fluid temperatures are always shown. The difference between the borehole wall temperature and the average fluid temperature is determined by the effective borehole thermal resistance.




The maximum and minimum average fluid temperature over the whole simulation period at peak power are 16,26 °C and 9,76 °C respectively. The minimum average fluid temperatures during the baseload are respectively 10,60 °C and 12,27 °C.

### Pressure drop

The pressure drop over a single borehole is 18,16 kPa during extration and 18,16 kPa during injection.

## 4.8 Residential - monthly (answers 2.1)

In the first subsection, the scenario-specific input parameters will be discussed. Afterwards, the simulation results are presented.

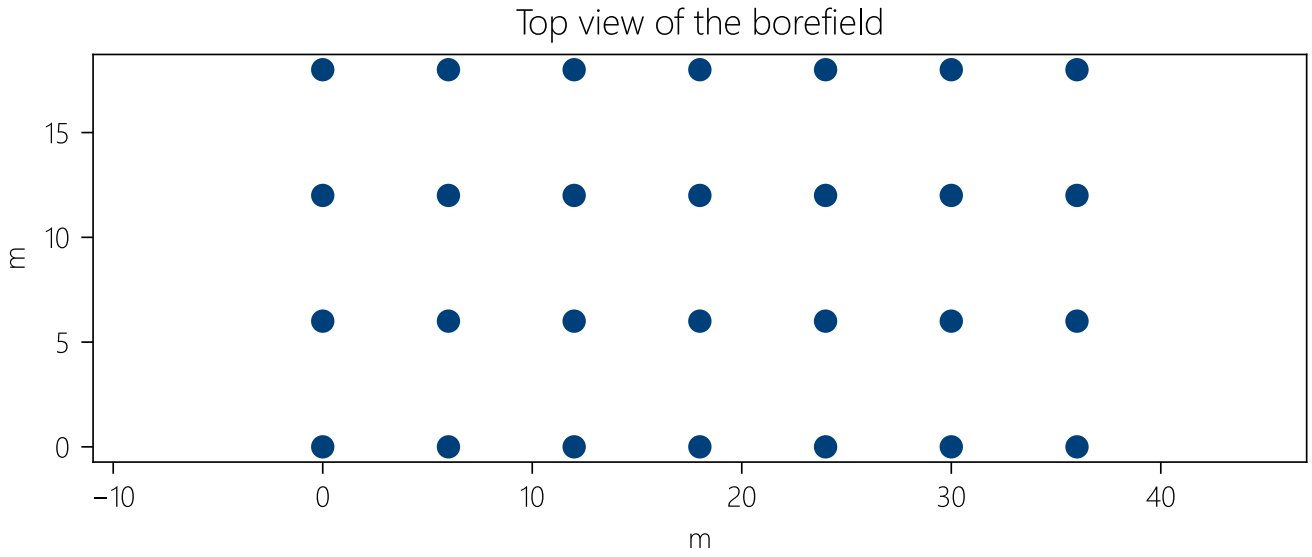
### 4.8.1 Input

#### Borefield configuration

The simulations were carried out with a borefield consisting of 28 boreholes, with an average buried depth of 1,00 m, an average borehole depth of 150,00 m and an average borehole length of 149,00 m. This results in a total borehole length of 4 172,00 m.

The minimum average borehole spacing is 6,00 m. This is defined as the average of the smallest distances between the centres of all pairs of boreholes in the borefield.

(The borehole depth is defined as the vertical distance between the ground surface and the deepest point of the borehole. The buried depth is the distance between the ground surface and the start of the borehole. The borehole length, sometimes called the 'active length' is the actual length of the heat exchanger measured along the borehole.)

