GHEtool calculation report

Course 3.4

30/03/26

Licensed report by:

Enead BV

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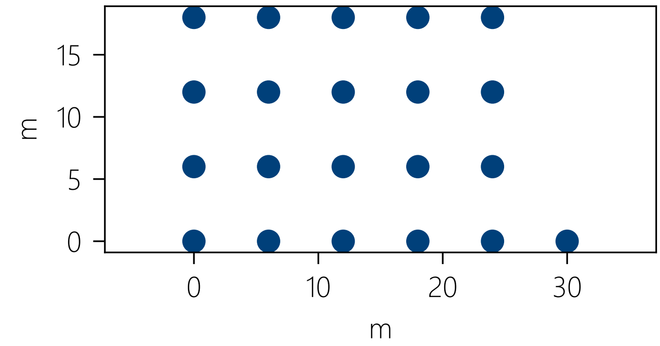
1.1 Structure of the report

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 Scenario 1

Input



Number of boreholes: 21

Average minimum borehole spacing: 6,0 m

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

2 x U tube DN32 PN16

25,0 v/v% MPG

SCOP heating: 3,41; SEER cooling: 20,00

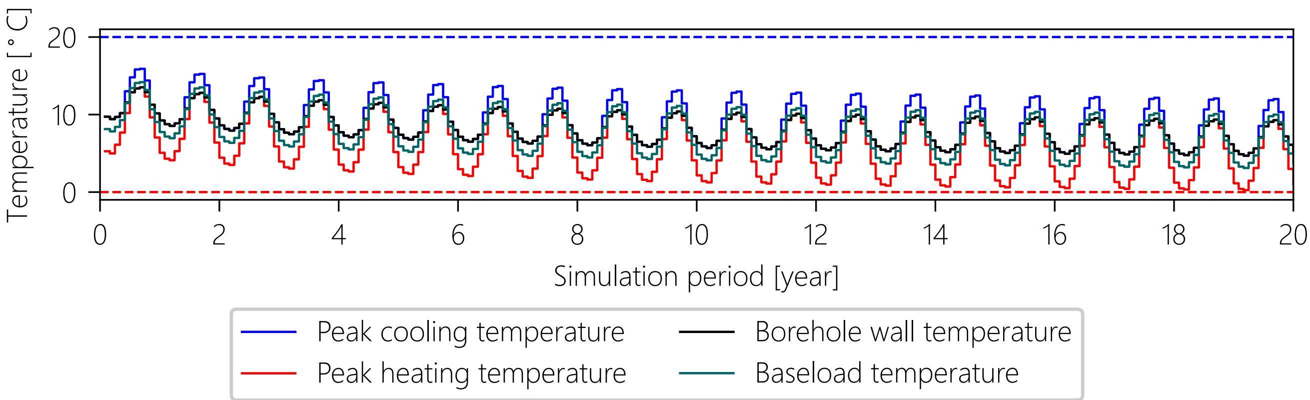
Building demand	Yearly load	Peak power
Heating demand	200 000 kWh/y	100,0 kW
Cooling demand	40 000 kWh/y	40,0 kW

Results

Effective borehole thermal resistance (extraction): 0,1478 m·K/W, Reynolds number: 1 275 (laminar)

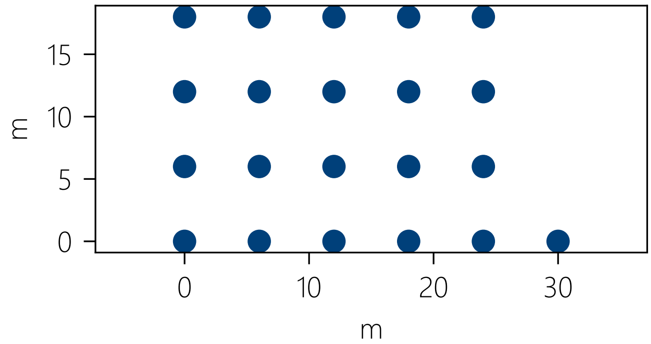
Effective borehole thermal resistance (injection): 0,1210 m·K/W, Reynolds number: 2 482 (transient)

Maximum average fluid temperature: 15,90 °C, Minimum average fluid temperature: 0,26 °C



2.2 Scenario 1 (hourly)

Input



Number of boreholes: 21

Average minimum borehole spacing: 6,0 m

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

2 x U tube DN32 PN16

25,0 v/v% MPG

SCOP heating: 3,41; SEER cooling: 20,00

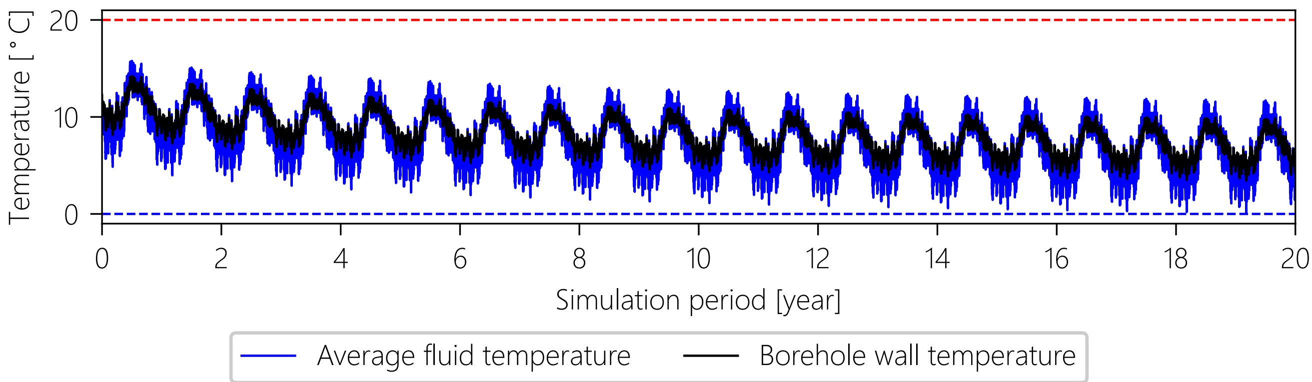
Building demand	Yearly load	Peak power
Heating demand	200 000 kWh/y	100,0 kW
Cooling demand	40 000 kWh/y	40,0 kW

Results

Effective borehole thermal resistance (extraction): 0,1478 m·K/W, Reynolds number: 1 267 (laminar)

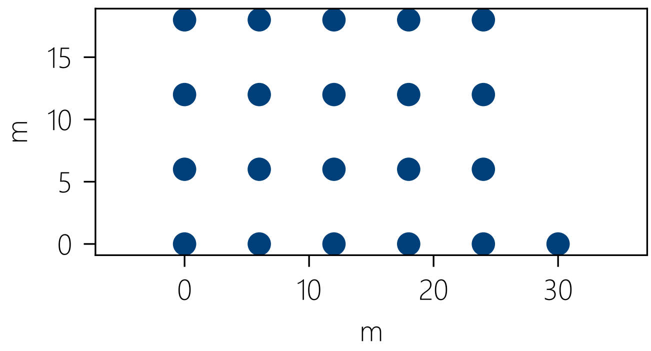
Effective borehole thermal resistance (injection): 0,1215 m·K/W, Reynolds number: 2 471 (transient)

Maximum average fluid temperature: 15,78 °C, Minimum average fluid temperature: 0,12 °C



2.3 Scenario 2 (HP500)

Input



Number of boreholes: 21

Average minimum borehole spacing: 6,0 m

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

2 x U tube DN32 PN16

25,0 v/v% MPG

Used heat pump: HP500 (Enrad) | SEER cooling: 20.0

Building demand	Yearly load	Peak power
Heating demand	200 000 kWh/y	100,0 kW
Cooling demand	40 000 kWh/y	40,0 kW

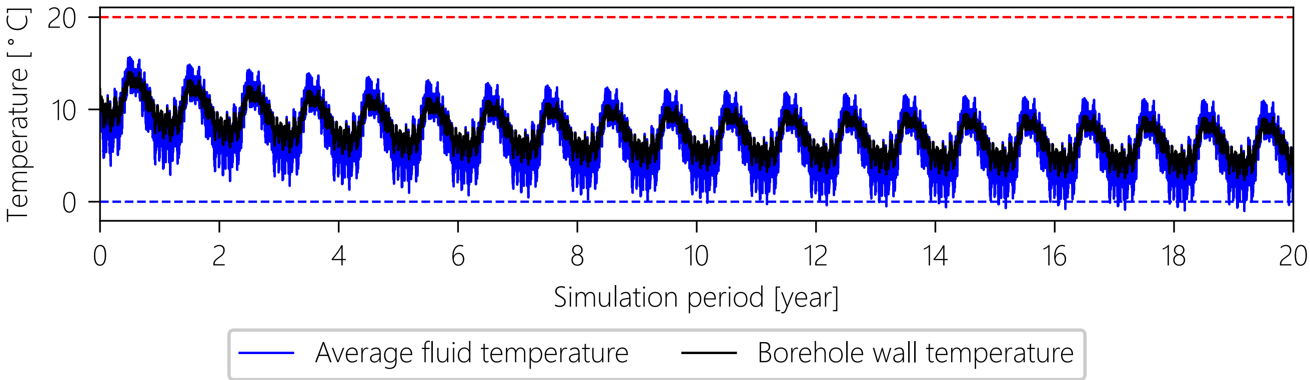
Results

Effective borehole thermal resistance (extraction): 0,1480 m·K/W, Reynolds number: 1 199 (laminar)

Effective borehole thermal resistance (injection): 0,1222 m·K/W, Reynolds number: 2 460 (transient)

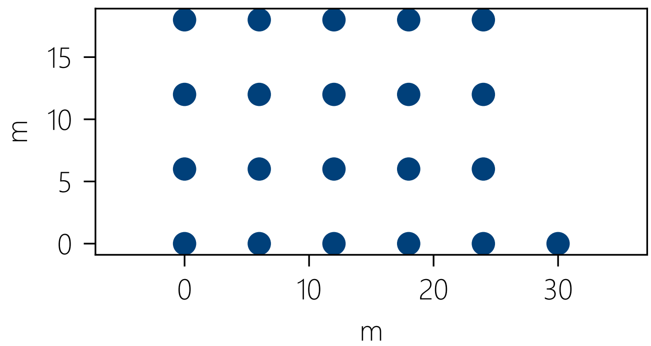
Calculated efficiency: 4,66 (SCOP heating)

Maximum average fluid temperature: 15,67 °C, Minimum average fluid temperature: -1,02 °C



2.4 Scenario 3 (2 x HP300)

Input



Number of boreholes: 21

Average minimum borehole spacing: 6,0 m

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

2 x U tube DN32 PN16

25,0 v/v% MPG

Used heat pump: HP300 (Enrad) x2 | SEER cooling: 20.0

Building demand	Yearly load	Peak power
Heating demand	200 000 kWh/y	100,0 kW
Cooling demand	40 000 kWh/y	40,0 kW

