GHEtool calculation report

Course 9.4



14/10/26

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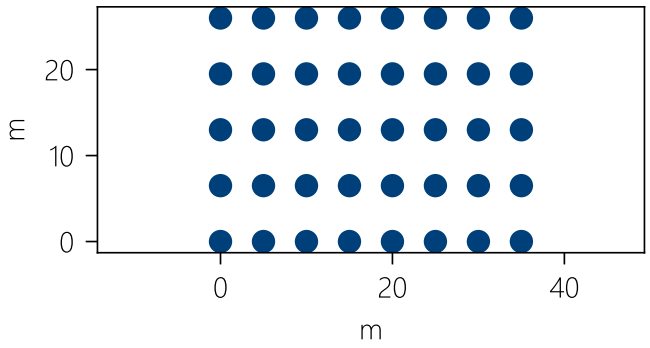
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1.1 Structure of the report

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 Req size

Input



Number of boreholes: 40

Average minimum borehole spacing: 5,0 m

Borehole depth (w.r.t. surface): 100,0 m

2 x U tube DN32 PN16

25,0 v/v% MPG

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

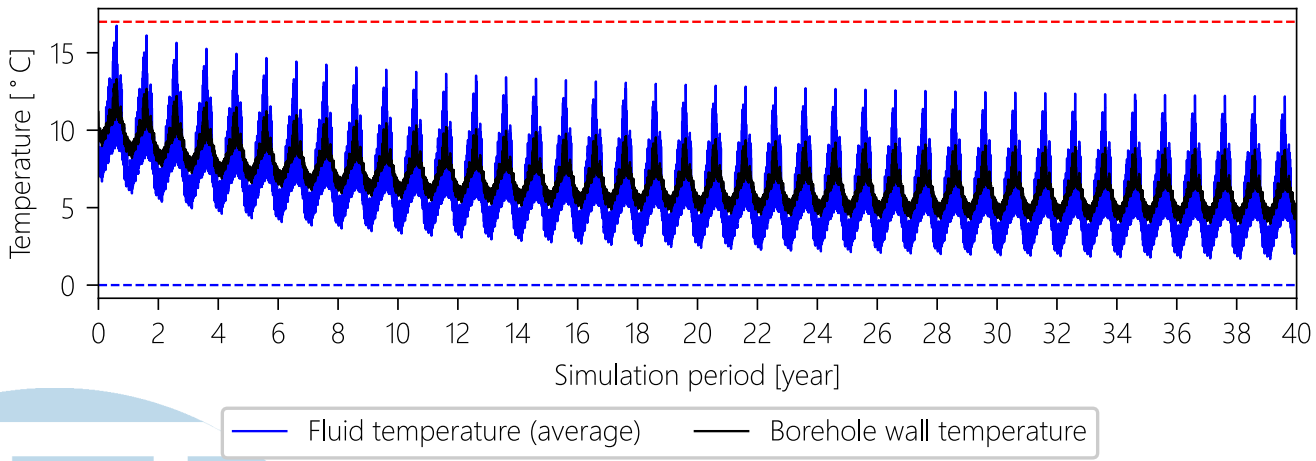
Building demand	Yearly load	Peak power
Heating demand	92 547 kWh/y	47,7 kW
Domestic hot water demand	60 017 kWh/y	29,6 kW
Cooling demand	24 084 kWh/y	96,7 kW

Results

Effective borehole thermal resistance (extraction): 0,1814 m·K/W, Reynolds number: 503 (laminar)

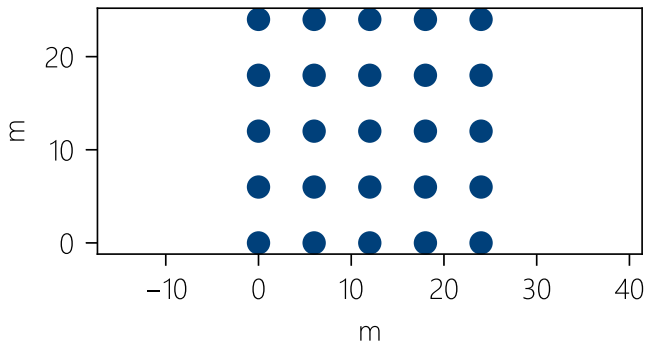
Effective borehole thermal resistance (injection): 0,1440 m·K/W, Reynolds number: 1 887 (laminar)

Maximum average fluid temperature: 16,75 °C, Minimum average fluid temperature: 1,68 °C



2.2 Optimise balance - 5x5

Input



Number of boreholes: 25

Average minimum borehole spacing: 6,0 m

Borehole depth (w.r.t. surface): 100,0 m

2 x U tube DN32 PN16

25,0 v/v% MPG

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

Building demand	Yearly load	Peak power
Heating demand	92 547 kWh/y	47,7 kW
Domestic hot water demand	60 017 kWh/y	29,6 kW
Cooling demand	24 084 kWh/y	96,7 kW

Results

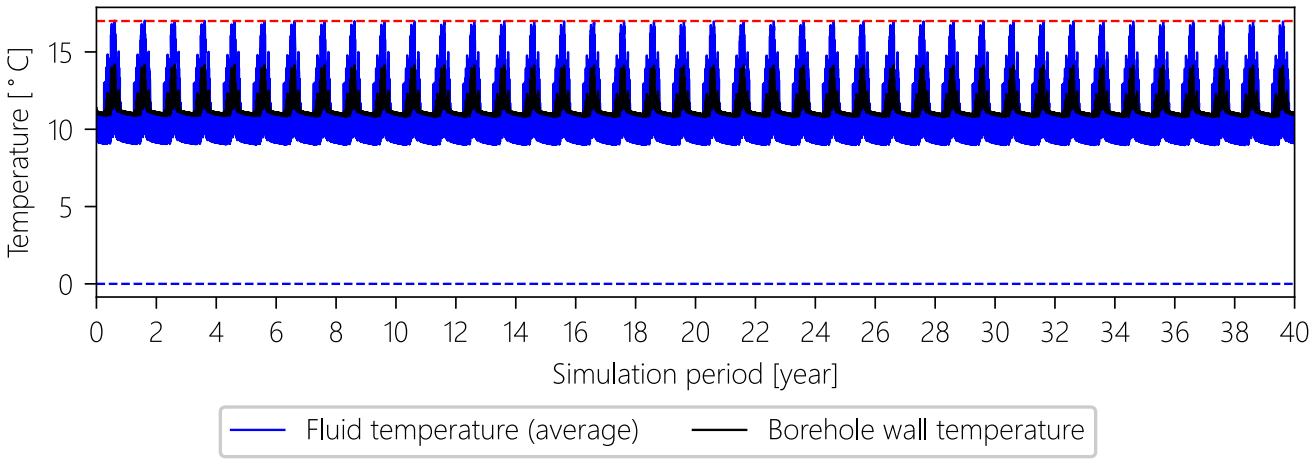
Yearly load	Heating demand	Cooling demand	Domestic hot water demand
Geothermal	588 kWh/y (0,64 %)	22 692 kWh/y (94,22 %)	36 915 kWh/y (61,51 %)
Hybrid	91 959 kWh/y (99,36 %)	1 392 kWh/y (5,78 %)	23 102 kWh/y (38,49 %)

Peak power	Heating demand	Cooling demand	Domestic hot water demand
Geothermal	0,1 kW (0,21 %)	45,0 kW (46,58 %)	8,2 kW(27,78 %)
Hybrid	47,6 kW (99,79 %)	51,6 kW (53,42 %)	21,4 kW(72,22 %)

Effective borehole thermal resistance (extraction): 0,8125 m·K/W, Reynolds number: 123 (laminar)

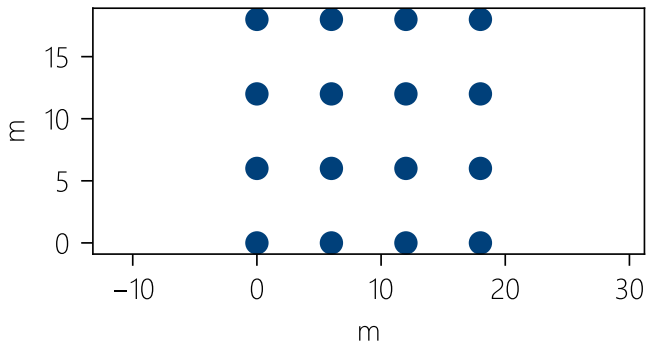
Effective borehole thermal resistance (injection): 0,1538 m·K/W, Reynolds number: 1 421 (laminar)

Maximum average fluid temperature: 17,03 °C, Minimum average fluid temperature: 8,97 °C


Temperature [° C]
15
10
5
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
Simulation period [year]
Fluid temperature (average)
Borehole wall temperature

2.3 Optimise balance - 4x4

Input



Number of boreholes: 16

Average minimum borehole spacing: 6,0 m

Borehole depth (w.r.t. surface): 100,0 m

2 x U tube DN32 PN16

25,0 v/v% MPG

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

Building demand	Yearly load	Peak power
Heating demand	92 547 kWh/y	47,7 kW
Domestic hot water demand	60 017 kWh/y	29,6 kW
Cooling demand	24 084 kWh/y	96,7 kW