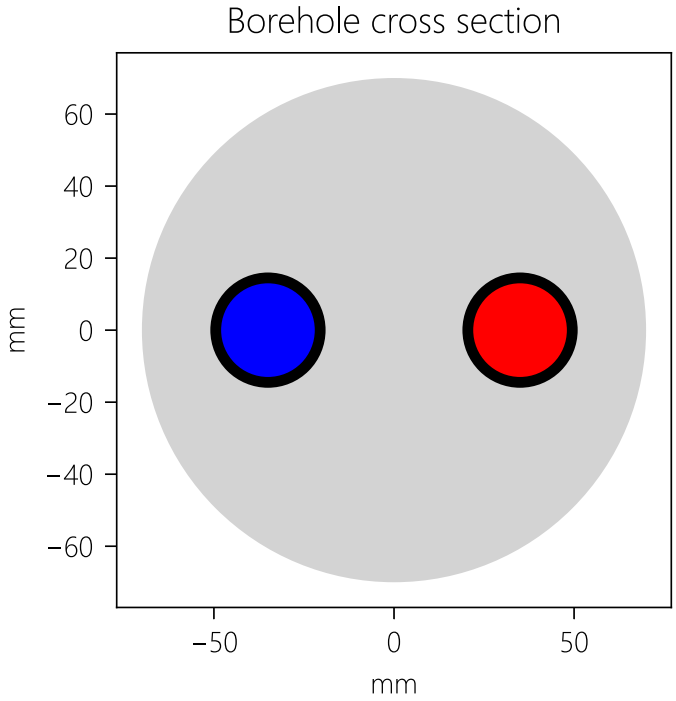


The coordinates of the different boreholes are given in the table below.

| x [m] | y [m] | Length [m] | Depth [m] | Buried depth [m] | Tilt [°] | Orientation [°] |
|---|---|---|---|---|---|---|
| 0,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

### Pipe data

Inside the borehole with a diameter of 140 mm, a single U-tube DN32 PN16 is installed. The borehole will be grouted with a material that has a thermal conductivity of 1,50 W/(m·K).




### Fluid data

As a heat transfer fluid, MPG with 21,0 v/v% was selected, which provides frost protection down to approximately -8 °C. For a more accurate simulation, the fluid properties (such as viscosity and density) are assumed to be temperature-dependent and therefore vary throughout the simulation period. This is particularly important for buildings with a high cooling demand, since heat transfer during heat injection (i.e., cooling) is more efficient than during extraction (i.e., heating). To account for this, no single fixed value should be used for the fluid properties.

The total flow rate through the borefield is 5,60 kg/s, corresponding to a flow of 0,20 kg/s per borehole in the system.