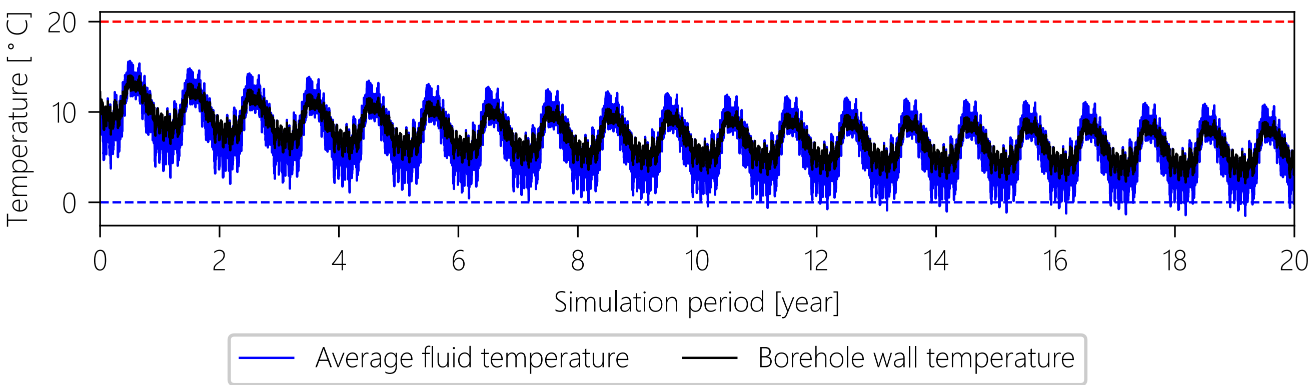
Results

Effective borehole thermal resistance (extraction): 0,1480 m·K/W, Reynolds number: 1 170 (laminar)

Effective borehole thermal resistance (injection): 0,1223 m·K/W, Reynolds number: 2 459 (transient)

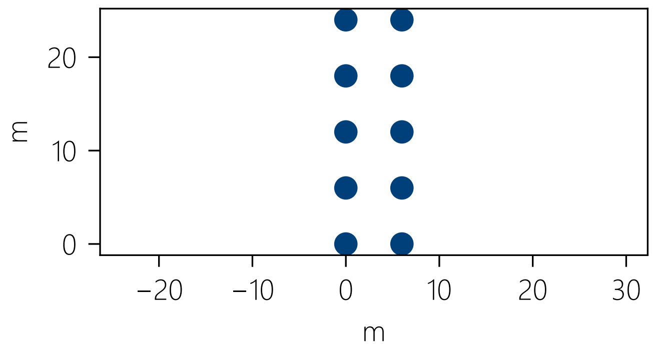
Calculated efficiency: 4,93 (SCOP heating)

Maximum average fluid temperature: 15,65 °C, Minimum average fluid temperature: -1,50 °C



2.5 Scenario 4 (2 x HP300, deeper boreholes)

Input



Number of boreholes: 10

Average minimum borehole spacing: 6,0 m

Borehole depth (w.r.t. surface): 250,0 m

2 x U tube DN32 PN16

25,0 v/v% MPG

Used heat pump: HP300 (Enrad) x2 | SEER cooling: 20.0

Building demand	Yearly load	Peak power
Heating demand	200 000 kWh/y	100,0 kW
Cooling demand	40 000 kWh/y	40,0 kW

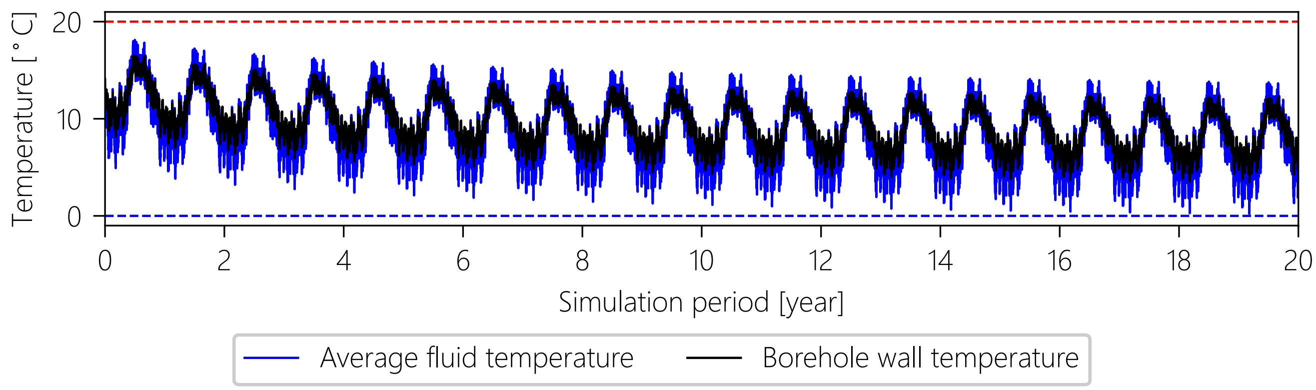
Results

Effective borehole thermal resistance (extraction): 0,1052 m·K/W, Reynolds number: 2 671 (transient)

Effective borehole thermal resistance (injection): 0,0980 m·K/W, Reynolds number: 5 656 (turbulent)

Calculated efficiency: 5,14 (SCOP heating)

Maximum average fluid temperature: 18,12 °C, Minimum average fluid temperature: 0,20 °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, pipe data, and fluid data.

3.1 General simulation settings

The scenarios in this report have been simulated with a simulation period of 20 years, starting in January. The maximum and minimum average fluid temperatures were 0,00 °C and 20,00 °C respectively. The simulations were carried out with GHEtool Cloud v2.6.1.2.

3.2 Ground data

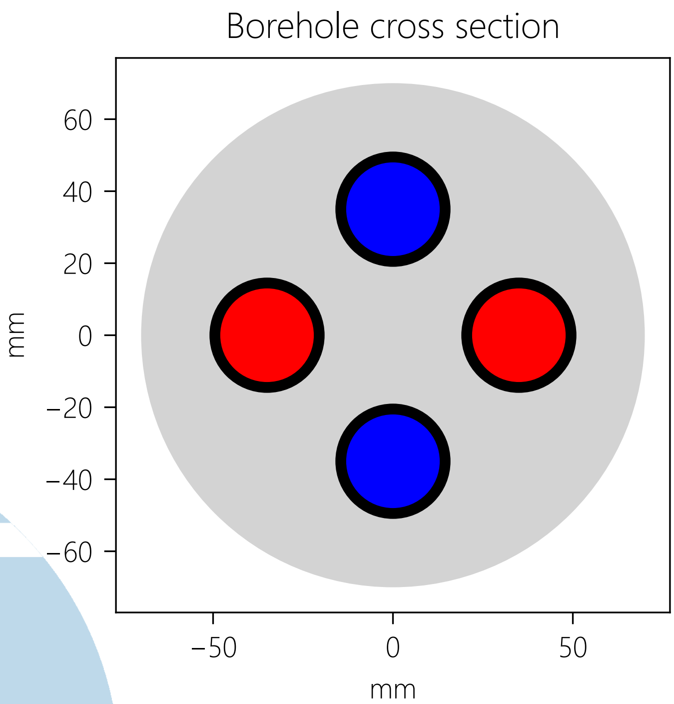
The ground is modelled as a single homogeneous layer with an average thermal conductivity of 2,00 W/(m·K) and a volumetric heat capacity of 2,40 MJ/(m³·K). This means that the ground properties are assumed to remain constant at all depths.

A ground temperature gradient is taken into account. Using a geothermal heat flux of 0,08 W/m², a ground surface temperature of 9,70 °C and the ground thermal conductivity, the average ground temperature can be calculated for each borehole depth. For example, the average ground temperature is 11,19 °C at 74 m and 12,68 °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 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).



3.4 Fluid data

As a heat transfer fluid, MPG with 25,0 v/v% was selected, which provides frost protection down to approximately -11 °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 6,30 l/s, corresponding to a flow of 0,30 l/s per borehole in the system.

4.1 Scenario 1

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

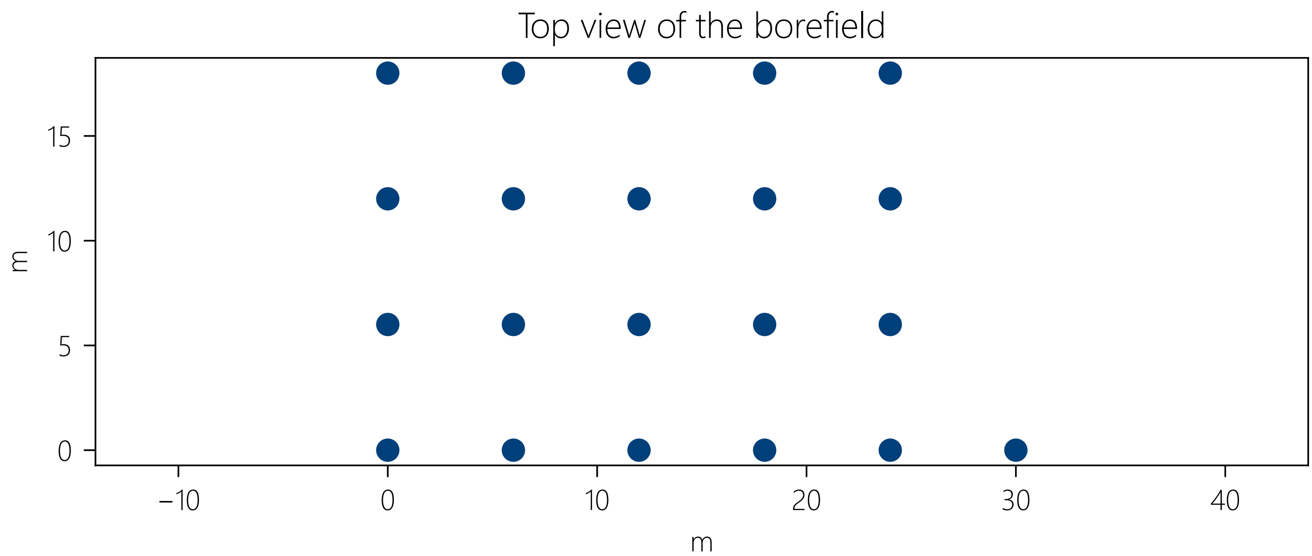
4.1.1 Input

Borefield configuration

The simulations were carried out with a borefield consisting of 21 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 3 129,00 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
30,00	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

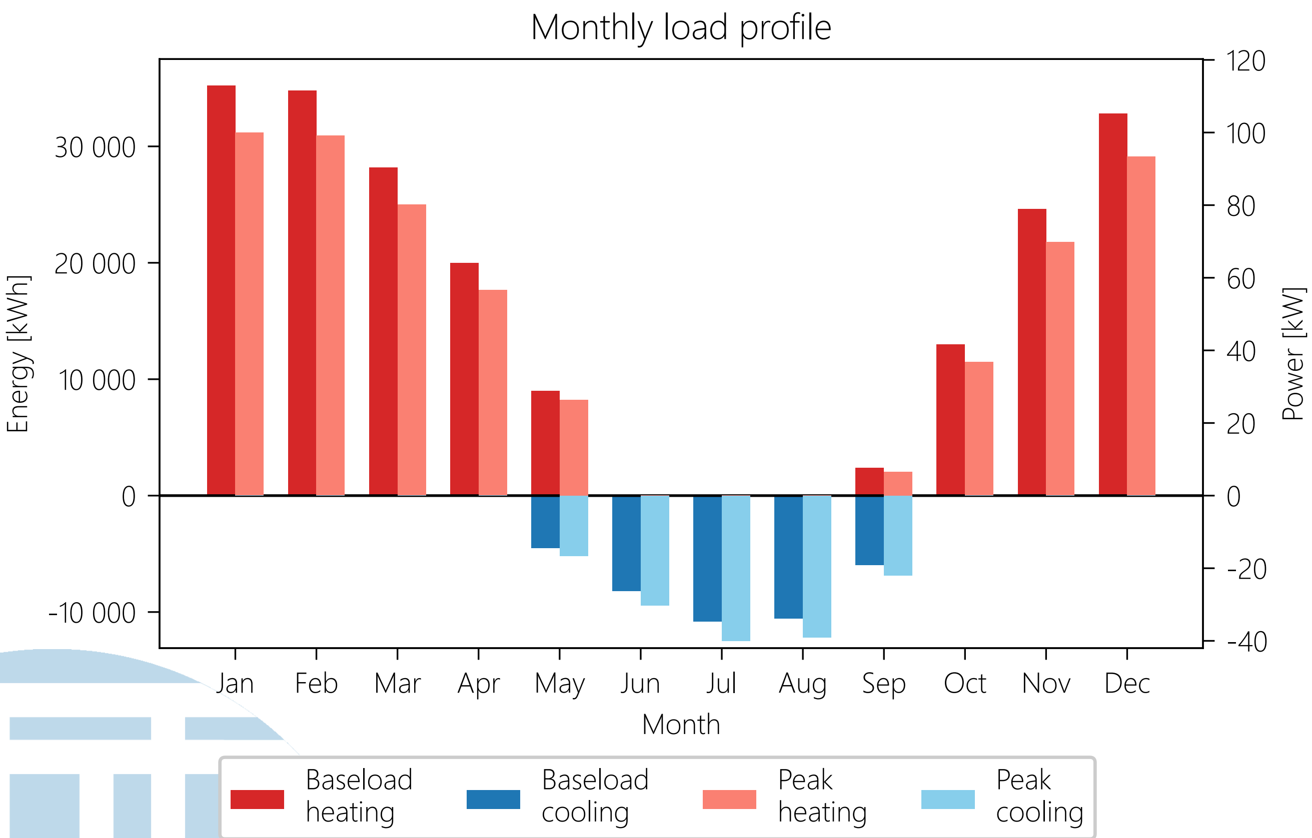
Load data

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	200 000 kWh/y	100,0 kW
Cooling demand	40 000 kWh/y	40,0 kW

The monthly distribution is given in the table below.