Results

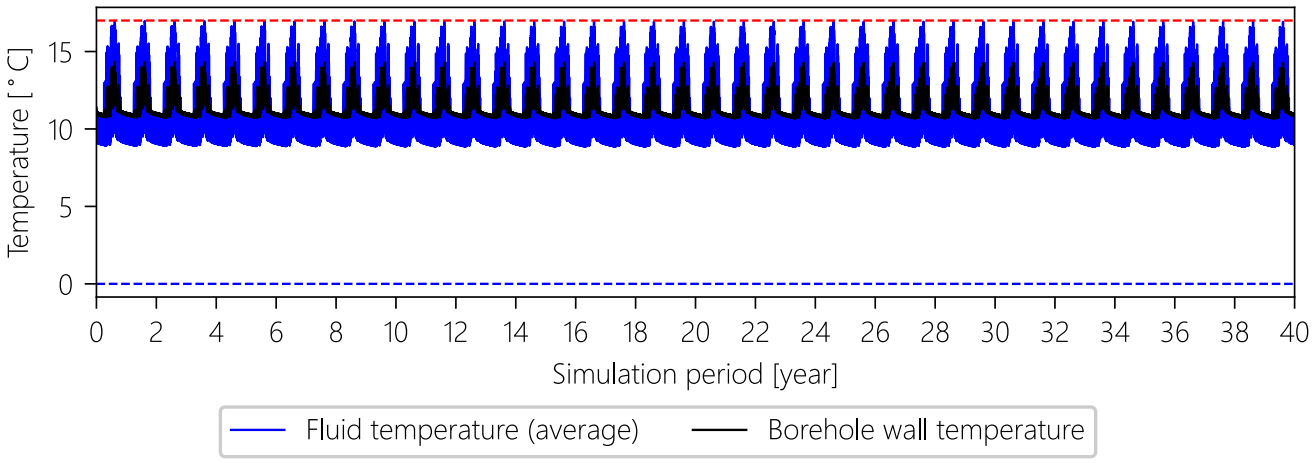
Yearly load	Heating demand	Cooling demand	Domestic hot water demand
Geothermal	588 kWh/y (0,64 %)	18 863 kWh/y (78,32 %)	30 567 kWh/y (50,93 %)
Hybrid	91 959 kWh/y (99,36 %)	5 221 kWh/y (21,68 %)	29 450 kWh/y (49,07 %)

Peak power	Heating demand	Cooling demand	Domestic hot water demand
Geothermal	0,1 kW (0,21 %)	26,9 kW (27,84 %)	5,9 kW(20,02 %)
Hybrid	47,6 kW (99,79 %)	69,8 kW (72,16 %)	23,7 kW(79,98 %)

Effective borehole thermal resistance (extraction): 0,7177 m·K/W, Reynolds number: 138 (laminar)

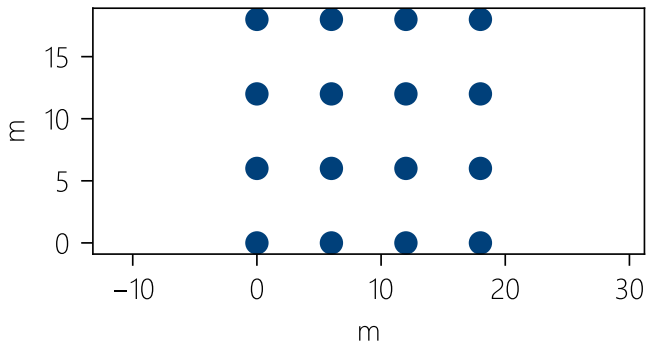
Effective borehole thermal resistance (injection): 0,1570 m·K/W, Reynolds number: 1 324 (laminar)

Maximum average fluid temperature: 16,98 °C, Minimum average fluid temperature: 8,85 °C


Temperature [° C]
15
10
5
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
Simulation period [year]
Fluid temperature (average)
Borehole wall temperature

2.4 Optimise balance - 4x4 - 25%

Input



Number of boreholes: 16

Average minimum borehole spacing: 6,0 m

Borehole depth (w.r.t. surface): 100,0 m

2 x U tube DN32 PN16

25,0 v/v% MPG

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

Building demand	Yearly load	Peak power
Heating demand	92 547 kWh/y	47,7 kW
Domestic hot water demand	60 017 kWh/y	29,6 kW
Cooling demand	24 084 kWh/y	96,7 kW

Results

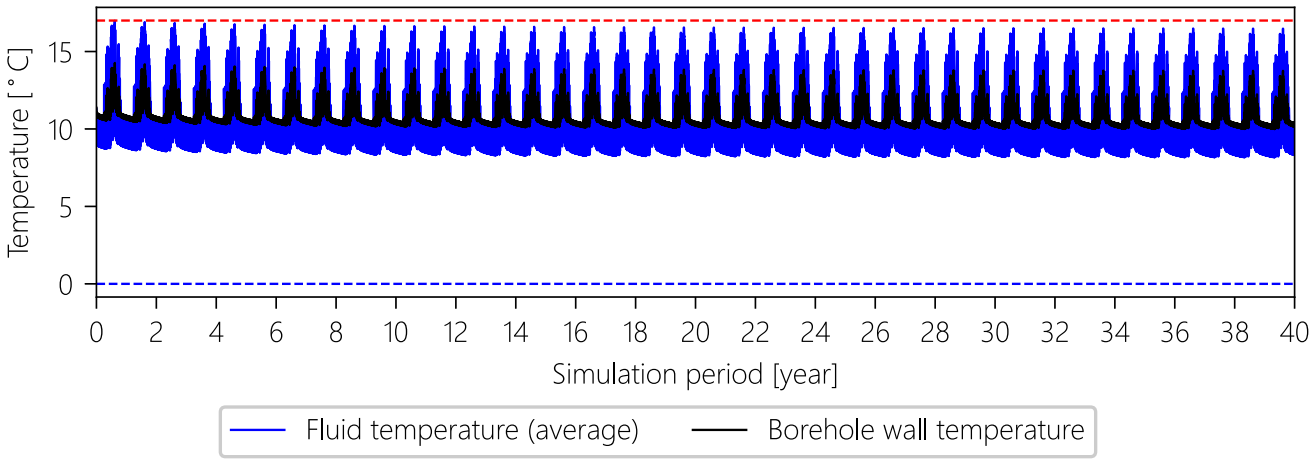
Yearly load	Heating demand	Cooling demand	Domestic hot water demand
Geothermal	588 kWh/y (0,64 %)	19 135 kWh/y (79,45 %)	39 479 kWh/y (65,78 %)
Hybrid	91 959 kWh/y (99,36 %)	4 948 kWh/y (20,55 %)	20 538 kWh/y (34,22 %)

Peak power	Heating demand	Cooling demand	Domestic hot water demand
Geothermal	0,1 kW (0,21 %)	27,8 kW (28,73 %)	9,3 kW(31,28 %)
Hybrid	47,6 kW (99,79 %)	68,9 kW (71,27 %)	20,3 kW(68,72 %)

Effective borehole thermal resistance (extraction): 0,4634 m·K/W, Reynolds number: 208 (laminar)

Effective borehole thermal resistance (injection): 0,1555 m·K/W, Reynolds number: 1 367 (laminar)

Maximum average fluid temperature: 16,99 °C, Minimum average fluid temperature: 8,17 °C


Temperature [° C]
15
10
5
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
Simulation period [year]
Fluid temperature (average)
Borehole wall temperature

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, fluid data, load data, and efficiency data.

3.1 General simulation settings

The scenarios in this report have been simulated with a simulation period of 40 years, starting in January. The maximum and minimum average fluid temperatures were 0,00 °C and 17,00 °C respectively. The simulations were carried out with GHEtool Cloud v2.9.0.1.

3.2 Ground data

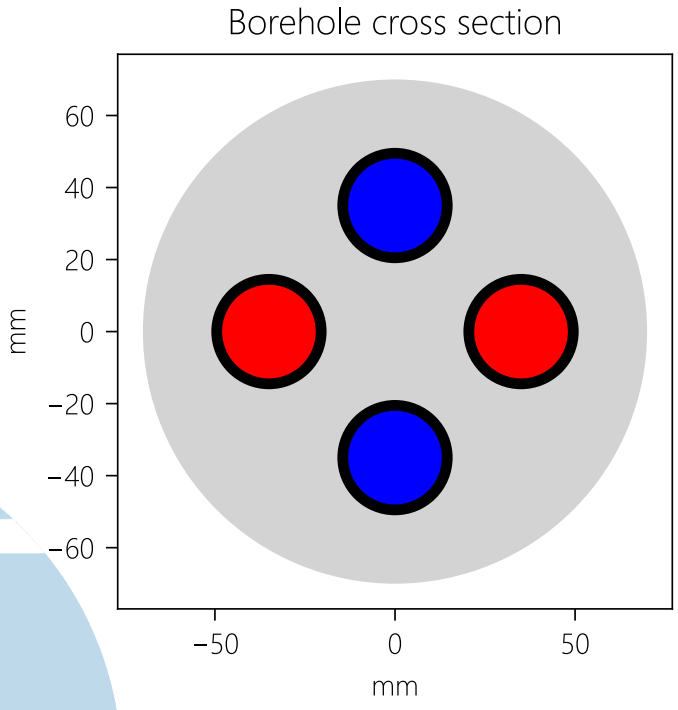
The ground is modelled as a single homogeneous layer with an average thermal conductivity of 2,00 W/(m·K) and a volumetric heat capacity of 2,40 MJ/(m^3·K). This means that the ground properties are assumed to remain constant at all depths.

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 10,47 °C at 50 m and 11,35 °C at 100 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 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).