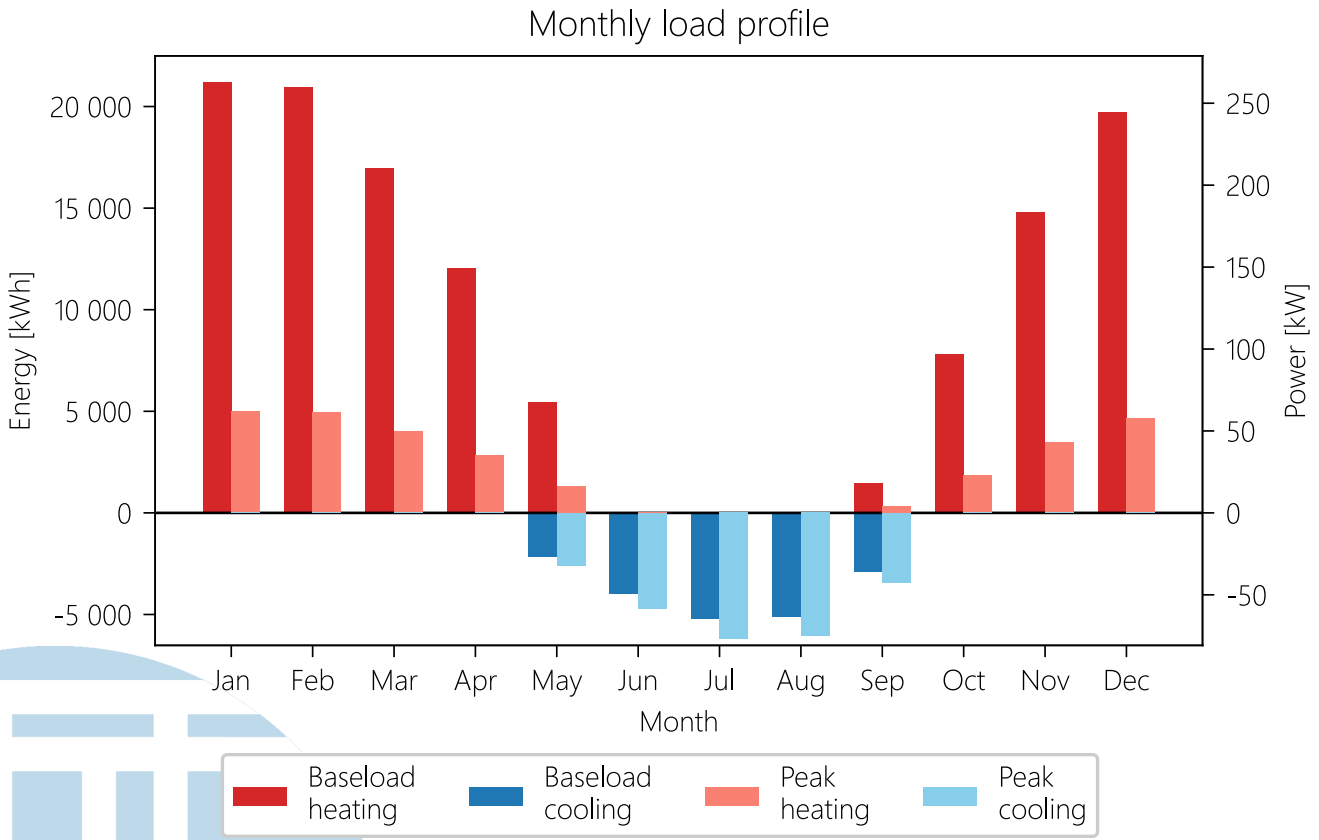
### Load data

For the simulation, a building load was used. This means that, in order to calculate the resulting extraction and injection loads for the ground, the efficiency of the heat pump will be taken into account. Below you can find a summary of the load.

| Building demand | Yearly load | Peak power |
|---|---|---|
| Heating demand | 120 310 kWh/y | 62,0 kW |
| Domestic hot water demand | 60 000 kWh/y | - |
| Cooling demand | 19 266 kWh/y | 77,0 kW |

The monthly distribution is given in the table below.

| Month | Baseload heating [kWh] | Baseload cooling [kWh] | Peak heating [kW] | Peak cooling [kW] |
|---|---|---|---|---|
| January | 21 175 | 0 | 62,0 | 0,0 |
| February | 20 934 | 0 | 61,4 | 0,0 |
| March | 16 964 | 0 | 49,7 | 0,0 |
| April | 12 031 | 0 | 35,1 | 0,0 |
| May | 5 414 | 2 158 | 16,4 | 32,0 |
| June | 0 | 3 950 | 0,0 | 58,2 |
| July | 0 | 5 202 | 0,0 | 77,0 |
| August | 0 | 5 086 | 0,0 | 75,2 |
| September | 1 444 | 2 871 | 4,1 | 42,3 |
| October | 7 820 | 0 | 22,8 | 0,0 |
| November | 14 798 | 0 | 43,3 | 0,0 |
| December | 19 731 | 0 | 57,9 | 0,0 |




The peak duration during heating is 8 hours, and for cooling it is 8 hours. The peak duration is defined as the longest runtime of the maximum heating/cooling power in a year. This value is typically higher with slow

emission systems (such as floor heating or concrete core activation) and lower for fast emission systems (such as air-based systems).