Month	Baseload heating [kWh]	Baseload cooling [kWh]	Peak heating [kW]	Peak cooling [kW]
January	35 200	0	100,0	0,0
February	34 800	0	99,1	0,0
March	28 200	0	80,2	0,0
April	20 000	0	56,6	0,0
May	9 000	4 480	26,4	16,6
June	0	8 200	0,0	30,2
July	0	10 800	0,0	40,0
August	0	10 560	0,0	39,0
September	2 400	5 960	6,6	22,0
October	13 000	0	36,8	0,0
November	24 600	0	69,8	0,0
December	32 800	0	93,4	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).

Efficiency data

To calculate the resulting geothermal load, the heat pump is modelled to have an SCOP of 3,41 in heating. The cooling is modelled with an SEER of 20,00.

4.1.2 Results

Ground load

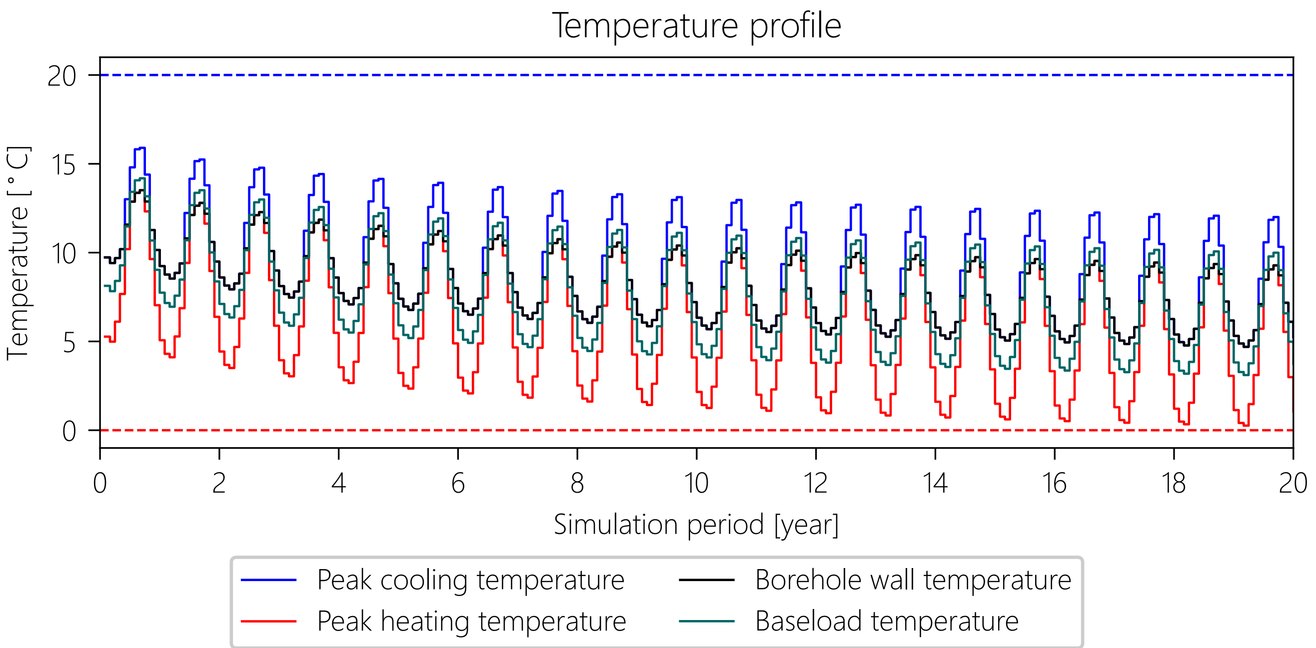
Because we are working with building loads (i.e. secondary loads), these must be converted into injection and extraction loads using the efficiency data. A summary of the resulting yearly ground load is given in the table below.

Ground demand	Yearly load	Peak power
Extraction demand	141 349 kWh/y	70,7 kW
Injection demand	42 000 kWh/y	42,0 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 1 275, whilst it was 2 482 during injection. This corresponds respectively to a laminar and transient flow regime, with an effective borehole thermal resistance of 0,1478 m·K/W and 0,1210 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 15,90 °C and 0,26 °C respectively. The minimum average fluid temperatures during the baseload are respectively 3,11 °C and 14,19 °C.

Pressure drop

The pressure drop over a single borehole is 23,60 kPa during extration and 21,61 kPa during injection.

4.2 Scenario 1 (hourly)

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

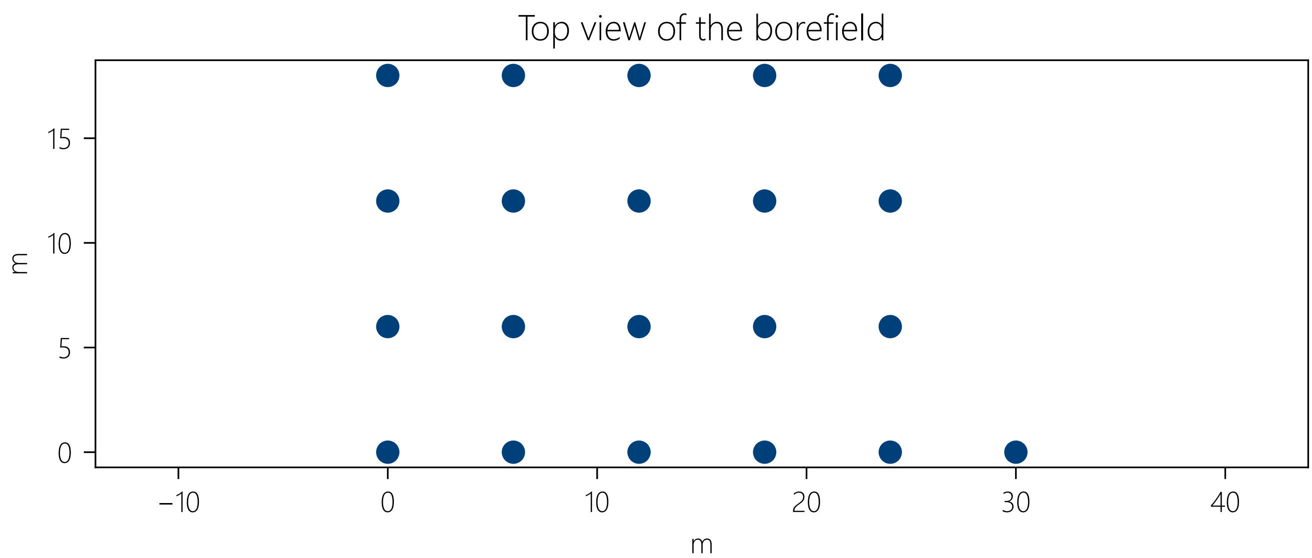
4.2.1 Input

Borefield configuration

The simulations were carried out with a borefield consisting of 21 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 3 129,00 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.)



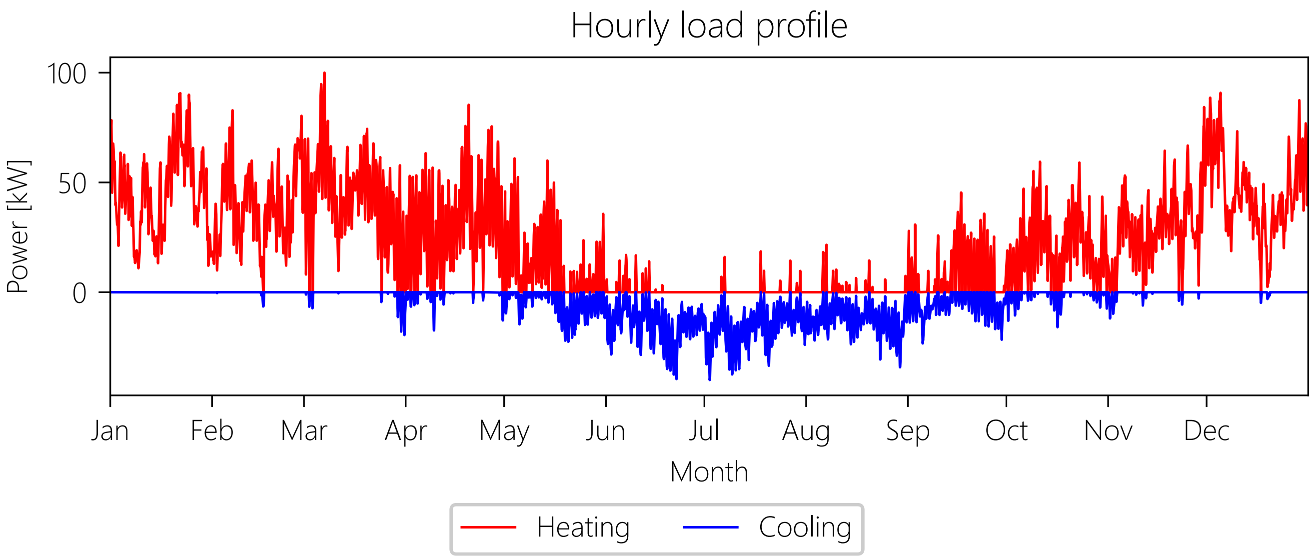
The coordinates of the different boreholes are given in the table below.