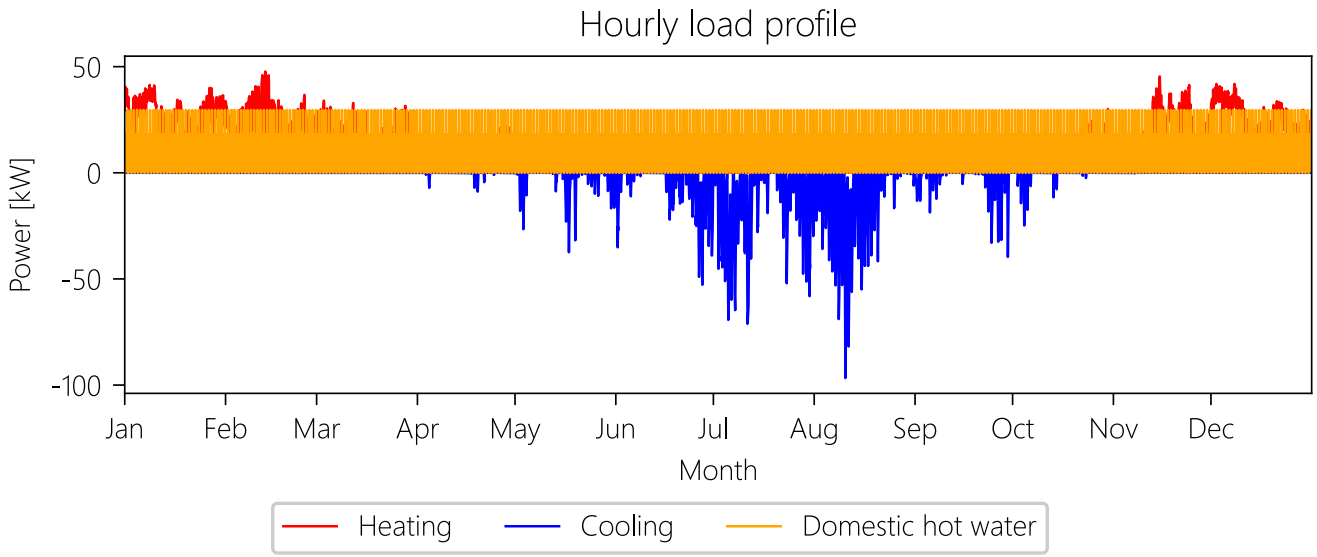
3.4 Fluid data

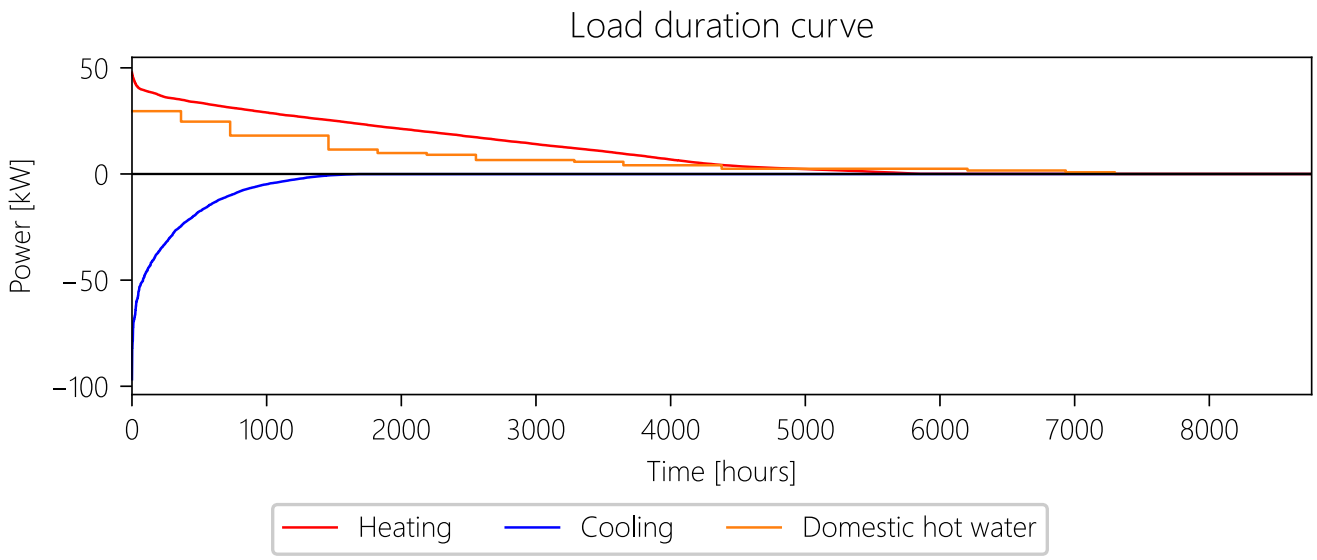
As a heat transfer fluid, MPG with 25,0 v/v% was selected, which provides frost protection down to approximately -10 °C. For a more accurate simulation, the fluid properties (such as viscosity and density) are assumed to be temperature-dependent and therefore vary throughout the simulation period. This 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.

3.5 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	92 547 kWh/y	47,7 kW
Domestic hot water demand	60 017 kWh/y	29,6 kW
Cooling demand	24 084 kWh/y	96,7 kW





3.6 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 Req size

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

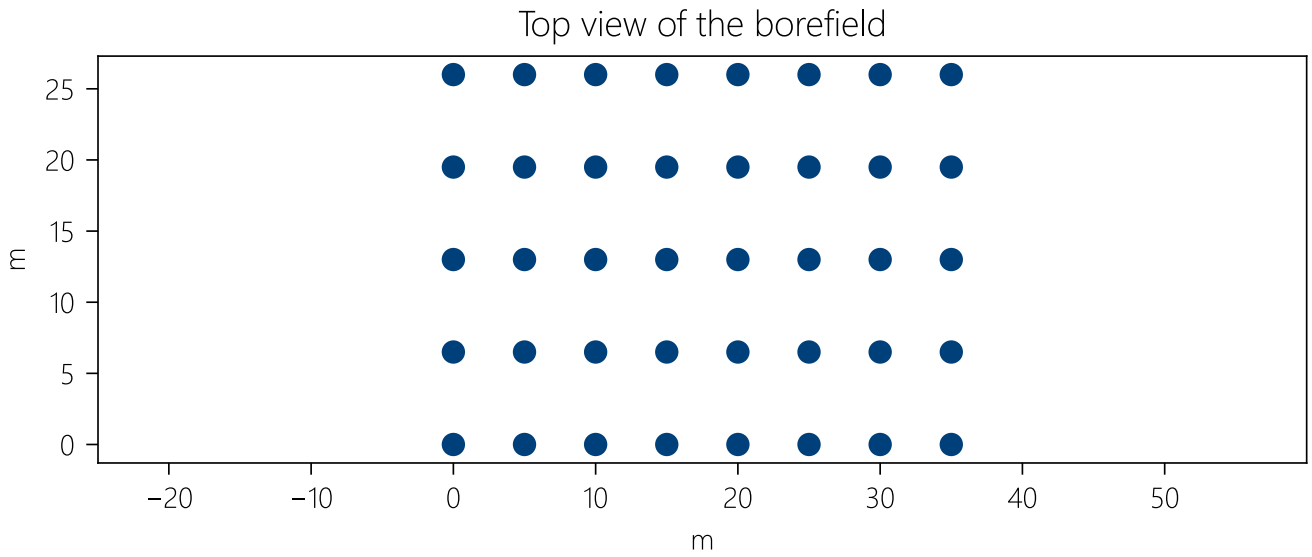
4.1.1 Input

Borefield configuration

The simulations were carried out with a borefield consisting of 40 boreholes, with an average buried depth of 1,00 m, an average borehole depth of 101,00 m and an average borehole length of 100,00 m. This results in a total borehole length of 4 000,00 m.

The minimum average borehole spacing is 5,00 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	100,00	101,00	1,00	0,00	0,00
5,00	0,00	100,00	101,00	1,00	0,00	0,00
10,00	0,00	100,00	101,00	1,00	0,00	0,00
15,00	0,00	100,00	101,00	1,00	0,00	0,00
20,00	0,00	100,00	101,00	1,00	0,00	0,00
25,00	0,00	100,00	101,00	1,00	0,00	0,00
30,00	0,00	100,00	101,00	1,00	0,00	0,00
35,00	0,00	100,00	101,00	1,00	0,00	0,00
0,00	6,50	100,00	101,00	1,00	0,00	0,00
5,00	6,50	100,00	101,00	1,00	0,00	0,00
10,00	6,50	100,00	101,00	1,00	0,00	0,00
15,00	6,50	100,00	101,00	1,00	0,00	0,00
20,00	6,50	100,00	101,00	1,00	0,00	0,00
25,00	6,50	100,00	101,00	1,00	0,00	0,00
30,00	6,50	100,00	101,00	1,00	0,00	0,00
35,00	6,50	100,00	101,00	1,00	0,00	0,00
0,00	13,00	100,00	101,00	1,00	0,00	0,00
5,00	13,00	100,00	101,00	1,00	0,00	0,00
10,00	13,00	100,00	101,00	1,00	0,00	0,00
15,00	13,00	100,00	101,00	1,00	0,00	0,00
20,00	13,00	100,00	101,00	1,00	0,00	0,00
25,00	13,00	100,00	101,00	1,00	0,00	0,00
30,00	13,00	100,00	101,00	1,00	0,00	0,00
35,00	13,00	100,00	101,00	1,00	0,00	0,00
0,00	19,50	100,00	101,00	1,00	0,00	0,00
5,00	19,50	100,00	101,00	1,00	0,00	0,00
10,00	19,50	100,00	101,00	1,00	0,00	0,00
15,00	19,50	100,00	101,00	1,00	0,00	0,00
20,00	19,50	100,00	101,00	1,00	0,00	0,00
25,00	19,50	100,00	101,00	1,00	0,00	0,00
30,00	19,50	100,00	101,00	1,00	0,00	0,00
35,00	19,50	100,00	101,00	1,00	0,00	0,00

0,00	26,00	100,00	101,00	1,00	0,00	0,00
5,00	26,00	100,00	101,00	1,00	0,00	0,00
10,00	26,00	100,00	101,00	1,00	0,00	0,00
15,00	26,00	100,00	101,00	1,00	0,00	0,00
20,00	26,00	100,00	101,00	1,00	0,00	0,00
25,00	26,00	100,00	101,00	1,00	0,00	0,00
30,00	26,00	100,00	101,00	1,00	0,00	0,00
35,00	26,00	100,00	101,00	1,00	0,00	0,00

Flow data

The system was simulated with a variable flow rate, where a constant temperature difference across the borefield was used of 3,00 °C in extraction and 3,00 °C in injection, with a minimum flow percentage of 10%. The resulting maximum flow rate through the borefield is 4,21 l/s and 8,49 l/s respectively.