## 4.8.2 Results

### Ground load

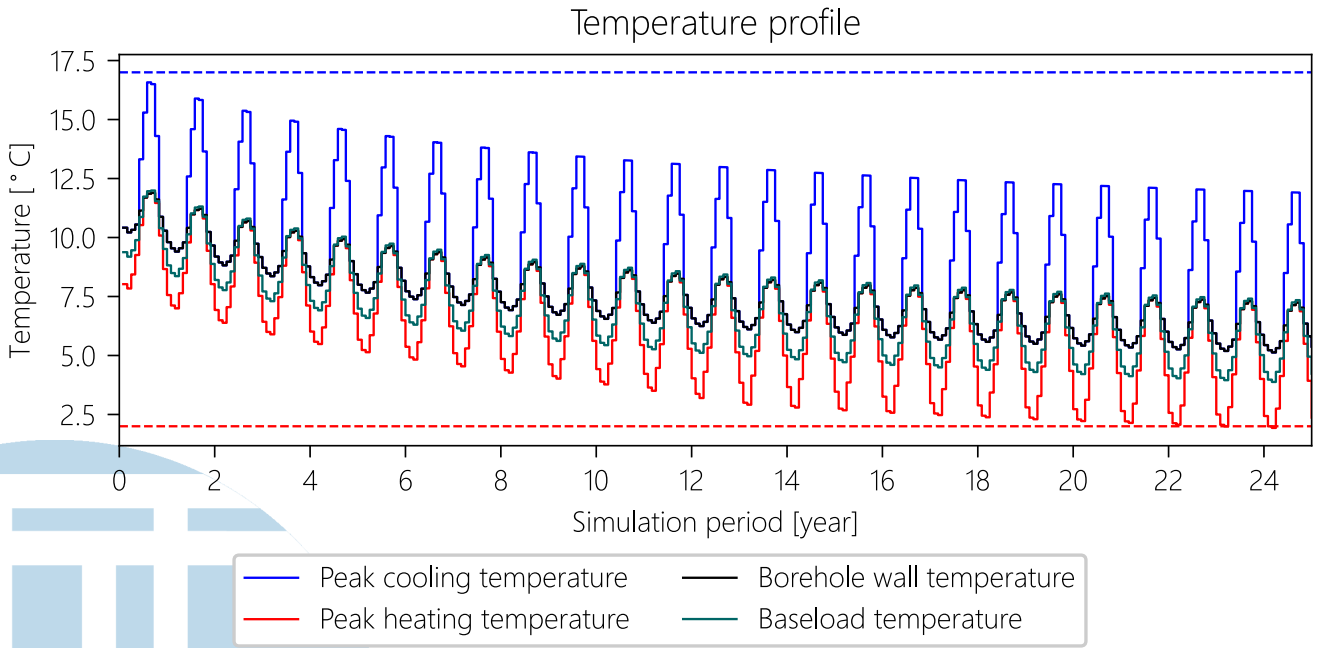
Because we are working with building loads (i.e. secondary loads), these must be converted into injection and extraction loads using the efficiency data. A summary of the resulting yearly ground load is given in the table below.

| Ground demand | Yearly load | Peak power |
|---|---|---|
| Extraction demand | 136 248 kWh/y | 49,6 kW |
| Injection demand | 20 229 kWh/y | 80,8 kW |

### Temperature evolution of the borefield

Using the pipe, fluid, and flow properties, the Reynolds number was calculated. Since this number depends on the fluid temperature and therefore varies over the simulation period, it was updated at every timestep to achieve the most accurate result possible.
Doing so, the Reynolds number during heat extraction was 2 197, whilst it was 3 919 during injection. This corresponds respectively to a laminar and transient flow regime, with an effective borehole thermal resistance of 0,2287 m·K/W and 0,1500 m·K/W during heat extraction and injection.

Below, the monthly simulation for the borefield is shown. For each month, three lines are displayed. The black line represents the borehole wall temperature, which is the temperature at the interface between the borehole and the ground. The other two lines, red and blue, show the average fluid temperature (between borehole inlet and outlet) during peak heating and peak cooling, respectively.
Since the simulation uses monthly resolution, both heating and cooling peaks can occur in the same month. Therefore, both fluid temperatures are always shown. The difference between the borehole wall temperature and the average fluid temperature is determined by the effective borehole thermal resistance.




The maximum and minimum average fluid temperature over the whole simulation period at peak power are 16,58 °C and 1,93 °C respectively. The minimum average fluid temperatures during the baseload are

respectively 3,88 °C and 11,99 °C.

### Pressure drop

The pressure drop over a single borehole is 23,18 kPa during extration and 32,11 kPa during injection.

## 5.1 Design Data - Residential - monthly

### Design parameters

- Maximum average fluid temperature: 17,00 °C
- Minimum average fluid temperature: 2,00 °C
- First month of simulation: 1
- Simulation period: 25 years

### Ground parameters

- Homogeneous ground conductivity: 2,00 W/(m·K)
- Homogeneous volumetric heat capacity: 2,40 MJ/(m$^3$·K)
- Ground surface temperature: 9,60 °C
- Ground flux: 0,07000 W/m$^2$

### Borehole parameters

- Borehole diameter: 140,00 mm

#### Pipe parameters

- U tube DN32 PN16
- Grout thermal conductivity: 1,50 W/(m·K)
- Number of U-tubes: 2
- Pipe conductivity: 0,40 W/(m·K)
- Pipe roughness: 0,00100 mm