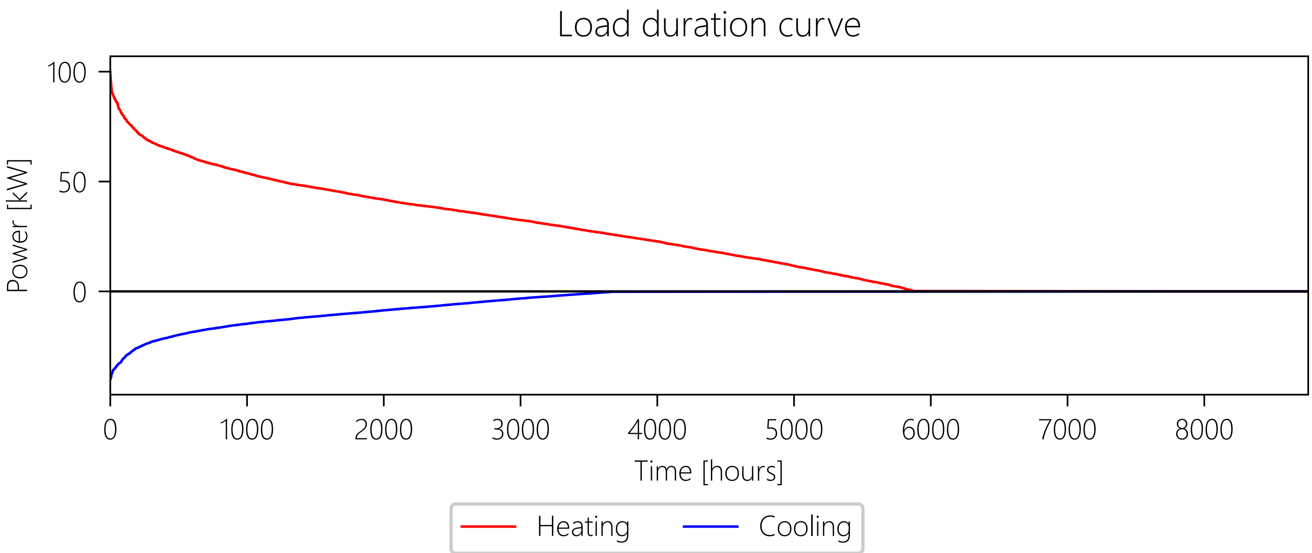
x [m]	y [m]	Length [m]	Depth [m]	Buried depth [m]	Tilt [°]	Orientation [°]
0,00	0,00	149,00	150,00	1,00	0,00	0,00
0,00	6,00	149,00	150,00	1,00	0,00	0,00
0,00	12,00	149,00	150,00	1,00	0,00	0,00
0,00	18,00	149,00	150,00	1,00	0,00	0,00
6,00	0,00	149,00	150,00	1,00	0,00	0,00
6,00	6,00	149,00	150,00	1,00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

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	200 000 kWh/y	100,0 kW
Cooling demand	40 000 kWh/y	40,0 kW





Efficiency data

To calculate the resulting geothermal load, the heat pump is modelled to have an SCOP of 3,41 in heating. The cooling is modelled with an SEER of 20,00.

4.2.2 Results

Ground load

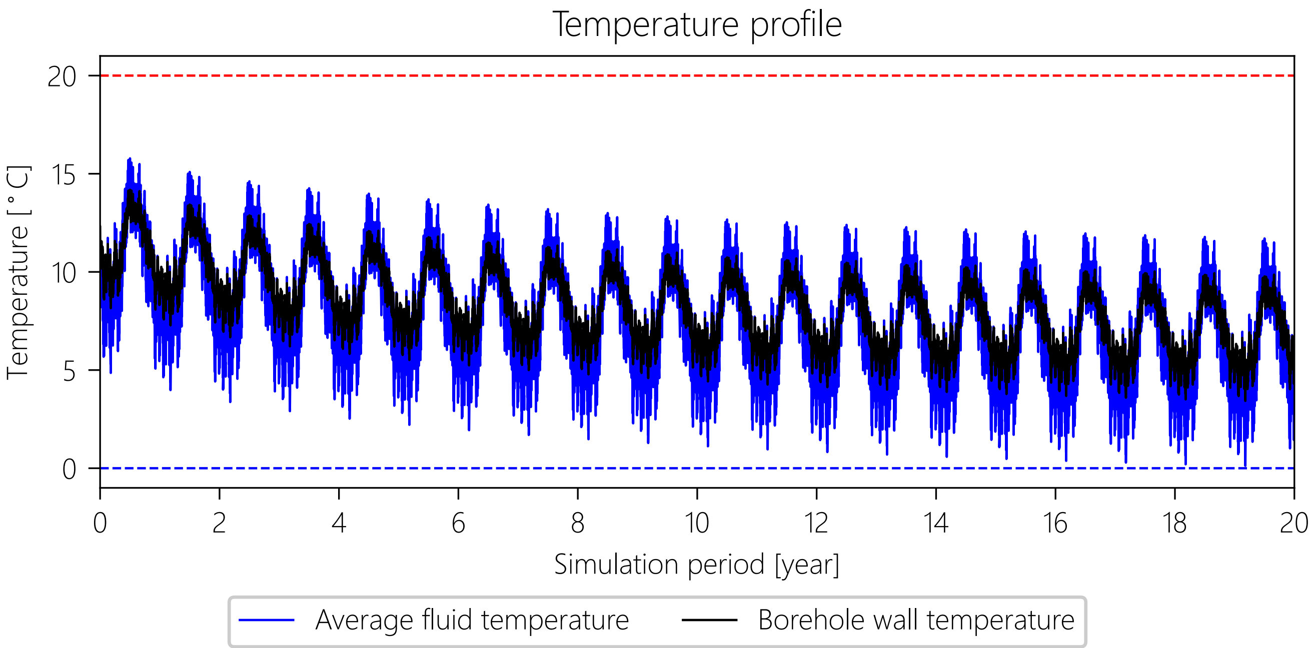
Because we are working with building loads (i.e. secondary loads), these must be converted into injection and extraction loads using the efficiency data. A summary of the resulting yearly ground load is given in the table below.

Ground demand	Yearly load	Peak power
Extraction demand	141 349 kWh/y	70,7 kW
Injection demand	42 000 kWh/y	42,0 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 1 267, whilst it was 2 471 during injection. This corresponds respectively to a laminar and transient flow regime, with an effective borehole thermal resistance of 0,1478 m·K/W and 0,1215 m·K/W during heat extraction and injection.

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 15,78 °C, and the minimum average fluid temperature is 0,12 °C.

Pressure drop

The pressure drop over a single borehole is 23,75 kPa during extration and 21,64 kPa during injection.

4.3 Scenario 2 (HP500)

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 21 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 3 129,00 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.

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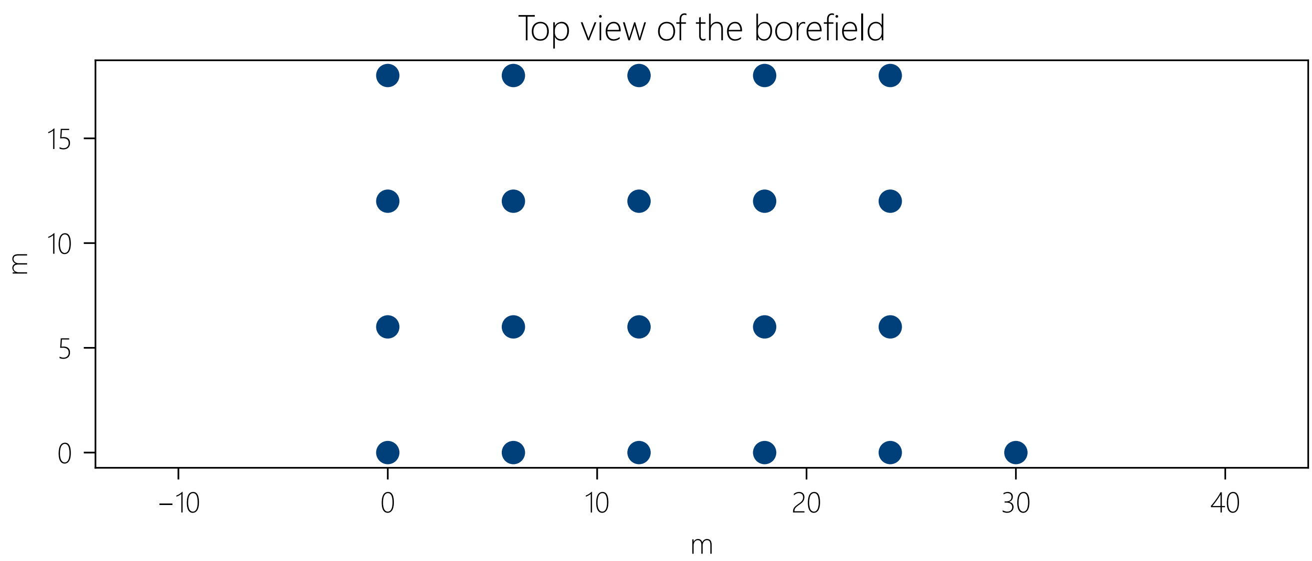

The coordinates of the different boreholes are given in the table below.

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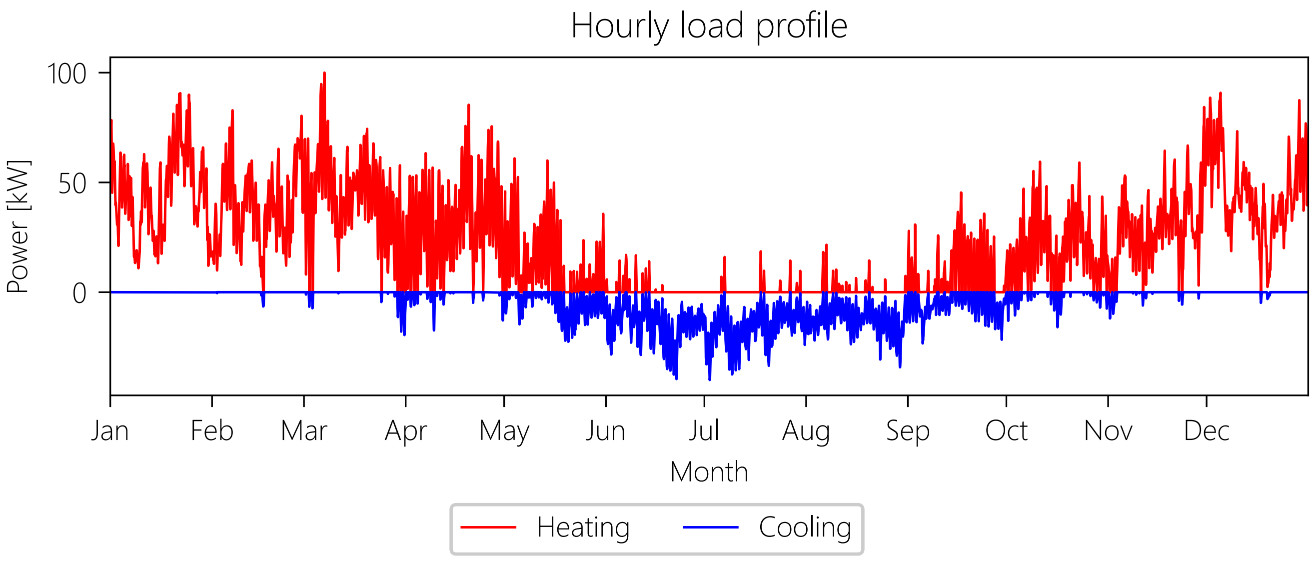
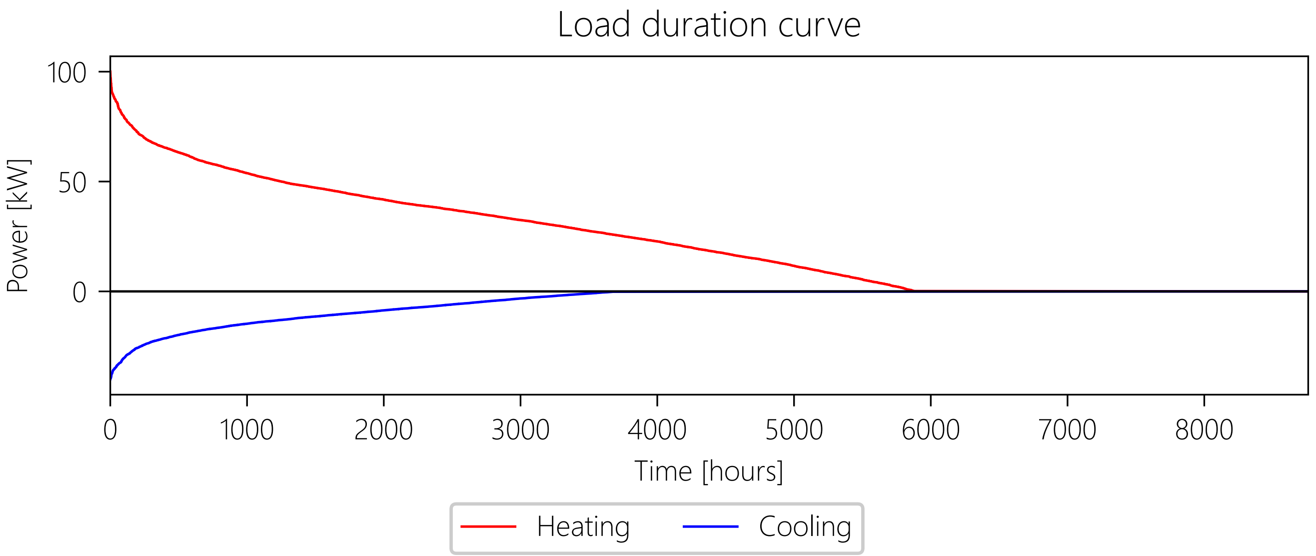
0,00	18,00	149,00	150,00	1,00	0,00	0,00
6,00	0,00	149,00	150,00	1,00	0,00	0,00
6,00	6,00	149,00	150,00	1,00	0,00	0,00
6,00	12,00	149,00	150,00	1,00	0,00	0,00
6,00	18,00	149,00	150,00	1,00	0,00	0,00
12,00	0,00	149,00	150,00	1,00	0,00	0,00
12,00	6,00	149,00	150,00	1,00	0,00	0,00
12,00	12,00	149,00	150,00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