4.1.2 Results

Ground load

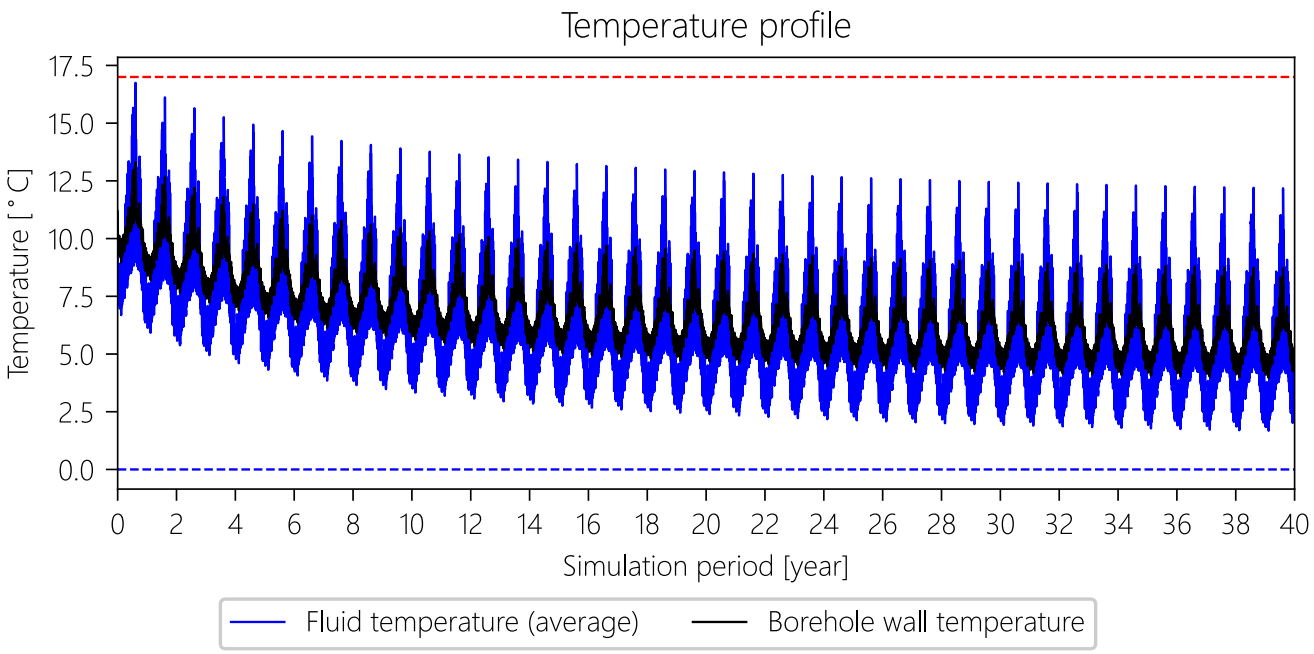
Because we are working with building loads (i.e. secondary loads), these must be converted into injection and extraction loads using the efficiency data. A summary of the resulting yearly ground load is given in the table below.

Ground demand	Yearly load	Peak power
Extraction demand	114 049 kWh/y	50,1 kW
Injection demand	25 288 kWh/y	101,5 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 503, whilst it was 1 887 during injection. This corresponds respectively to a laminar and laminar flow regime, with an effective borehole thermal resistance of 0,1814 m·K/W and 0,1440 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 16,75 °C, and the minimum average fluid temperature is 1,68 °C.

Pressure drop

The pressure drop over a single borehole is 4,88 kPa during extration and 6,28 kPa during injection.

4.2 Optimise balance - 5x5

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

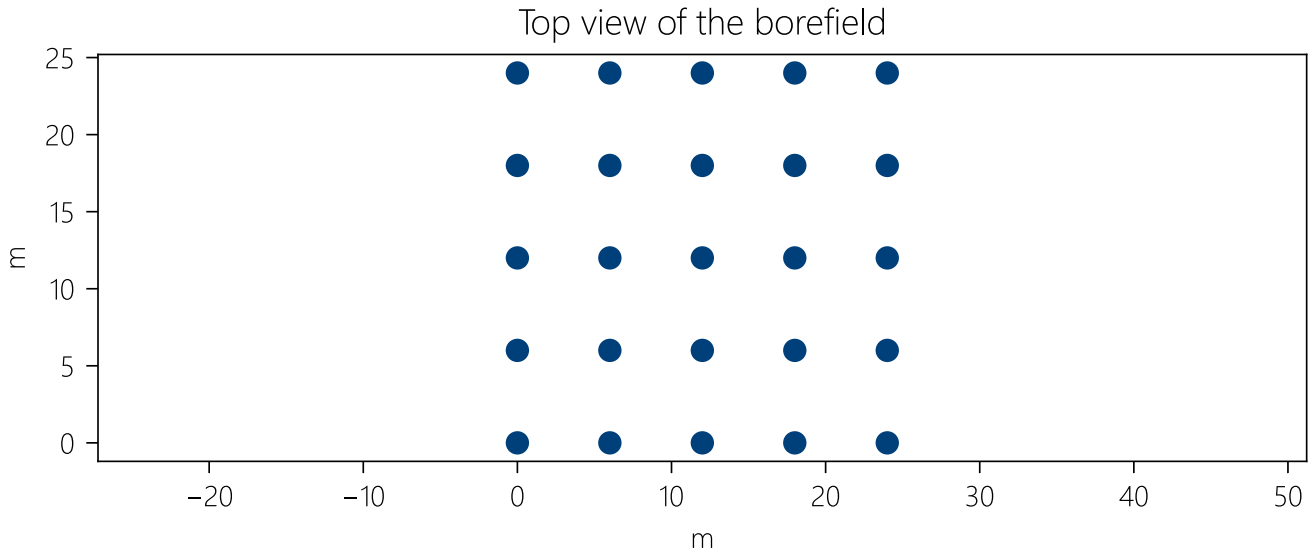
4.2.1 Input

Borefield configuration

The simulations were carried out with a borefield consisting of 25 boreholes, with an average buried depth of 1,00 m, an average borehole depth of 100,00 m and an average borehole length of 99,00 m. This results in a total borehole length of 2 475,00 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	99,00	100,00	1,00	0,00	0,00
0,00	6,00	99,00	100,00	1,00	0,00	0,00
0,00	12,00	99,00	100,00	1,00	0,00	0,00
0,00	18,00	99,00	100,00	1,00	0,00	0,00
0,00	24,00	99,00	100,00	1,00	0,00	0,00
6,00	0,00	99,00	100,00	1,00	0,00	0,00
6,00	6,00	99,00	100,00	1,00	0,00	0,00
6,00	12,00	99,00	100,00	1,00	0,00	0,00
6,00	18,00	99,00	100,00	1,00	0,00	0,00
6,00	24,00	99,00	100,00	1,00	0,00	0,00
12,00	0,00	99,00	100,00	1,00	0,00	0,00
12,00	6,00	99,00	100,00	1,00	0,00	0,00
12,00	12,00	99,00	100,00	1,00	0,00	0,00
12,00	18,00	99,00	100,00	1,00	0,00	0,00
12,00	24,00	99,00	100,00	1,00	0,00	0,00
18,00	0,00	99,00	100,00	1,00	0,00	0,00
18,00	6,00	99,00	100,00	1,00	0,00	0,00
18,00	12,00	99,00	100,00	1,00	0,00	0,00
18,00	18,00	99,00	100,00	1,00	0,00	0,00
18,00	24,00	99,00	100,00	1,00	0,00	0,00
24,00	0,00	99,00	100,00	1,00	0,00	0,00
24,00	6,00	99,00	100,00	1,00	0,00	0,00
24,00	12,00	99,00	100,00	1,00	0,00	0,00
24,00	18,00	99,00	100,00	1,00	0,00	0,00
24,00	24,00	99,00	100,00	1,00	0,00	0,00

Flow data

The system was simulated with a variable flow rate, where a constant temperature difference across the borefield was used of 3,00 °C in extraction and 3,00 °C in injection, with a minimum flow percentage of 10%. The resulting maximum flow rate through the borefield is 4,20 l/s and 8,49 l/s respectively.

4.2.2 Results

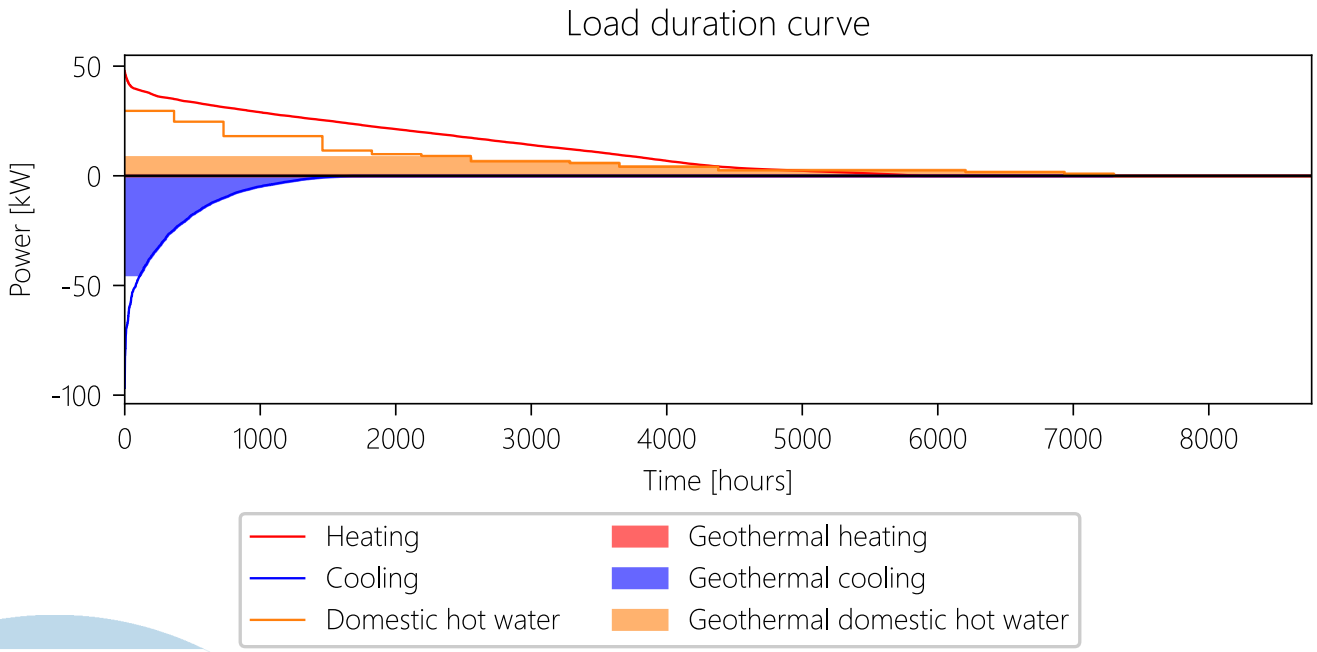
Hybrid system

For this scenario, a hybrid system was simulated using the 'optimise for balance' method in GHEtool. Given a fixed borefield size and building demand, the geothermal share is calculated based on the maximum amount of heating and cooling power that can be assigned to the borefield throughout the whole simulation period, while staying within the temperature limits of 0,00 °C and 17,00 °C. In addition, only a 5 % imbalance is allowed. This optimisation results in a solution with zero oversizing for the entire heating and cooling system.