#### Fluid properties

- 30.0 v/v% MPG @ 2.00 °C
- Thermal conductivity of the fluid: 0,42 W/(m·K)
- Thermal capacity of the fluid: 3 781,04 J/(kg·K)
- Density of the fluid: 1 032,94 kg/m$^3$
- Dynamic viscosity: 0,00706 Pa·s
- Mass flow rate per borefield: 5,60 kg/s
- Number of boreholes in series: 1

## Thermal demand

| Baseload heating [kWh] | Baseload cooling [kWh] | Peak heating [kW] | Peak cooling [kW] |
|---|---|---|---|
| 21 174,56 | 0,00 | 62,00 | 0,00 |
| 20 933,94 | 0,00 | 61,44 | 0,00 |
| 16 963,71 | 0,00 | 49,72 | 0,00 |
| 12 031,00 | 0,00 | 35,09 | 0,00 |
| 5 413,95 | 2 157,79 | 16,37 | 31,96 |
| 0,00 | 3 949,53 | 0,00 | 58,21 |
| 0,00 | 5 201,82 | 0,00 | 77,00 |
| 0,00 | 5 086,22 | 0,00 | 75,15 |
| 1 443,72 | 2 870,63 | 4,09 | 42,27 |
| 7 820,15 | 0,00 | 22,82 | 0,00 |
| 14 798,13 | 0,00 | 43,28 | 0,00 |
| 19 730,84 | 0,00 | 57,91 | 0,00 |

- Domestic hot water: 60 000,00 kWh/year
- SCOP heating: 5,00
- SCOP domestic hot water: 3,00
- SEER cooling: 20,00
- Peak heating duration: 8,00 hours
- Peak cooling duration: 8,00 hours

## Borefield parameters

| x [m] | y [m] | Length [m] | Depth [m] | Buried depth [m] | Tilt [°] | Orientation [°] |
|---|---|---|---|---|---|---|
| 0,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 18,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

## 5.2 Design Data - Residential - hourly

### Design parameters

- Maximum average fluid temperature: 17,00 °C
- Minimum average fluid temperature: 2,00 °C
- First month of simulation: 1
- Simulation period: 25 years

### Ground parameters

- Homogeneous ground conductivity: 2,00 W/(m·K)
- Homogeneous volumetric heat capacity: 2,40 MJ/(m$^3$·K)
- Ground surface temperature: 9,60 °C
- Ground flux: 0,07000 W/m$^2$

### Borehole parameters

- Borehole diameter: 140,00 mm

#### Pipe parameters

- U tube DN32 PN16
- Grout thermal conductivity: 1,50 W/(m·K)
- Number of U-tubes: 2
- Pipe conductivity: 0,40 W/(m·K)
- Pipe roughness: 0,00100 mm

#### Fluid properties

- 30.0 v/v% MPG @ 2.00 °C
- Thermal conductivity of the fluid: 0,42 W/(m·K)
- Thermal capacity of the fluid: 3 781,04 J/(kg·K)
- Density of the fluid: 1 032,94 kg/m$^3$
- Dynamic viscosity: 0,00706 Pa·s
- Mass flow rate per borefield: 5,60 kg/s
- Number of boreholes in series: 1

### Thermal demand

- Type of load: Hourly building load
- Domestic hot water: 60 000,00 kWh/year
- SCOP heating: 5,00
- SCOP domestic hot water: 3,00
- SEER cooling: 20,00

### Borefield parameters

| x [m] | y [m] | Length [m] | Depth [m] | Buried depth [m] | Tilt [°] | Orientation [°] |
|---|---|---|---|---|---|---|
| 0,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

## 5.3 Design Data - Auditorium - monthly

### Design parameters

- Maximum average fluid temperature: 17,00 °C
- Minimum average fluid temperature: 2,00 °C
- First month of simulation: 1
- Simulation period: 25 years

### Ground parameters

- Homogeneous ground conductivity: 2,00 W/(m·K)
- Homogeneous volumetric heat capacity: 2,40 MJ/(m$^3$·K)
- Ground surface temperature: 9,60 °C
- Ground flux: 0,07000 W/m$^2$

### Borehole parameters

- Borehole diameter: 140,00 mm

#### Pipe parameters

- U tube DN32 PN16
- Grout thermal conductivity: 1,50 W/(m·K)
- Number of U-tubes: 2
- Pipe conductivity: 0,40 W/(m·K)
- Pipe roughness: 0,00100 mm