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	200 000 kWh/y	100,0 kW
Cooling demand	40 000 kWh/y	40,0 kW





Efficiency data

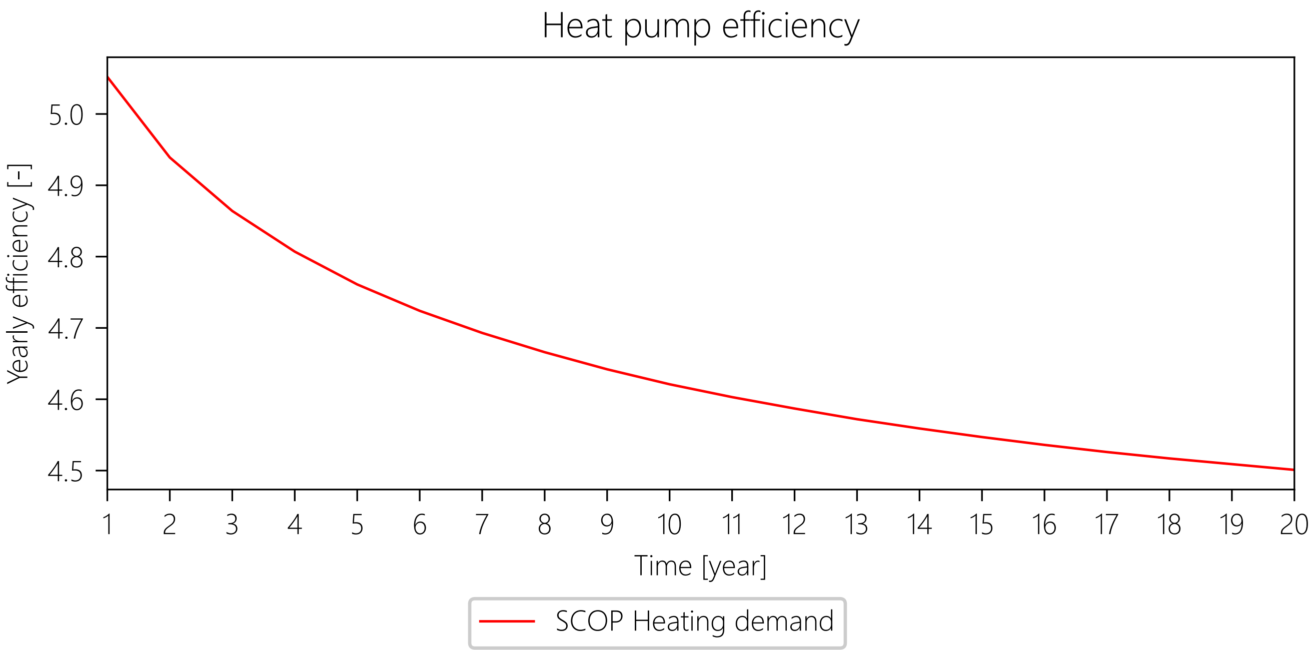
For the simulation, the following heat pump are used: HP500 (Enrad). Using the temperature and part-load dependent COP of this machine, the building load was converted to a geothermal load with the highest accuracy. The cooling is modelled with an SEER of 20,00.

4.3.2 Results

Calculated efficiency

The simulation is done with a temperature and part-load dependent efficiency. This means that over the simulation period, the efficiency of the heat pump will change significantly, leading to a more complex ground load. On average, the yearly calculated efficiency of the heat pump is: 4,66 (SCOP heating).

In the graph below, the change in yearly efficiency is shown for the whole simulation period.



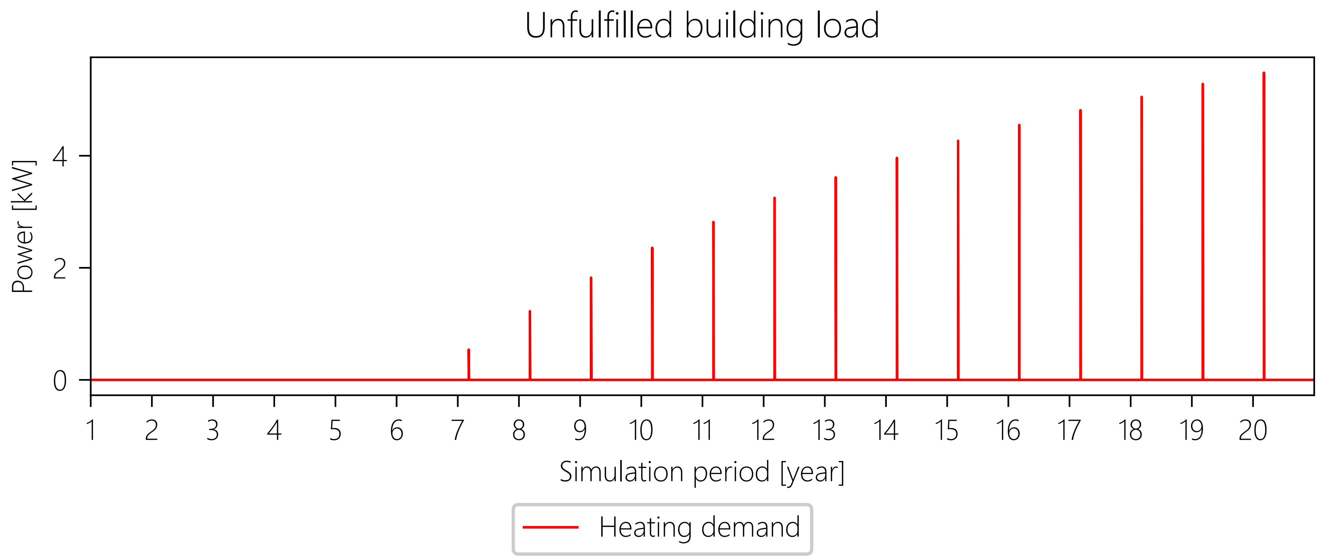
Ground load

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	157 047 kWh/y	78,9 kW
Injection demand	42 000 kWh/y	42,0 kW

The selected heat pump is not able to provide 100% of the entire building load. In the table below, the unfulfilled building demand is given.

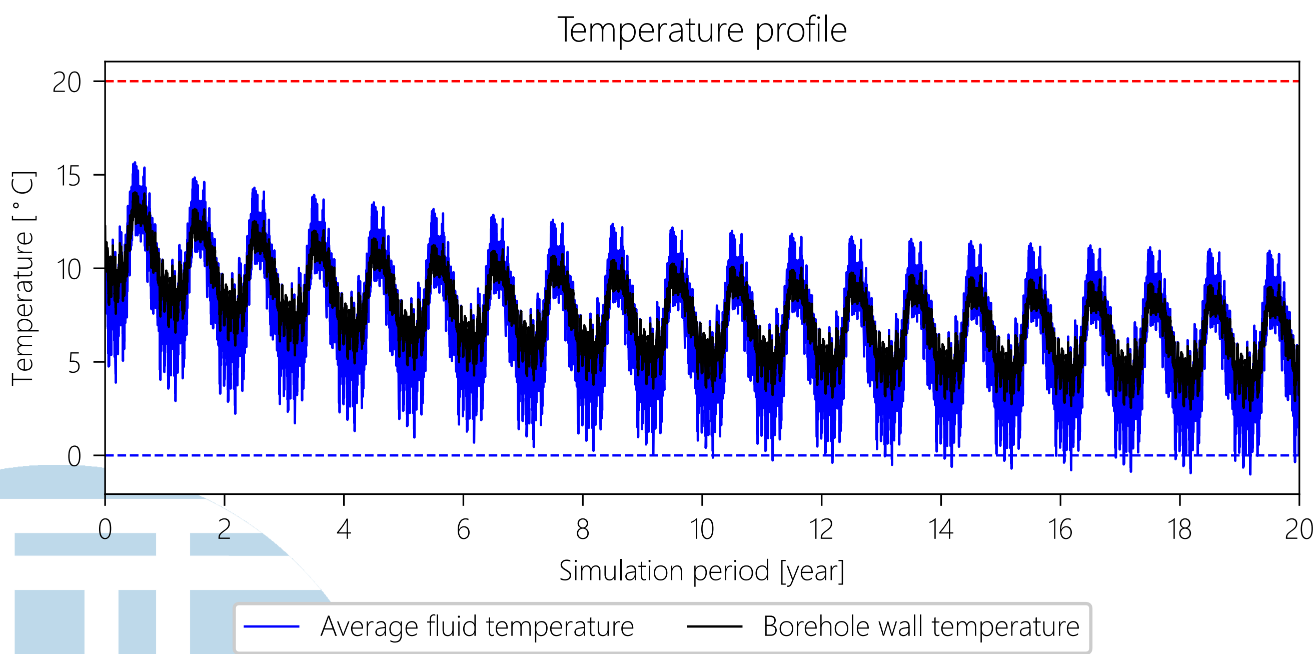
Unfulfilled demand	Yearly load	Peak power
Heating demand	6 kWh/y	5,5 kW



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 1 199, whilst it was 2 460 during injection. This corresponds respectively to a laminar and transient flow regime, with an effective borehole thermal resistance of 0,1480 m·K/W and 0,1222 m·K/W during heat extraction and injection.

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 15,67 °C, and the minimum average fluid temperature is -1,02 °C.

Pressure drop

The pressure drop over a single borehole is 25,11 kPa during extration and 21,67 kPa during injection.