Yearly load	Heating demand	Cooling demand	Domestic hot water demand
Geothermal	588 kWh/y (0,64 %)	22 692 kWh/y (94,22 %)	36 915 kWh/y (61,51 %)
Hybrid	91 959 kWh/y (99,36 %)	1 392 kWh/y (5,78 %)	23 102 kWh/y (38,49 %)

Peak power	Heating demand	Cooling demand	Domestic hot water demand
Geothermal	0,1 kW (0,21 %)	45,0 kW (46,58 %)	8,2 kW(27,78 %)
Hybrid	47,6 kW (99,79 %)	51,6 kW (53,42 %)	21,4 kW(72,22 %)

The graph below shows the load duration curve of the building and the percentage that can be fulfilled by the geothermal system. The uncoloured area is supplied by the hybrid system.



Ground load

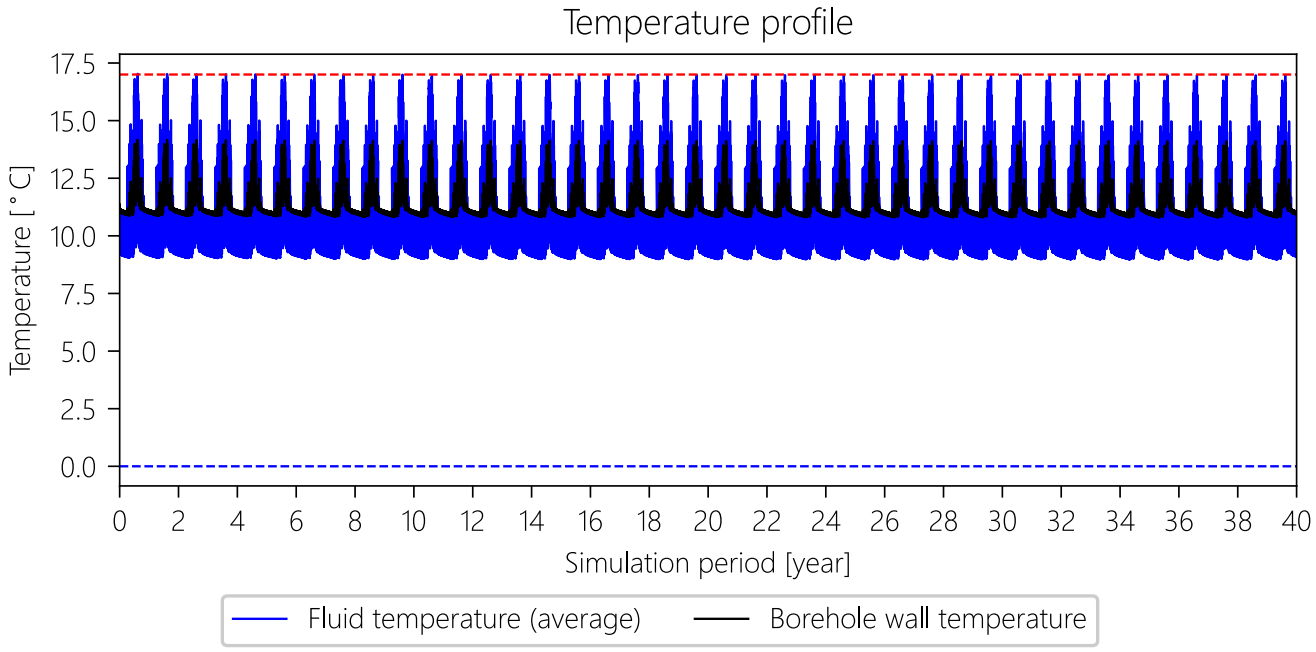
Because we are working with building loads (i.e. secondary loads), these must be converted into injection and extraction loads using the efficiency data. A summary of the resulting yearly ground load is given in the table below.

Ground demand	Yearly load	Peak power
Extraction demand	25 080 kWh/y	5,6 kW
Injection demand	23 826 kWh/y	47,3 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 123, whilst it was 1 421 during injection. This corresponds respectively to a laminar and laminar flow regime, with an effective borehole thermal resistance of 0,8125 m·K/W and 0,1538 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 17,03 °C, and the minimum average fluid temperature is 8,97 °C.

Pressure drop

The pressure drop over a single borehole is 0,63 kPa during extration and 4,15 kPa during injection.

4.3 Optimise balance - 4x4

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

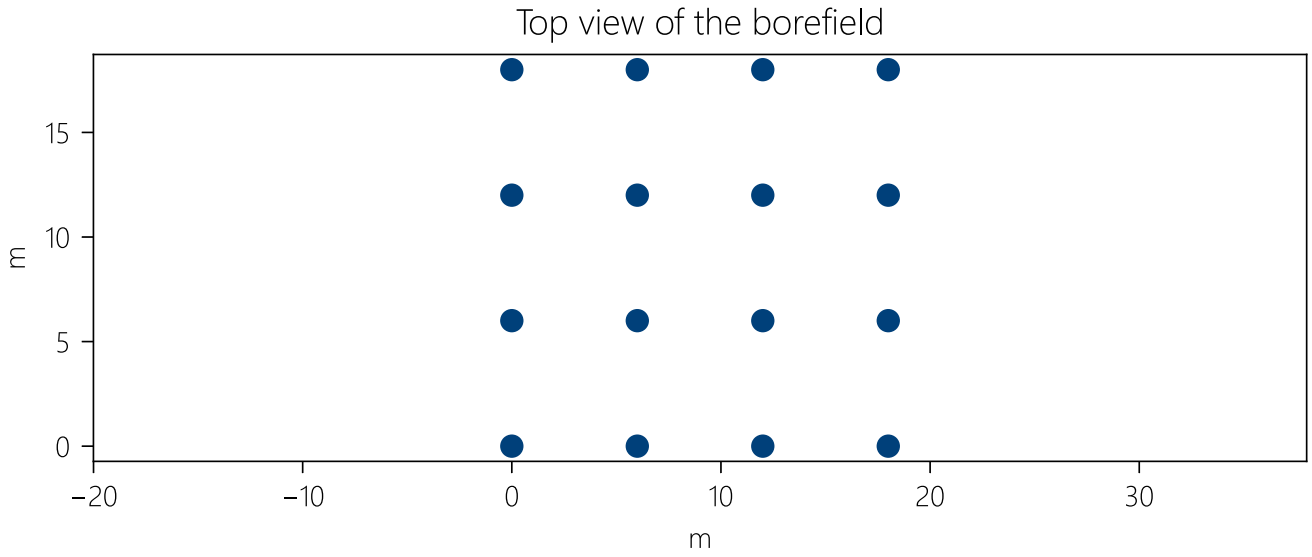
4.3.1 Input

Borefield configuration

The simulations were carried out with a borefield consisting of 16 boreholes, with an average buried depth of 1,00 m, an average borehole depth of 100,00 m and an average borehole length of 99,00 m. This results in a total borehole length of 1 584,00 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	99,00	100,00	1,00	0,00	0,00
0,00	6,00	99,00	100,00	1,00	0,00	0,00
0,00	12,00	99,00	100,00	1,00	0,00	0,00
0,00	18,00	99,00	100,00	1,00	0,00	0,00
6,00	0,00	99,00	100,00	1,00	0,00	0,00
6,00	6,00	99,00	100,00	1,00	0,00	0,00
6,00	12,00	99,00	100,00	1,00	0,00	0,00
6,00	18,00	99,00	100,00	1,00	0,00	0,00
12,00	0,00	99,00	100,00	1,00	0,00	0,00
12,00	6,00	99,00	100,00	1,00	0,00	0,00
12,00	12,00	99,00	100,00	1,00	0,00	0,00
12,00	18,00	99,00	100,00	1,00	0,00	0,00
18,00	0,00	99,00	100,00	1,00	0,00	0,00
18,00	6,00	99,00	100,00	1,00	0,00	0,00
18,00	12,00	99,00	100,00	1,00	0,00	0,00
18,00	18,00	99,00	100,00	1,00	0,00	0,00

Flow data

The system was simulated with a variable flow rate, where a constant temperature difference across the borefield was used of 3,00 °C in extraction and 3,00 °C in injection, with a minimum flow percentage of 10%. The resulting maximum flow rate through the borefield is 4,20 l/s and 8,49 l/s respectively.