#### Fluid properties

- 30.0 v/v% MPG @ 2.00 °C
- Thermal conductivity of the fluid: 0,42 W/(m·K)
- Thermal capacity of the fluid: 3 781,04 J/(kg·K)
- Density of the fluid: 1 032,94 kg/m$^3$
- Dynamic viscosity: 0,00706 Pa·s
- Mass flow rate per borefield: 7,20 kg/s
- Number of boreholes in series: 1

## Thermal demand

| Baseload heating [kWh] | Baseload cooling [kWh] | Peak heating [kW] | Peak cooling [kW] |
|---|---|---|---|
| 6 739,39 | 0,00 | 32,00 | 0,00 |
| 6 662,81 | 0,00 | 31,71 | 0,00 |
| 5 399,17 | 0,00 | 25,66 | 0,00 |
| 3 829,20 | 0,00 | 18,11 | 0,00 |
| 1 723,14 | 432,32 | 8,45 | 37,35 |
| 0,00 | 791,30 | 0,00 | 68,04 |
| 0,00 | 1 042,20 | 0,00 | 90,00 |
| 0,00 | 1 019,04 | 0,00 | 87,84 |
| 459,50 | 575,14 | 2,11 | 49,41 |
| 2 488,98 | 0,00 | 11,78 | 0,00 |
| 4 709,92 | 0,00 | 22,34 | 0,00 |
| 6 279,89 | 0,00 | 29,89 | 0,00 |

- SCOP heating: 5,00
- SEER cooling: 20,00
- Peak heating duration: 8,00 hours
- Peak cooling duration: 8,00 hours

## Borefield parameters

| x [m] | y [m] | Length [m] | Depth [m] | Buried depth [m] | Tilt [°] | Orientation [°] |
|---|---|---|---|---|---|---|
| 0,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 24,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

## 5.4 Design Data - Auditorium - hourly

### Design parameters

- Maximum average fluid temperature: 17,00 °C
- Minimum average fluid temperature: 2,00 °C
- First month of simulation: 1
- Simulation period: 25 years

### Ground parameters

- Homogeneous ground conductivity: 2,00 W/(m·K)
- Homogeneous volumetric heat capacity: 2,40 MJ/(m$^3$·K)
- Ground surface temperature: 9,60 °C
- Ground flux: 0,07000 W/m$^2$

### Borehole parameters

- Borehole diameter: 140,00 mm

#### Pipe parameters

- U tube DN32 PN16
- Grout thermal conductivity: 1,50 W/(m·K)
- Number of U-tubes: 2
- Pipe conductivity: 0,40 W/(m·K)
- Pipe roughness: 0,00100 mm

#### Fluid properties

- 30.0 v/v% MPG @ 2.00 °C
- Thermal conductivity of the fluid: 0,42 W/(m·K)
- Thermal capacity of the fluid: 3 781,04 J/(kg·K)
- Density of the fluid: 1 032,94 kg/m$^3$
- Dynamic viscosity: 0,00706 Pa·s
- Mass flow rate per borefield: 7,20 kg/s
- Number of boreholes in series: 1

### Thermal demand

- Type of load: Hourly building load
- SCOP heating: 5,00
- SEER cooling: 20,00

### Borefield parameters

| x [m] | y [m] | Length [m] | Depth [m] | Buried depth [m] | Tilt [°] | Orientation [°] |
|---|---|---|---|---|---|---|
| 0,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

## 5.5 Design Data - Auditorium - hourly (smaller borefield)

### Design parameters

- Maximum average fluid temperature: 17,00 °C
- Minimum average fluid temperature: 2,00 °C
- First month of simulation: 1
- Simulation period: 25 years

### Ground parameters

- Homogeneous ground conductivity: 2,00 W/(m·K)
- Homogeneous volumetric heat capacity: 2,40 MJ/(m$^3$·K)
- Ground surface temperature: 9,60 °C
- Ground flux: 0,07000 W/m$^2$

### Borehole parameters

- Borehole diameter: 140,00 mm

#### Pipe parameters

- U tube DN32 PN16
- Grout thermal conductivity: 1,50 W/(m·K)
- Number of U-tubes: 2
- Pipe conductivity: 0,40 W/(m·K)
- Pipe roughness: 0,00100 mm