4.4 Scenario 3 (2 x HP300)

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

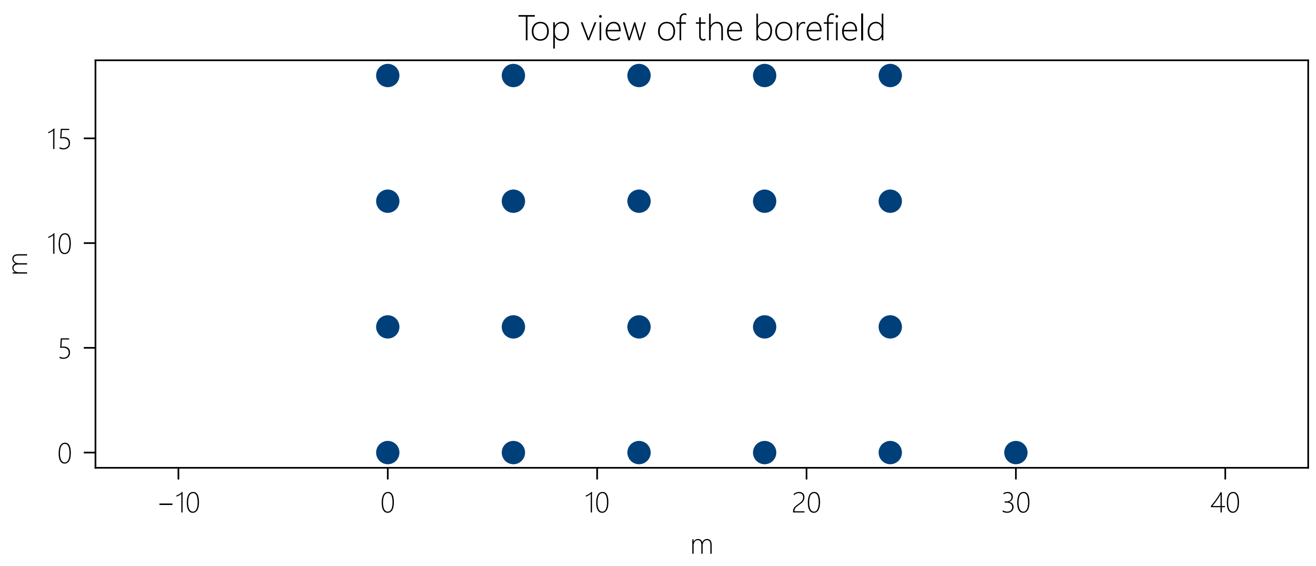
4.4.1 Input

Borefield configuration

The simulations were carried out with a borefield consisting of 21 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 3 129,00 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.)



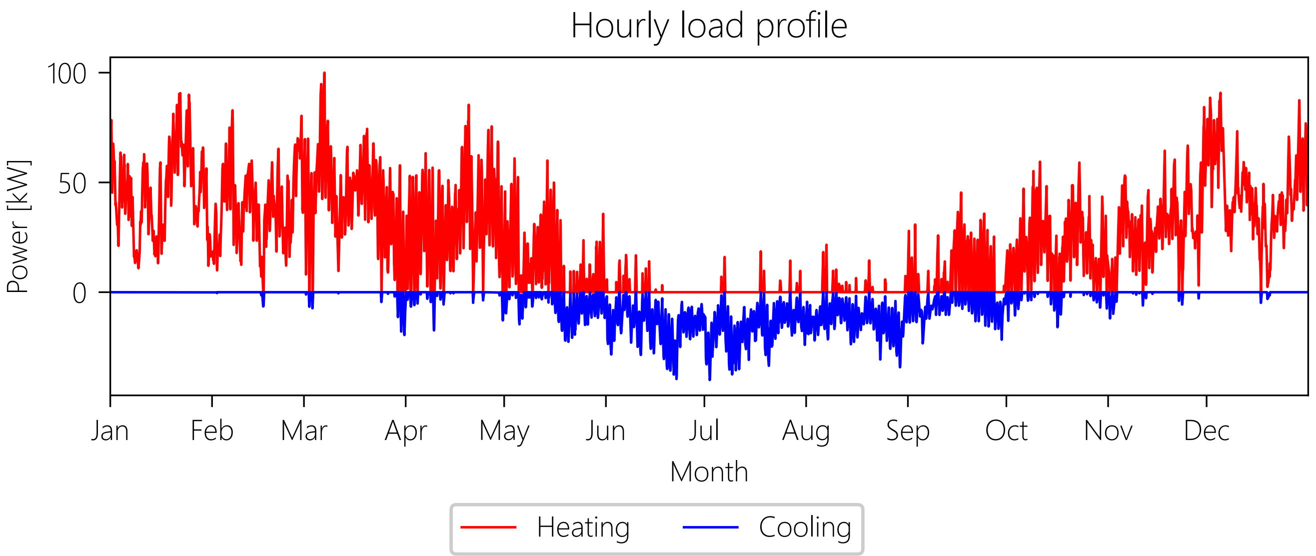
The coordinates of the different boreholes are given in the table below.

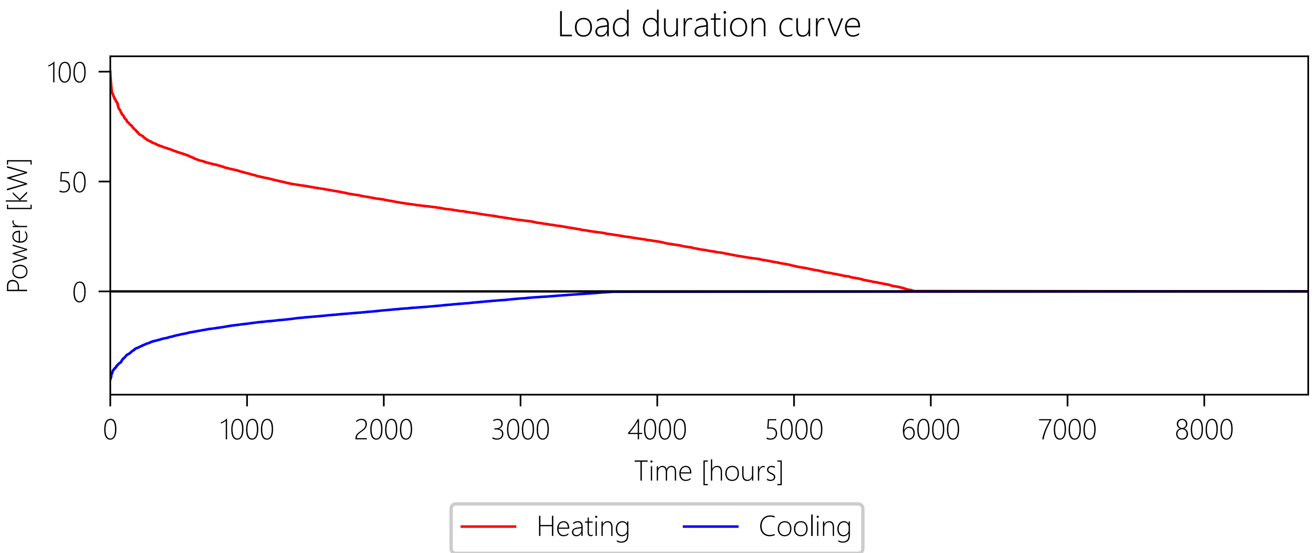
x [m]	y [m]	Length [m]	Depth [m]	Buried depth [m]	Tilt [°]	Orientation [°]
0,00	0,00	149,00	150,00	1,00	0,00	0,00
0,00	6,00	149,00	150,00	1,00	0,00	0,00
0,00	12,00	149,00	150,00	1,00	0,00	0,00
0,00	18,00	149,00	150,00	1,00	0,00	0,00
6,00	0,00	149,00	150,00	1,00	0,00	0,00
6,00	6,00	149,00	150,00	1,00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

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	200 000 kWh/y	100,0 kW
Cooling demand	40 000 kWh/y	40,0 kW





Efficiency data

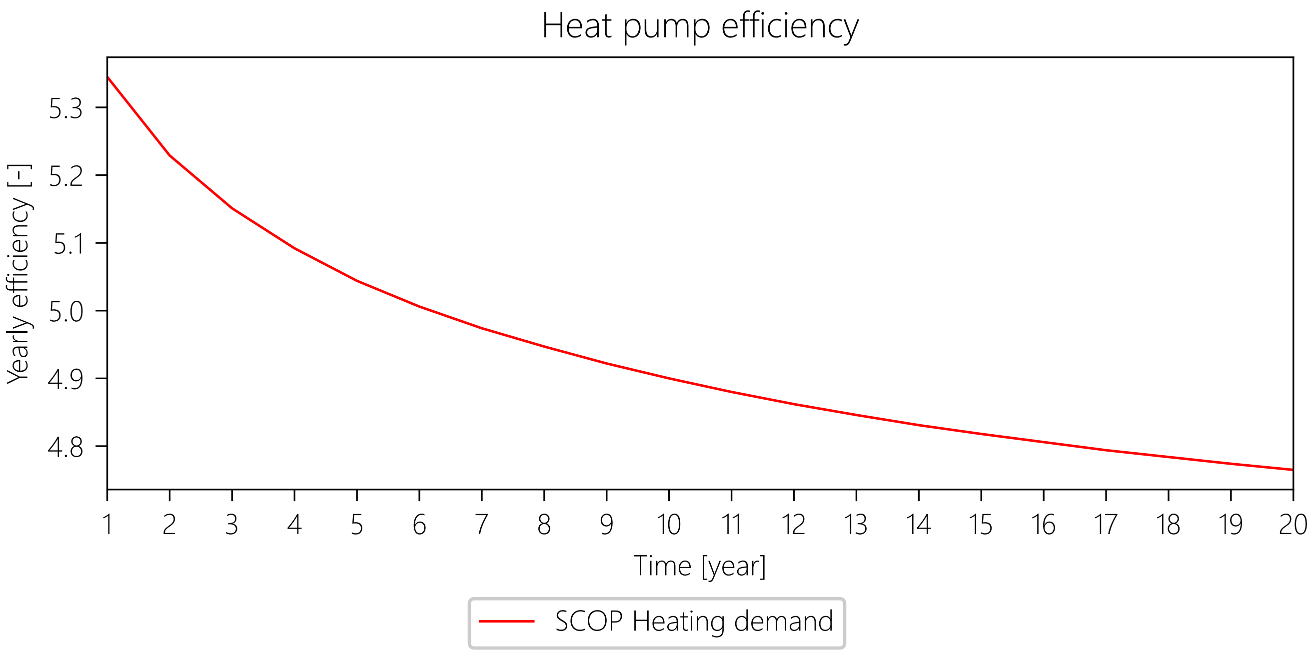
For the simulation, the following heat pump are used: HP300 (Enrad) x2. Using the temperature and part-load dependent COP of this machine, the building load was converted to a geothermal load with the highest accuracy. The cooling is modelled with an SEER of 20,00.

4.4.2 Results

Calculated efficiency

The simulation is done with a temperature and part-load dependent efficiency. This means that over the simulation period, the efficiency of the heat pump will change significantly, leading to a more complex ground load. On average, the yearly calculated efficiency of the heat pump is: 4,93 (SCOP heating).

In the graph below, the change in yearly efficiency is shown for the whole simulation period.