4.3.2 Results

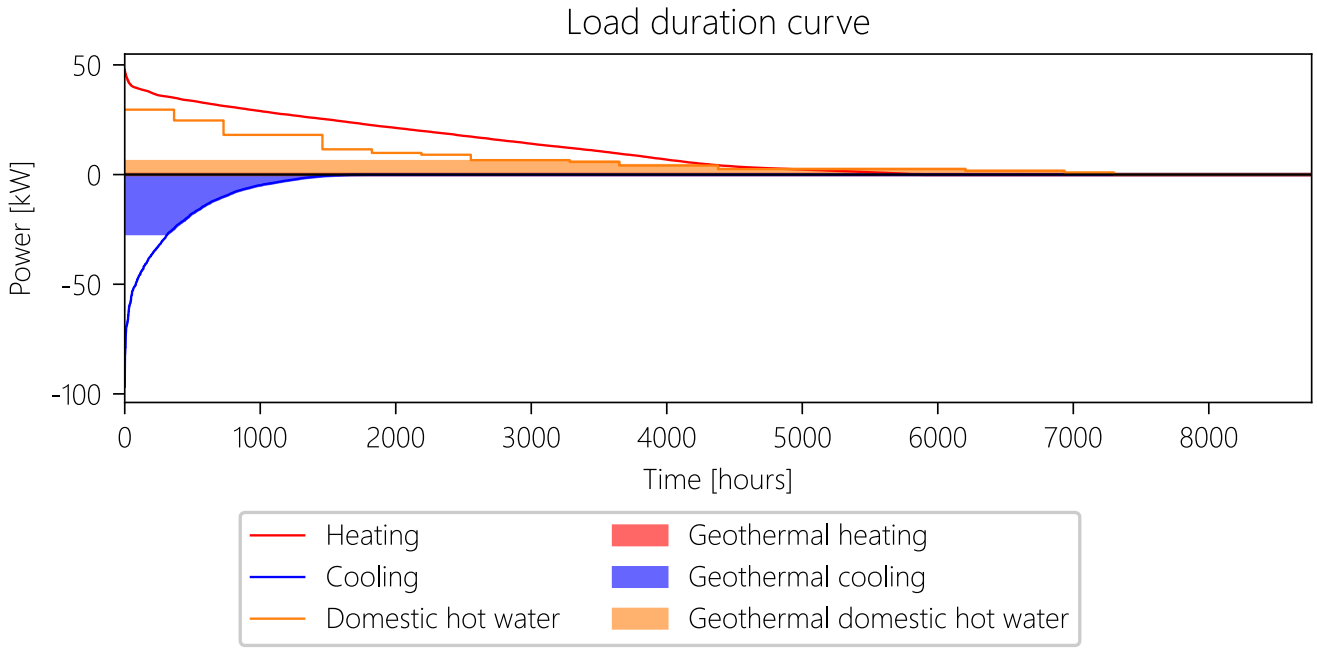
Hybrid system

For this scenario, a hybrid system was simulated using the 'optimise for balance' method in GHEtool. Given a fixed borefield size and building demand, the geothermal share is calculated based on the maximum amount of heating and cooling power that can be assigned to the borefield throughout the whole simulation period, while staying within the temperature limits of 0,00 °C and 17,00 °C. In addition, only a 5 % imbalance is allowed. This optimisation results in a solution with zero oversizing for the entire heating and cooling system.

Yearly load	Heating demand	Cooling demand	Domestic hot water demand
Geothermal	588 kWh/y (0,64 %)	18 863 kWh/y (78,32 %)	30 567 kWh/y (50,93 %)
Hybrid	91 959 kWh/y (99,36 %)	5 221 kWh/y (21,68 %)	29 450 kWh/y (49,07 %)

Peak power	Heating demand	Cooling demand	Domestic hot water demand
Geothermal	0,1 kW (0,21 %)	26,9 kW (27,84 %)	5,9 kW(20,02 %)
Hybrid	47,6 kW (99,79 %)	69,8 kW (72,16 %)	23,7 kW(79,98 %)

The graph below shows the load duration curve of the building and the percentage that can be fulfilled by the geothermal system. The uncoloured area is supplied by the hybrid system.



Ground load

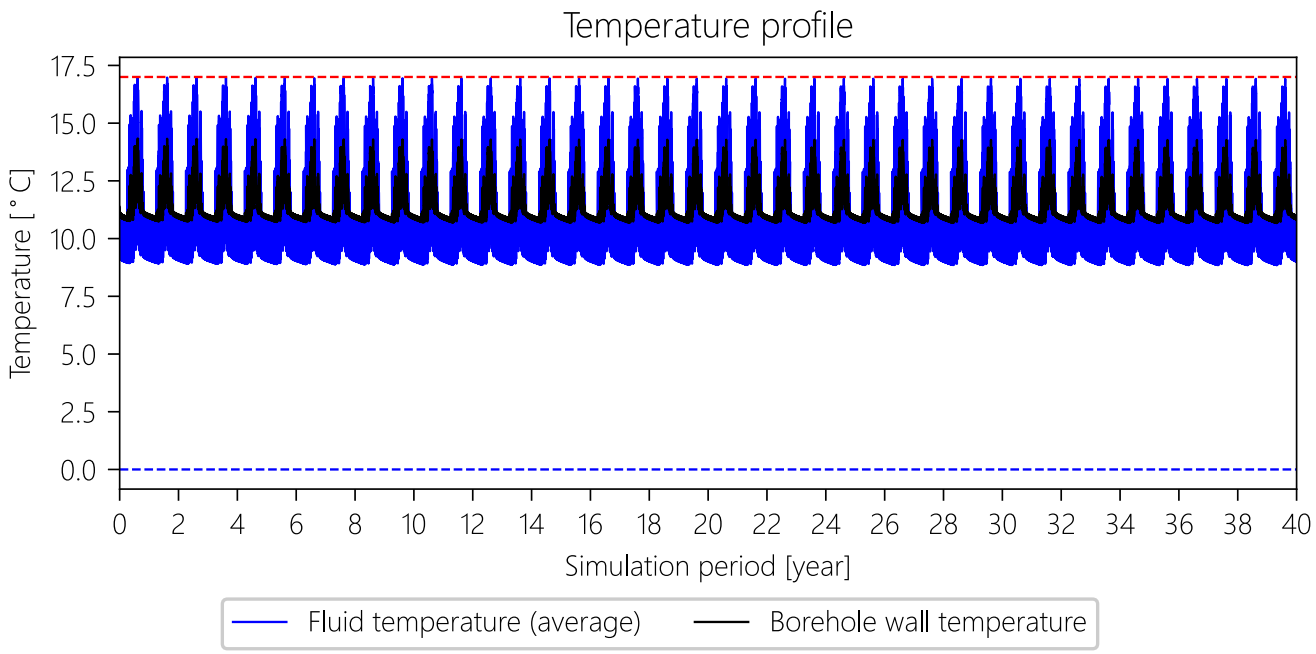
Because we are working with building loads (i.e. secondary loads), these must be converted into injection and extraction loads using the efficiency data. A summary of the resulting yearly ground load is given in the table below.

Ground demand	Yearly load	Peak power
Extraction demand	20 848 kWh/y	4,0 kW
Injection demand	19 806 kWh/y	28,3 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 138, whilst it was 1 324 during injection. This corresponds respectively to a laminar and laminar flow regime, with an effective borehole thermal resistance of 0,7177 m·K/W and 0,1570 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 16,98 °C, and the minimum average fluid temperature is 8,85 °C.

Pressure drop

The pressure drop over a single borehole is 0,71 kPa during extration and 4,00 kPa during injection.

4.4 Optimise balance - 4x4 - 25%

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

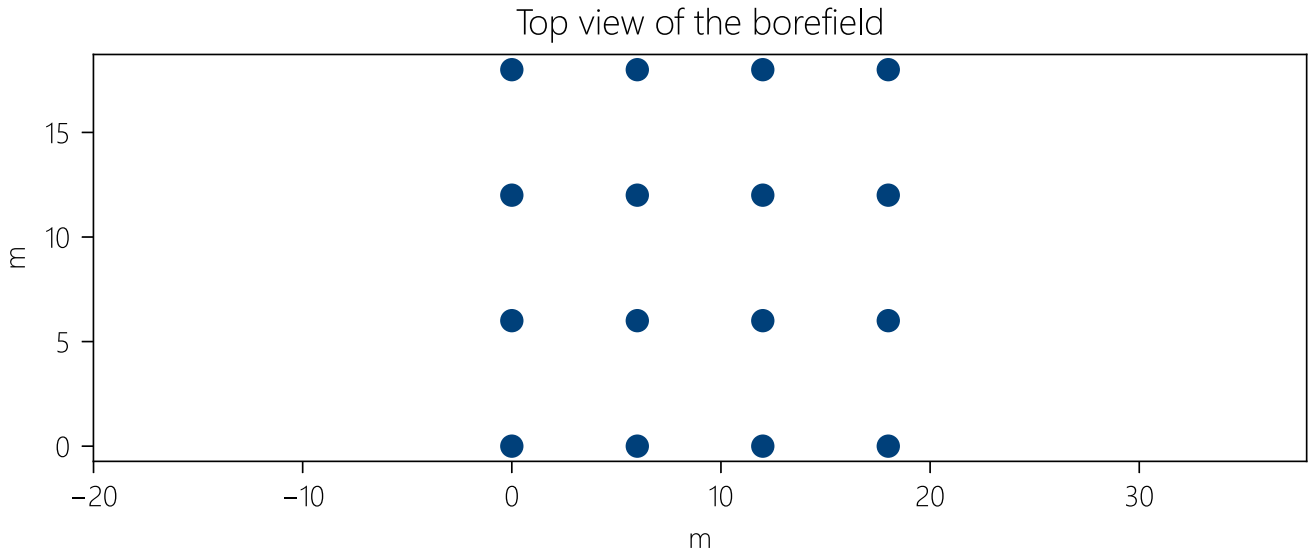
4.4.1 Input

Borefield configuration

The simulations were carried out with a borefield consisting of 16 boreholes, with an average buried depth of 1,00 m, an average borehole depth of 100,00 m and an average borehole length of 99,00 m. This results in a total borehole length of 1 584,00 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	99,00	100,00	1,00	0,00	0,00
0,00	6,00	99,00	100,00	1,00	0,00	0,00
0,00	12,00	99,00	100,00	1,00	0,00	0,00
0,00	18,00	99,00	100,00	1,00	0,00	0,00
6,00	0,00	99,00	100,00	1,00	0,00	0,00
6,00	6,00	99,00	100,00	1,00	0,00	0,00
6,00	12,00	99,00	100,00	1,00	0,00	0,00
6,00	18,00	99,00	100,00	1,00	0,00	0,00
12,00	0,00	99,00	100,00	1,00	0,00	0,00
12,00	6,00	99,00	100,00	1,00	0,00	0,00
12,00	12,00	99,00	100,00	1,00	0,00	0,00
12,00	18,00	99,00	100,00	1,00	0,00	0,00
18,00	0,00	99,00	100,00	1,00	0,00	0,00
18,00	6,00	99,00	100,00	1,00	0,00	0,00
18,00	12,00	99,00	100,00	1,00	0,00	0,00
18,00	18,00	99,00	100,00	1,00	0,00	0,00

Flow data

The system was simulated with a variable flow rate, where a constant temperature difference across the borefield was used of 3,00 °C in extraction and 3,00 °C in injection, with a minimum flow percentage of 10%. The resulting maximum flow rate through the borefield is 4,20 l/s and 8,49 l/s respectively.