#### Fluid properties

- 30.0 v/v% MPG @ 2.00 °C
- Thermal conductivity of the fluid: 0,42 W/(m·K)
- Thermal capacity of the fluid: 3 781,04 J/(kg·K)
- Density of the fluid: 1 032,94 kg/m$^3$
- Dynamic viscosity: 0,00706 Pa·s
- Mass flow rate per borefield: 7,20 kg/s
- Number of boreholes in series: 1

### Thermal demand

- Type of load: Hourly building load
- SCOP heating: 5,00
- SEER cooling: 20,00

### Borefield parameters

| x [m] | y [m] | Length [m] | Depth [m] | Buried depth [m] | Tilt [°] | Orientation [°] |
|---|---|---|---|---|---|---|
| 0,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

## 5.6 Design Data - Residential - monthly (answer)

### Design parameters

- Maximum average fluid temperature: 17,00 °C
- Minimum average fluid temperature: 2,00 °C
- First month of simulation: 1
- Simulation period: 25 years

### Ground parameters

- Homogeneous ground conductivity: 2,00 W/(m·K)
- Homogeneous volumetric heat capacity: 2,40 MJ/(m$^3$·K)
- Ground surface temperature: 9,60 °C
- Ground flux: 0,07000 W/m$^2$

### Borehole parameters

- Borehole diameter: 140,00 mm

#### Pipe parameters

- U tube DN32 PN16
- Grout thermal conductivity: 1,50 W/(m·K)
- Number of U-tubes: 2
- Pipe conductivity: 0,40 W/(m·K)
- Pipe roughness: 0,00100 mm

#### Fluid properties

- 30.0 v/v% MPG @ 2.00 °C
- Thermal conductivity of the fluid: 0,42 W/(m·K)
- Thermal capacity of the fluid: 3 781,04 J/(kg·K)
- Density of the fluid: 1 032,94 kg/m$^3$
- Dynamic viscosity: 0,00706 Pa·s
- Mass flow rate per borefield: 5,60 kg/s
- Number of boreholes in series: 1

## Thermal demand

| Baseload heating [kWh] | Baseload cooling [kWh] | Peak heating [kW] | Peak cooling [kW] |
|---|---|---|---|
| 21 174,56 | 0,00 | 62,00 | 0,00 |
| 20 933,94 | 0,00 | 61,44 | 0,00 |
| 16 963,71 | 0,00 | 49,72 | 0,00 |
| 12 031,00 | 0,00 | 35,09 | 0,00 |
| 5 413,95 | 2 157,79 | 16,37 | 31,96 |
| 0,00 | 3 949,53 | 0,00 | 58,21 |
| 0,00 | 5 201,82 | 0,00 | 77,00 |
| 0,00 | 5 086,22 | 0,00 | 75,15 |
| 1 443,72 | 2 870,63 | 4,09 | 42,27 |
| 7 820,15 | 0,00 | 22,82 | 0,00 |
| 14 798,13 | 0,00 | 43,28 | 0,00 |
| 19 730,84 | 0,00 | 57,91 | 0,00 |

- Domestic hot water: 60 000,00 kWh/year
- SCOP heating: 5,00
- SCOP domestic hot water: 3,00
- SEER cooling: 20,00
- Peak heating duration: 115,00 hours
- Peak cooling duration: 4,00 hours

## Borefield parameters

| x [m] | y [m] | Length [m] | Depth [m] | Buried depth [m] | Tilt [°] | Orientation [°] |
|---|---|---|---|---|---|---|
| 0,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 18,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

## 5.7 Design Data - Auditorium - monthly (answer)

### Design parameters

- Maximum average fluid temperature: 17,00 °C
- Minimum average fluid temperature: 2,00 °C
- First month of simulation: 1
- Simulation period: 25 years

### Ground parameters

- Homogeneous ground conductivity: 2,00 W/(m·K)
- Homogeneous volumetric heat capacity: 2,40 MJ/(m$^3$·K)
- Ground surface temperature: 9,60 °C
- Ground flux: 0,07000 W/m$^2$

### Borehole parameters

- Borehole diameter: 140,00 mm

#### Pipe parameters

- U tube DN32 PN16
- Grout thermal conductivity: 1,50 W/(m·K)
- Number of U-tubes: 2
- Pipe conductivity: 0,40 W/(m·K)
- Pipe roughness: 0,00100 mm