Ground load

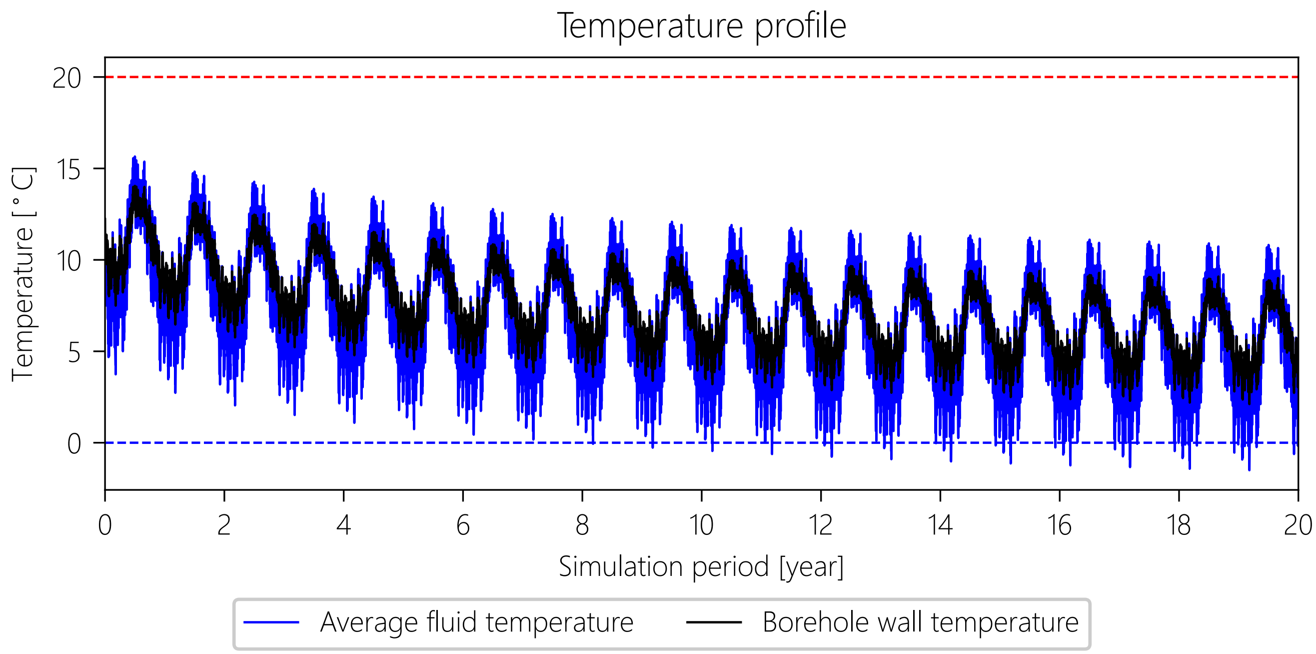
Because we are working with building loads (i.e. secondary loads), these must be converted into injection and extraction loads using the efficiency data. A summary of the resulting yearly ground load is given in the table below.

Ground demand	Yearly load	Peak power
Extraction demand	159 462 kWh/y	80,5 kW
Injection demand	42 000 kWh/y	42,0 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 1 170, whilst it was 2 459 during injection. This corresponds respectively to a laminar and transient flow regime, with an effective borehole thermal resistance of 0,1480 m·K/W and 0,1223 m·K/W during heat extraction and injection.

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 15,65 °C, and the minimum average fluid temperature is -1,50 °C.

Pressure drop

The pressure drop over a single borehole is 25,72 kPa during extration and 21,68 kPa during injection.

4.5 Scenario 4 (2 x HP300, deeper boreholes)

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

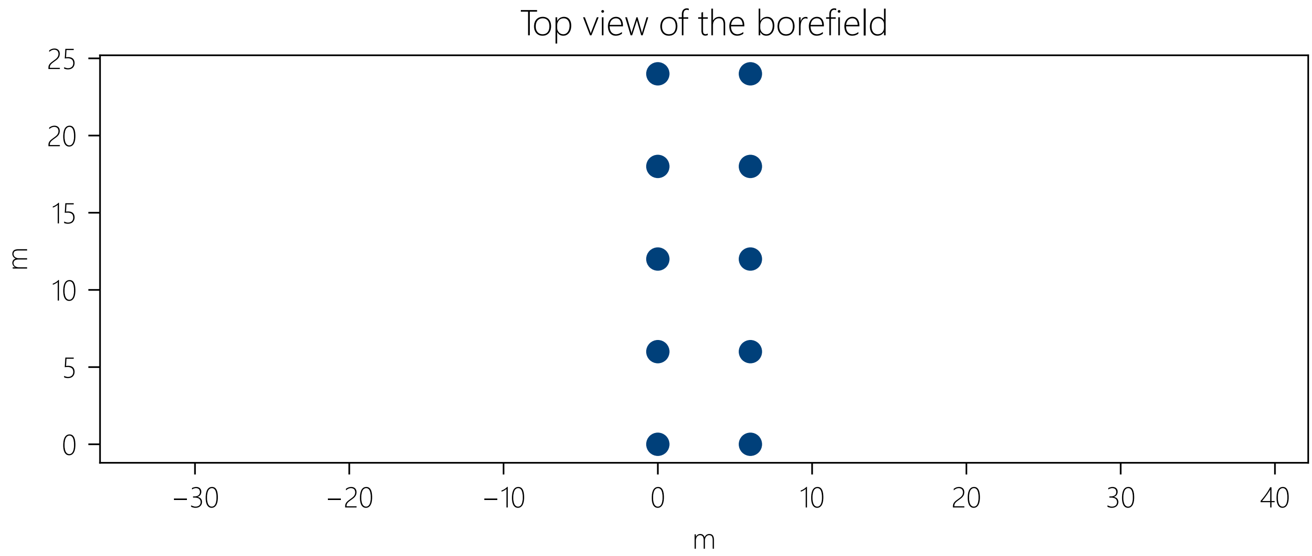
4.5.1 Input

Borefield configuration

The simulations were carried out with a borefield consisting of 10 boreholes, with an average buried depth of 1,00 m, an average borehole depth of 250,00 m and an average borehole length of 249,00 m. This results in a total borehole length of 2 490,00 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.)



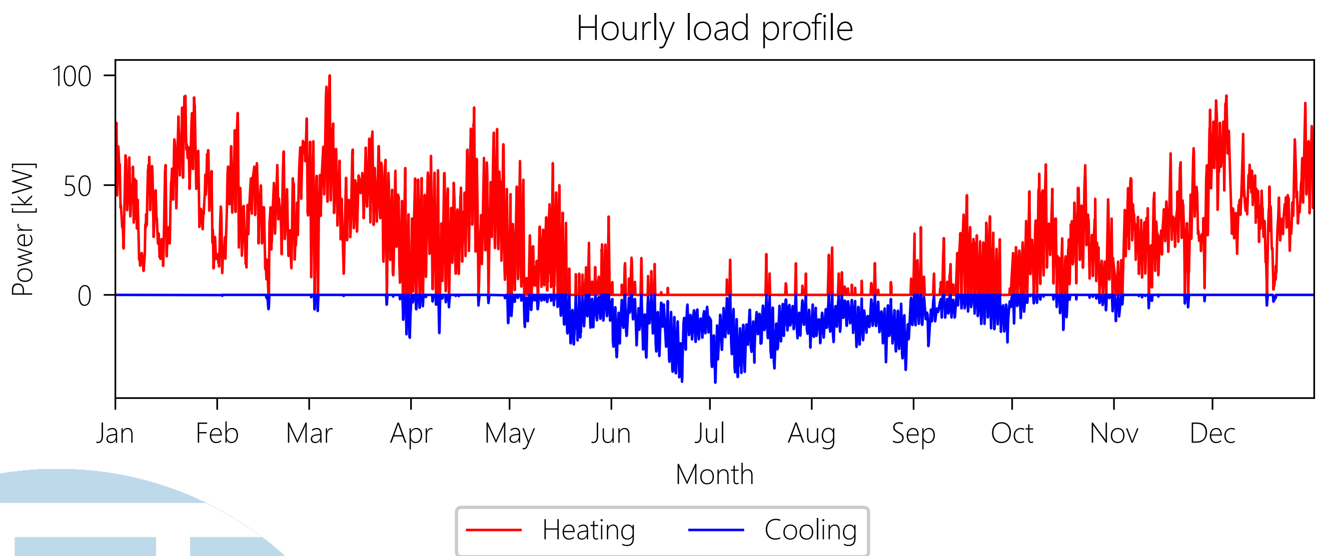
The coordinates of the different boreholes are given in the table below.

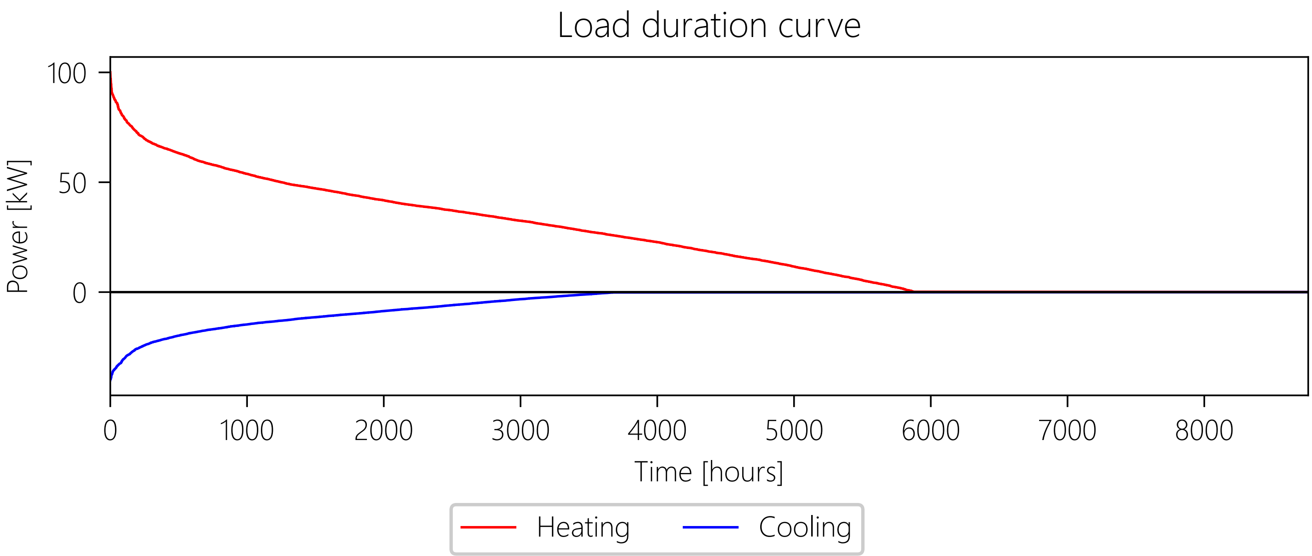
x [m]	y [m]	Length [m]	Depth [m]	Buried depth [m]	Tilt [°]	Orientation [°]
0,00	0,00	249,00	250,00	1,00	0,00	0,00
0,00	6,00	249,00	250,00	1,00	0,00	0,00
0,00	12,00	249,00	250,00	1,00	0,00	0,00
0,00	18,00	249,00	250,00	1,00	0,00	0,00
0,00	24,00	249,00	250,00	1,00	0,00	0,00
6,00	0,00	249,00	250,00	1,00	0,00	0,00
6,00	6,00	249,00	250,00	1,00	0,00	0,00
6,00	12,00	249,00	250,00	1,00	0,00	0,00
6,00	18,00	249,00	250,00	1,00	0,00	0,00
6,00	24,00	249,00	250,00	1,00	0,00	0,00

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	200 000 kWh/y	100,0 kW
Cooling demand	40 000 kWh/y	40,0 kW