4.4.2 Results

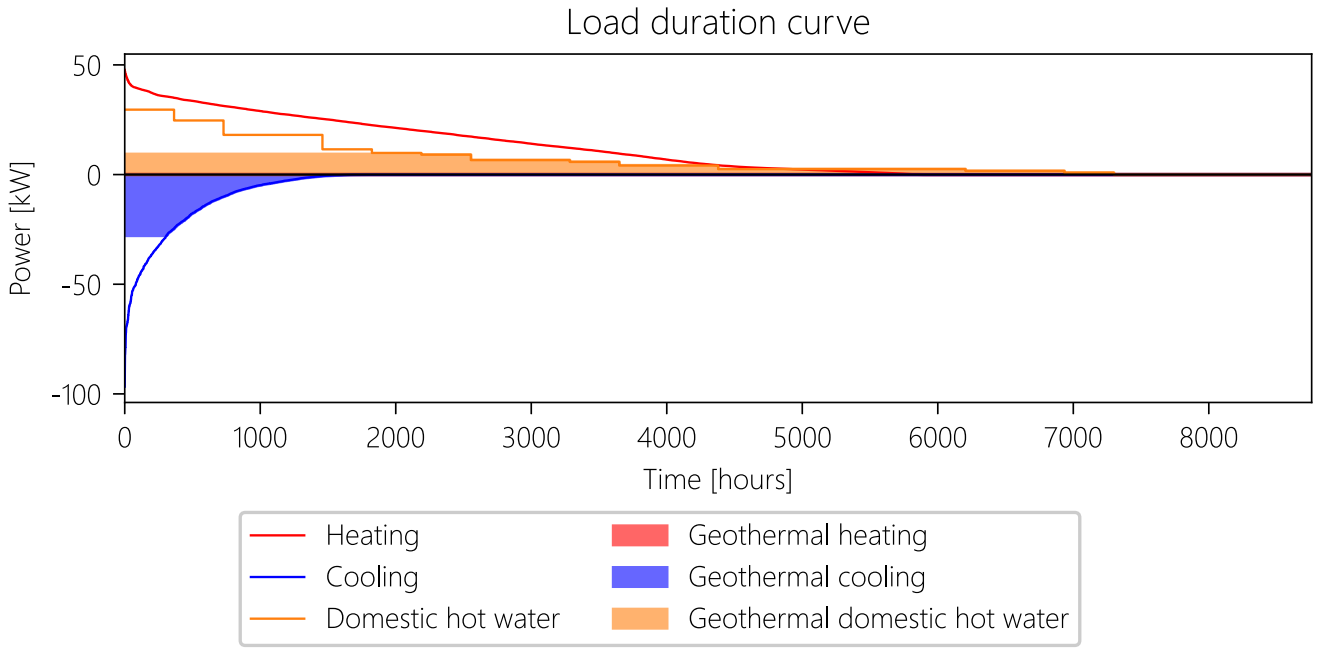
Hybrid system

For this scenario, a hybrid system was simulated using the 'optimise for balance' method in GHEtool. Given a fixed borefield size and building demand, the geothermal share is calculated based on the maximum amount of heating and cooling power that can be assigned to the borefield throughout the whole simulation period, while staying within the temperature limits of 0,00 °C and 17,00 °C. In addition, only a 25 % imbalance is allowed. This optimisation results in a solution with zero oversizing for the entire heating and cooling system.

Yearly load	Heating demand	Cooling demand	Domestic hot water demand
Geothermal	588 kWh/y (0,64 %)	19 135 kWh/y (79,45 %)	39 479 kWh/y (65,78 %)
Hybrid	91 959 kWh/y (99,36 %)	4 948 kWh/y (20,55 %)	20 538 kWh/y (34,22 %)

Peak power	Heating demand	Cooling demand	Domestic hot water demand
Geothermal	0,1 kW (0,21 %)	27,8 kW (28,73 %)	9,3 kW(31,28 %)
Hybrid	47,6 kW (99,79 %)	68,9 kW (71,27 %)	20,3 kW(68,72 %)

The graph below shows the load duration curve of the building and the percentage that can be fulfilled by the geothermal system. The uncoloured area is supplied by the hybrid system.



Ground load

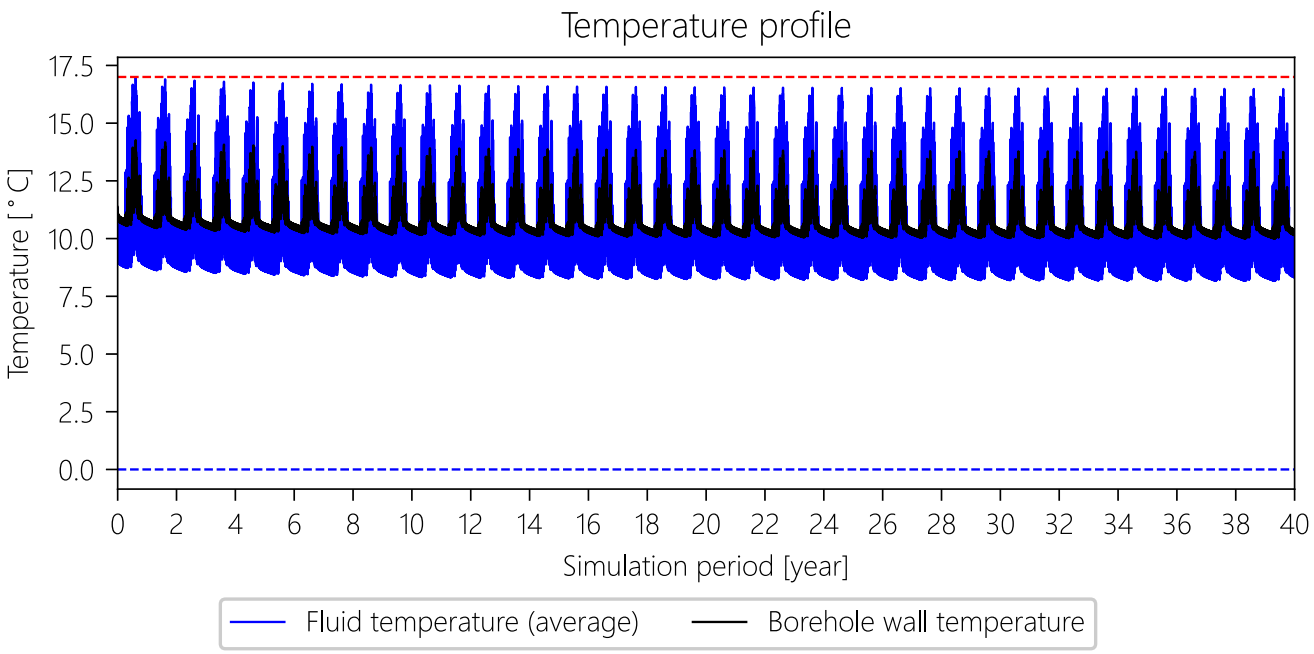
Because we are working with building loads (i.e. secondary loads), these must be converted into injection and extraction loads using the efficiency data. A summary of the resulting yearly ground load is given in the table below.

Ground demand	Yearly load	Peak power
Extraction demand	26 790 kWh/y	6,3 kW
Injection demand	20 092 kWh/y	29,2 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 208, whilst it was 1 367 during injection. This corresponds respectively to a laminar and laminar flow regime, with an effective borehole thermal resistance of 0,4634 m·K/W and 0,1555 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 16,99 °C, and the minimum average fluid temperature is 8,17 °C.

Pressure drop

The pressure drop over a single borehole is 1,14 kPa during extration and 4,21 kPa during injection.

5.1 Design Data - Req size

Design parameters

- Maximum average fluid temperature: 17 °C
- Minimum average fluid temperature: 0 °C
- First month of simulation: 1
- Simulation period: 40 years

Ground parameters

- Homogeneous ground conductivity: 2 W/(m·K)
- Homogeneous volumetric heat capacity: 2,4 MJ/(m^3·K)
- Ground surface temperature: 9,6 °C
- Ground flux: 0,07 W/m^2

Borehole parameters

- Borehole diameter: 140 mm

Pipe parameters

- U tube DN32 PN16
- Grout thermal conductivity: 1,5 W/(m·K)
- Number of U-tubes: 2
- Pipe conductivity: 0,4 W/(m·K)
- Pipe roughness: 0,001 mm

Fluid properties

- 25.0 v/v% MPG
- Temperature difference in extraction: 3 °C
- Temperature difference in injection: 3 °C
- Minimum flow percentage: 10
- Flow rate through borefield in extraction: 4,21 l/s
- Flow rate through borefield in injection: 8,50 l/s
- Number of boreholes in series: 1

Thermal demand

- Type of load: Hourly building load
- Domestic hot water: 60 016,95 kWh/year
- SCOP heating: 5
- SCOP domestic hot water: 3
- SEER cooling: 20