#### Fluid properties

- 30.0 v/v% MPG @ 2.00 °C
- Thermal conductivity of the fluid: 0,42 W/(m·K)
- Thermal capacity of the fluid: 3 781,04 J/(kg·K)
- Density of the fluid: 1 032,94 kg/m$^3$
- Dynamic viscosity: 0,00706 Pa·s
- Mass flow rate per borefield: 7,20 kg/s
- Number of boreholes in series: 1

## Thermal demand

| Baseload heating [kWh] | Baseload cooling [kWh] | Peak heating [kW] | Peak cooling [kW] |
|---|---|---|---|
| 6 739,39 | 0,00 | 32,00 | 0,00 |
| 6 662,81 | 0,00 | 31,71 | 0,00 |
| 5 399,17 | 0,00 | 25,66 | 0,00 |
| 3 829,20 | 0,00 | 18,11 | 0,00 |
| 1 723,14 | 432,32 | 8,45 | 37,35 |
| 0,00 | 791,30 | 0,00 | 68,04 |
| 0,00 | 1 042,20 | 0,00 | 90,00 |
| 0,00 | 1 019,04 | 0,00 | 87,84 |
| 459,50 | 575,14 | 2,11 | 49,41 |
| 2 488,98 | 0,00 | 11,78 | 0,00 |
| 4 709,92 | 0,00 | 22,34 | 0,00 |
| 6 279,89 | 0,00 | 29,89 | 0,00 |

- SCOP heating: 5,00
- SEER cooling: 20,00
- Peak heating duration: 5,00 hours
- Peak cooling duration: 3,00 hours

## Borefield parameters

| x [m] | y [m] | Length [m] | Depth [m] | Buried depth [m] | Tilt [°] | Orientation [°] |
|---|---|---|---|---|---|---|
| 0,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 24,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 42,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 48,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

## 5.8 Design Data - Residential - monthly (answers 2.1)

### Design parameters

- Maximum average fluid temperature: 17,00 °C
- Minimum average fluid temperature: 2,00 °C
- First month of simulation: 1
- Simulation period: 25 years

### Ground parameters

- Homogeneous ground conductivity: 2,00 W/(m·K)
- Homogeneous volumetric heat capacity: 2,40 MJ/($m^3$·K)
- Ground surface temperature: 9,60 °C
- Ground flux: 0,07000 W/$m^2$

### Borehole parameters

- Borehole diameter: 140,00 mm

#### Pipe parameters

- U tube DN32 PN16
- Grout thermal conductivity: 1,50 W/(m·K)
- Number of U-tubes: 1
- Pipe conductivity: 0,40 W/(m·K)
- Pipe roughness: 0,00100 mm

#### Fluid properties

- 21.0 v/v% MPG
- Mass flow rate per borefield: 5,60 kg/s
- Number of boreholes in series: 1

## Thermal demand

| Baseload heating [kWh] | Baseload cooling [kWh] | Peak heating [kW] | Peak cooling [kW] |
|---|---|---|---|
| 21 174,56 | 0,00 | 62,00 | 0,00 |
| 20 933,94 | 0,00 | 61,44 | 0,00 |
| 16 963,71 | 0,00 | 49,72 | 0,00 |
| 12 031,00 | 0,00 | 35,09 | 0,00 |
| 5 413,95 | 2 157,79 | 16,37 | 31,96 |
| 0,00 | 3 949,53 | 0,00 | 58,21 |
| 0,00 | 5 201,82 | 0,00 | 77,00 |
| 0,00 | 5 086,22 | 0,00 | 75,15 |
| 1 443,72 | 2 870,63 | 4,09 | 42,27 |
| 7 820,15 | 0,00 | 22,82 | 0,00 |
| 14 798,13 | 0,00 | 43,28 | 0,00 |
| 19 730,84 | 0,00 | 57,91 | 0,00 |

- Domestic hot water: 60 000,00 kWh/year
- SCOP heating: 5,00
- SCOP domestic hot water: 3,00
- SEER cooling: 20,00
- Peak heating duration: 8,00 hours
- Peak cooling duration: 8,00 hours

## Borefield parameters

| x [m] | y [m] | Length [m] | Depth [m] | Buried depth [m] | Tilt [°] | Orientation [°] |
|---|---|---|---|---|---|---|
| 0,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 0,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 6,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 12,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 18,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 18,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 24,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 30,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 0,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 6,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 12,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |
| 36,00 | 18,00 | 149,00 | 150,00 | 1,00 | 0,00 | 0,00 |

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