Efficiency data

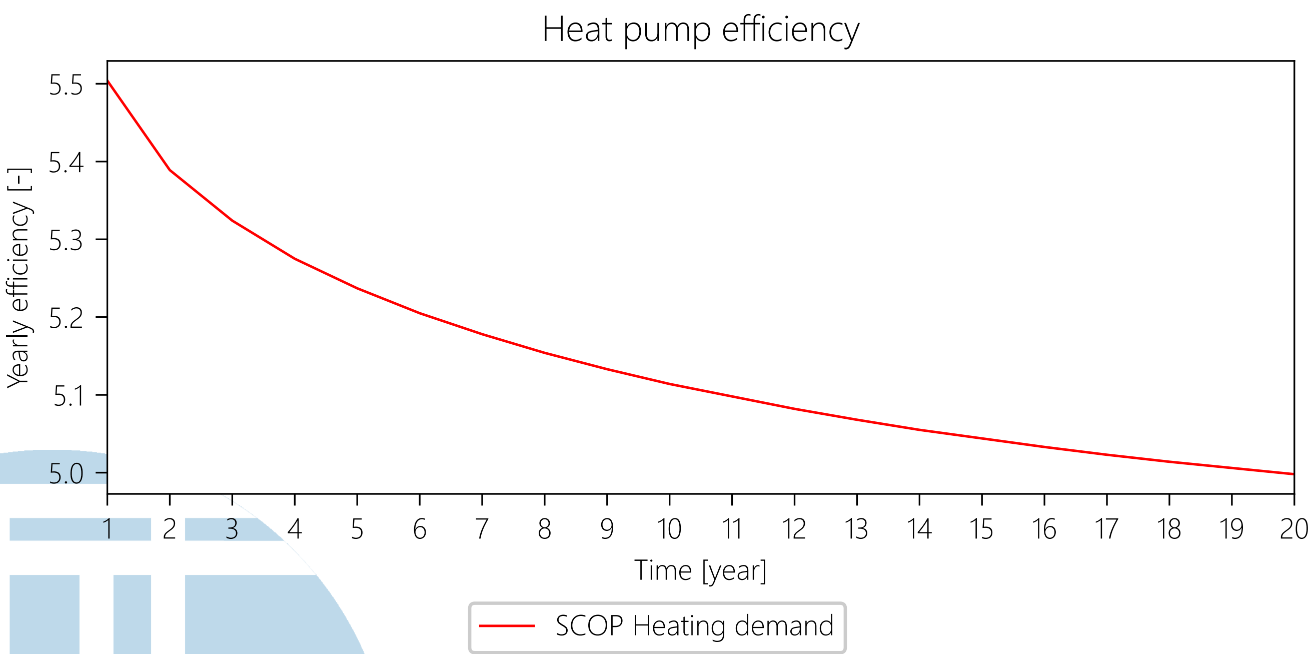
For the simulation, the following heat pump are used: HP300 (Enrad) x2. Using the temperature and part-load dependent COP of this machine, the building load was converted to a geothermal load with the highest accuracy. The cooling is modelled with an SEER of 20,00.

4.5.2 Results

Calculated efficiency

The simulation is done with a temperature and part-load dependent efficiency. This means that over the simulation period, the efficiency of the heat pump will change significantly, leading to a more complex ground load. On average, the yearly calculated efficiency of the heat pump is: 5,14 (SCOP heating).

In the graph below, the change in yearly efficiency is shown for the whole simulation period.



Ground load

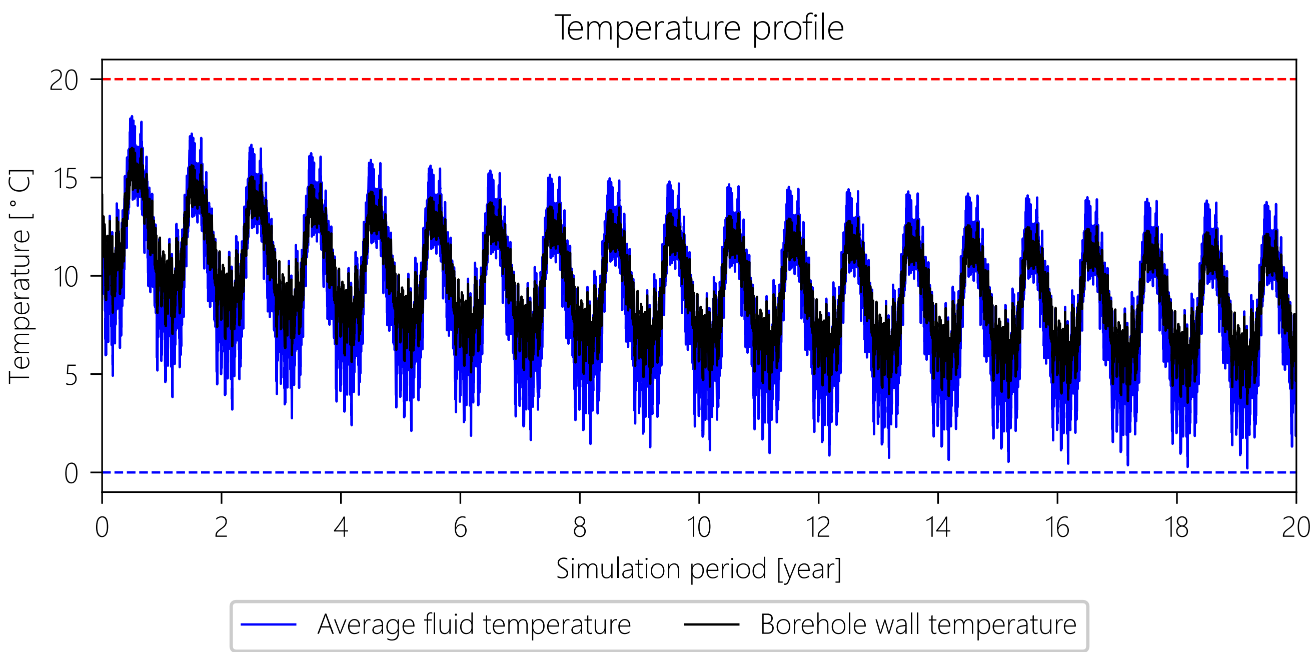
Because we are working with building loads (i.e. secondary loads), these must be converted into injection and extraction loads using the efficiency data. A summary of the resulting yearly ground load is given in the table below.

Ground demand	Yearly load	Peak power
Extraction demand	161 115 kWh/y	80,9 kW
Injection demand	42 000 kWh/y	42,0 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 2 671, whilst it was 5 656 during injection. This corresponds respectively to a transient and turbulent flow regime, with an effective borehole thermal resistance of 0,1052 m·K/W and 0,0980 m·K/W during heat extraction and injection.

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 18,12 °C, and the minimum average fluid temperature is 0,20 °C.

Pressure drop

The pressure drop over a single borehole is 156,43 kPa during extration and 124,51 kPa during injection.

5.1 Design Data - Scenario 1

Design parameters

- Maximum average fluid temperature: 20,00 °C
- Minimum average fluid temperature: 0,00000 °C
- First month of simulation: 1
- Simulation period: 20 years

Ground parameters

- Homogeneous ground conductivity: 2,00 W/(m·K)
- Homogeneous volumetric heat capacity: 2,40 MJ/(m^3·K)
- Ground surface temperature: 9,70 °C
- Ground flux: 0,08000 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

- 25.0 v/v% MPG
- Volume flow rate per borefield: 6,30 l/s
- Number of boreholes in series: 1

Thermal demand

Baseload heating [kWh]	Baseload cooling [kWh]	Peak heating [kW]	Peak cooling [kW]
35 200,00	0,00	100,00	0,00
34 800,00	0,00	99,10	0,00
28 200,00	0,00	80,20	0,00
20 000,00	0,00	56,60	0,00
9 000,00	4 480,00	26,40	16,60
0,00	8 200,00	0,00	30,24
0,00	10 800,00	0,00	40,00
0,00	10 560,00	0,00	39,04
2 400,00	5 960,00	6,60	21,96
13 000,00	0,00	36,80	0,00
24 600,00	0,00	69,80	0,00
32 800,00	0,00	93,40	0,00

- SCOP heating: 3,41
- 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
30,00	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

5.2 Design Data - Scenario 1 (hourly)

Design parameters

- Maximum average fluid temperature: 20,00 °C
- Minimum average fluid temperature: 0,00000 °C
- First month of simulation: 1
- Simulation period: 20 years

Ground parameters

- Homogeneous ground conductivity: 2,00 W/(m·K)
- Homogeneous volumetric heat capacity: 2,40 MJ/(m³·K)
- Ground surface temperature: 9,70 °C
- Ground flux: 0,08000 W/m²

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

- 25.0 v/v% MPG
- Volume flow rate per borefield: 6,30 l/s
- Number of boreholes in series: 1

Thermal demand

- Type of load: Hourly building load
- SCOP heating: 3,41
- 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
30,00	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

5.3 Design Data - Scenario 2 (HP500)

Design parameters

- Maximum average fluid temperature: 20,00 °C
- Minimum average fluid temperature: 0,00000 °C
- First month of simulation: 1
- Simulation period: 20 years

Ground parameters

- Homogeneous ground conductivity: 2,00 W/(m·K)
- Homogeneous volumetric heat capacity: 2,40 MJ/(m^3·K)
- Ground surface temperature: 9,70 °C
- Ground flux: 0,08000 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

- 25.0 v/v% MPG
- Volume flow rate per borefield: 6,30 l/s
- Number of boreholes in series: 1

Thermal demand

- Type of load: Hourly building load
- Used heat pump: HP500 (Enrad)
- 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
30,00	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

5.4 Design Data - Scenario 3 (2 x HP300)

Design parameters

- Maximum average fluid temperature: 20,00 °C
- Minimum average fluid temperature: 0,00000 °C
- First month of simulation: 1
- Simulation period: 20 years

Ground parameters

- Homogeneous ground conductivity: 2,00 W/(m·K)
- Homogeneous volumetric heat capacity: 2,40 MJ/(m³·K)
- Ground surface temperature: 9,70 °C
- Ground flux: 0,08000 W/m²

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

- 25.0 v/v% MPG
- Volume flow rate per borefield: 6,30 l/s
- Number of boreholes in series: 1

Thermal demand

- Type of load: Hourly building load
- Used heat pump: HP300 (Enrad) x2
- 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
30,00	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

5.5 Design Data - Scenario 4 (2 x HP300, deeper boreholes)

Design parameters

- Maximum average fluid temperature: 20,00 °C
- Minimum average fluid temperature: 0,00000 °C
- First month of simulation: 1
- Simulation period: 20 years

Ground parameters

- Homogeneous ground conductivity: 2,00 W/(m·K)
- Homogeneous volumetric heat capacity: 2,40 MJ/(m^3·K)
- Ground surface temperature: 9,70 °C
- Ground flux: 0,08000 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

- 25.0 v/v% MPG
- Volume flow rate per borefield: 6,30 l/s
- Number of boreholes in series: 1

Thermal demand

- Type of load: Hourly building load
- Used heat pump: HP300 (Enrad) x2
- SEER cooling: 20,00

Borefield parameters

x [m]	y [m]	Length [m]	Depth [m]	Buried depth [m]	Tilt [°]	Orientation [°]
0,00	0,00	249,00	250,00	1,00	0,00	0,00
0,00	6,00	249,00	250,00	1,00	0,00	0,00
0,00	12,00	249,00	250,00	1,00	0,00	0,00
0,00	18,00	249,00	250,00	1,00	0,00	0,00
0,00	24,00	249,00	250,00	1,00	0,00	0,00

6,00	0,00	249,00	250,00	1,00	0,00	0,00
6,00	6,00	249,00	250,00	1,00	0,00	0,00
6,00	12,00	249,00	250,00	1,00	0,00	0,00
6,00	18,00	249,00	250,00	1,00	0,00	0,00
6,00	24,00	249,00	250,00	1,00	0,00	0,00

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