Borefield parameters

x [m]	y [m]	Length [m]	Depth [m]	Buried depth [m]	Tilt [°]	Orientation [°]
0,00	0,00	100,00	101,00	1,00	0,00	0,00
5,00	0,00	100,00	101,00	1,00	0,00	0,00
10,00	0,00	100,00	101,00	1,00	0,00	0,00
15,00	0,00	100,00	101,00	1,00	0,00	0,00
20,00	0,00	100,00	101,00	1,00	0,00	0,00
25,00	0,00	100,00	101,00	1,00	0,00	0,00
30,00	0,00	100,00	101,00	1,00	0,00	0,00
35,00	0,00	100,00	101,00	1,00	0,00	0,00
0,00	6,50	100,00	101,00	1,00	0,00	0,00
5,00	6,50	100,00	101,00	1,00	0,00	0,00
10,00	6,50	100,00	101,00	1,00	0,00	0,00
15,00	6,50	100,00	101,00	1,00	0,00	0,00
20,00	6,50	100,00	101,00	1,00	0,00	0,00
25,00	6,50	100,00	101,00	1,00	0,00	0,00
30,00	6,50	100,00	101,00	1,00	0,00	0,00
35,00	6,50	100,00	101,00	1,00	0,00	0,00
0,00	13,00	100,00	101,00	1,00	0,00	0,00
5,00	13,00	100,00	101,00	1,00	0,00	0,00
10,00	13,00	100,00	101,00	1,00	0,00	0,00
15,00	13,00	100,00	101,00	1,00	0,00	0,00
20,00	13,00	100,00	101,00	1,00	0,00	0,00
25,00	13,00	100,00	101,00	1,00	0,00	0,00
30,00	13,00	100,00	101,00	1,00	0,00	0,00
35,00	13,00	100,00	101,00	1,00	0,00	0,00
0,00	19,50	100,00	101,00	1,00	0,00	0,00
5,00	19,50	100,00	101,00	1,00	0,00	0,00
10,00	19,50	100,00	101,00	1,00	0,00	0,00
15,00	19,50	100,00	101,00	1,00	0,00	0,00
20,00	19,50	100,00	101,00	1,00	0,00	0,00
25,00	19,50	100,00	101,00	1,00	0,00	0,00
30,00	19,50	100,00	101,00	1,00	0,00	0,00
35,00	19,50	100,00	101,00	1,00	0,00	0,00
0,00	26,00	100,00	101,00	1,00	0,00	0,00
5,00	26,00	100,00	101,00	1,00	0,00	0,00
10,00	26,00	100,00	101,00	1,00	0,00	0,00
15,00	26,00	100,00	101,00	1,00	0,00	0,00
20,00	26,00	100,00	101,00	1,00	0,00	0,00

25,00	26,00	100,00	101,00	1,00	0,00	0,00
30,00	26,00	100,00	101,00	1,00	0,00	0,00
35,00	26,00	100,00	101,00	1,00	0,00	0,00

5.2 Design Data - Optimise balance - 5x5

Design parameters

- Maximum average fluid temperature: 17 °C
- Minimum average fluid temperature: 0 °C
- First month of simulation: 1
- Simulation period: 40 years

Ground parameters

- Homogeneous ground conductivity: 2 W/(m·K)
- Homogeneous volumetric heat capacity: 2,4 MJ/(m^3·K)
- Ground surface temperature: 9,6 °C
- Ground flux: 0,07 W/m^2

Borehole parameters

- Borehole diameter: 140 mm

Pipe parameters

- U tube DN32 PN16
- Grout thermal conductivity: 1,5 W/(m·K)
- Number of U-tubes: 2
- Pipe conductivity: 0,4 W/(m·K)
- Pipe roughness: 0,001 mm

Fluid properties

- 25.0 v/v% MPG
- Temperature difference in extraction: 3 °C
- Temperature difference in injection: 3 °C
- Minimum flow percentage: 10
- Flow rate through borefield in extraction: 0,47 l/s
- Flow rate through borefield in injection: 3,95 l/s
- Number of boreholes in series: 1

Thermal demand

- Type of load: Hourly building load
- Domestic hot water: 60 016,95 kWh/year
- SCOP heating: 5
- SCOP domestic hot water: 3
- SEER cooling: 20

Borefield parameters

x [m]	y [m]	Length [m]	Depth [m]	Buried depth [m]	Tilt [°]	Orientation [°]
0,00	0,00	99,00	100,00	1,00	0,00	0,00
0,00	6,00	99,00	100,00	1,00	0,00	0,00
0,00	12,00	99,00	100,00	1,00	0,00	0,00
0,00	18,00	99,00	100,00	1,00	0,00	0,00
0,00	24,00	99,00	100,00	1,00	0,00	0,00
6,00	0,00	99,00	100,00	1,00	0,00	0,00
6,00	6,00	99,00	100,00	1,00	0,00	0,00
6,00	12,00	99,00	100,00	1,00	0,00	0,00
6,00	18,00	99,00	100,00	1,00	0,00	0,00
6,00	24,00	99,00	100,00	1,00	0,00	0,00
12,00	0,00	99,00	100,00	1,00	0,00	0,00
12,00	6,00	99,00	100,00	1,00	0,00	0,00
12,00	12,00	99,00	100,00	1,00	0,00	0,00
12,00	18,00	99,00	100,00	1,00	0,00	0,00
12,00	24,00	99,00	100,00	1,00	0,00	0,00
18,00	0,00	99,00	100,00	1,00	0,00	0,00
18,00	6,00	99,00	100,00	1,00	0,00	0,00
18,00	12,00	99,00	100,00	1,00	0,00	0,00
18,00	18,00	99,00	100,00	1,00	0,00	0,00
18,00	24,00	99,00	100,00	1,00	0,00	0,00
24,00	0,00	99,00	100,00	1,00	0,00	0,00
24,00	6,00	99,00	100,00	1,00	0,00	0,00
24,00	12,00	99,00	100,00	1,00	0,00	0,00
24,00	18,00	99,00	100,00	1,00	0,00	0,00
24,00	24,00	99,00	100,00	1,00	0,00	0,00

5.3 Design Data - Optimise balance - 4x4

Design parameters

- Maximum average fluid temperature: 17 °C
- Minimum average fluid temperature: 0 °C
- First month of simulation: 1
- Simulation period: 40 years

Ground parameters

- Homogeneous ground conductivity: 2 W/(m·K)
- Homogeneous volumetric heat capacity: 2,4 MJ/(m^3·K)
- Ground surface temperature: 9,6 °C
- Ground flux: 0,07 W/m^2

Borehole parameters

- Borehole diameter: 140 mm

Pipe parameters

- U tube DN32 PN16
- Grout thermal conductivity: 1,5 W/(m·K)
- Number of U-tubes: 2
- Pipe conductivity: 0,4 W/(m·K)
- Pipe roughness: 0,001 mm

Fluid properties

- 25.0 v/v% MPG
- Temperature difference in extraction: 3 °C
- Temperature difference in injection: 3 °C
- Minimum flow percentage: 10
- Flow rate through borefield in extraction: 0,34 l/s
- Flow rate through borefield in injection: 2,36 l/s
- Number of boreholes in series: 1

Thermal demand

- Type of load: Hourly building load
- Domestic hot water: 60 016,95 kWh/year
- SCOP heating: 5
- SCOP domestic hot water: 3
- SEER cooling: 20

Borefield parameters

x [m]	y [m]	Length [m]	Depth [m]	Buried depth [m]	Tilt [°]	Orientation [°]
0,00	0,00	99,00	100,00	1,00	0,00	0,00
0,00	6,00	99,00	100,00	1,00	0,00	0,00
0,00	12,00	99,00	100,00	1,00	0,00	0,00
0,00	18,00	99,00	100,00	1,00	0,00	0,00
6,00	0,00	99,00	100,00	1,00	0,00	0,00
6,00	6,00	99,00	100,00	1,00	0,00	0,00
6,00	12,00	99,00	100,00	1,00	0,00	0,00
6,00	18,00	99,00	100,00	1,00	0,00	0,00
12,00	0,00	99,00	100,00	1,00	0,00	0,00
12,00	6,00	99,00	100,00	1,00	0,00	0,00
12,00	12,00	99,00	100,00	1,00	0,00	0,00
12,00	18,00	99,00	100,00	1,00	0,00	0,00
18,00	0,00	99,00	100,00	1,00	0,00	0,00
18,00	6,00	99,00	100,00	1,00	0,00	0,00
18,00	12,00	99,00	100,00	1,00	0,00	0,00
18,00	18,00	99,00	100,00	1,00	0,00	0,00

5.4 Design Data - Optimise balance - 4x4 - 25%

Design parameters

- Maximum average fluid temperature: 17 °C
- Minimum average fluid temperature: 0 °C
- First month of simulation: 1
- Simulation period: 40 years

Ground parameters

- Homogeneous ground conductivity: 2 W/(m·K)
- Homogeneous volumetric heat capacity: 2,4 MJ/(m^3·K)
- Ground surface temperature: 9,6 °C
- Ground flux: 0,07 W/m^2

Borehole parameters

- Borehole diameter: 140 mm

Pipe parameters

- U tube DN32 PN16
- Grout thermal conductivity: 1,5 W/(m·K)
- Number of U-tubes: 2
- Pipe conductivity: 0,4 W/(m·K)
- Pipe roughness: 0,001 mm

Fluid properties

- 25.0 v/v% MPG
- Temperature difference in extraction: 3 °C
- Temperature difference in injection: 3 °C
- Minimum flow percentage: 10
- Flow rate through borefield in extraction: 0,52 l/s
- Flow rate through borefield in injection: 2,44 l/s
- Number of boreholes in series: 1

Thermal demand

- Type of load: Hourly building load
- Domestic hot water: 60 016,95 kWh/year
- SCOP heating: 5
- SCOP domestic hot water: 3
- SEER cooling: 20

Borefield parameters

x [m]	y [m]	Length [m]	Depth [m]	Buried depth [m]	Tilt [°]	Orientation [°]
0,00	0,00	99,00	100,00	1,00	0,00	0,00
0,00	6,00	99,00	100,00	1,00	0,00	0,00
0,00	12,00	99,00	100,00	1,00	0,00	0,00
0,00	18,00	99,00	100,00	1,00	0,00	0,00
6,00	0,00	99,00	100,00	1,00	0,00	0,00
6,00	6,00	99,00	100,00	1,00	0,00	0,00
6,00	12,00	99,00	100,00	1,00	0,00	0,00
6,00	18,00	99,00	100,00	1,00	0,00	0,00
12,00	0,00	99,00	100,00	1,00	0,00	0,00
12,00	6,00	99,00	100,00	1,00	0,00	0,00
12,00	12,00	99,00	100,00	1,00	0,00	0,00
12,00	18,00	99,00	100,00	1,00	0,00	0,00
18,00	0,00	99,00	100,00	1,00	0,00	0,00
18,00	6,00	99,00	100,00	1,00	0,00	0,00
18,00	12,00	99,00	100,00	1,00	0,00	0,00
18,00	18,00	99,00	100,00	1,00	0,00	0,00



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