

GHEtool calculation report

Course 8.2



18/09/26

Licensed report by:

Enead BV

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1.1 Structure of the report

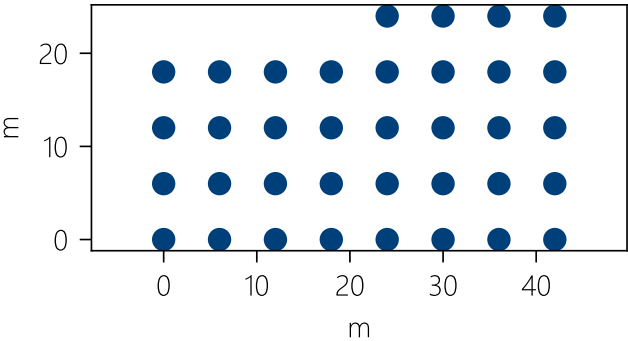
First, in Chapter 2, a summary of all the simulations will be provided. Chapter 3 discusses the inputs that are consistent across all scenarios. In Chapter 4, the different simulation results are presented and discussed. Chapter 5 contains appendices with more detailed information.



2. Summary of the simulations

2.1 Building A

Input



Number of boreholes: 36
Average minimum borehole spacing: 6,0 m
Borehole depth (w.r.t. surface): 73,0 m
2 x U tube DN32 PN16
25,0 v/v% MPG

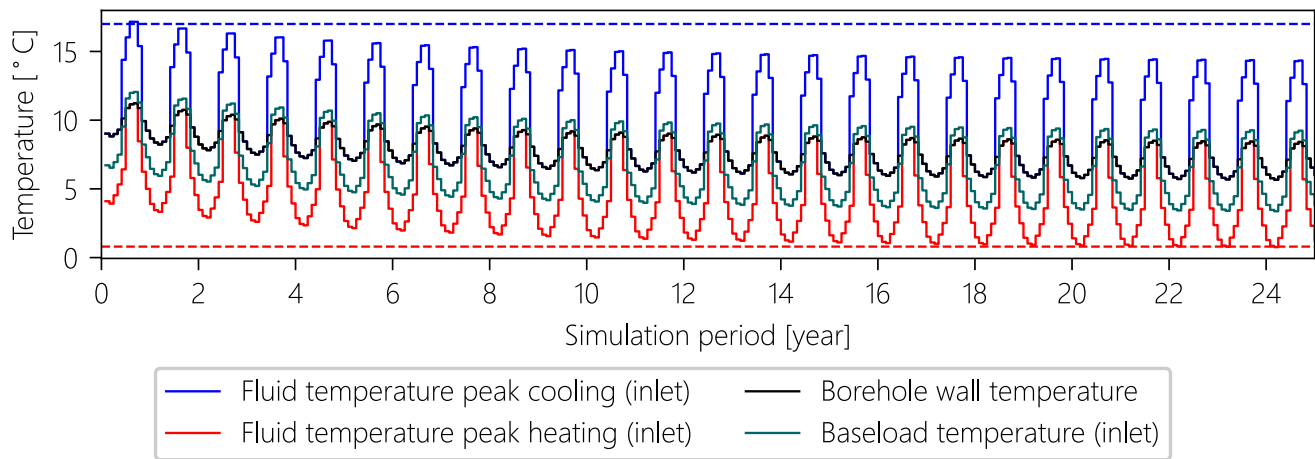
Ground demand	Yearly load	Peak power
Extraction demand	73 930 kWh/y	38,8 kW
Injection demand	18 968 kWh/y	49,4 kW

Results

Effective borehole thermal resistance (extraction): 0,1685 m·K/W, Reynolds number: 445 (laminar)

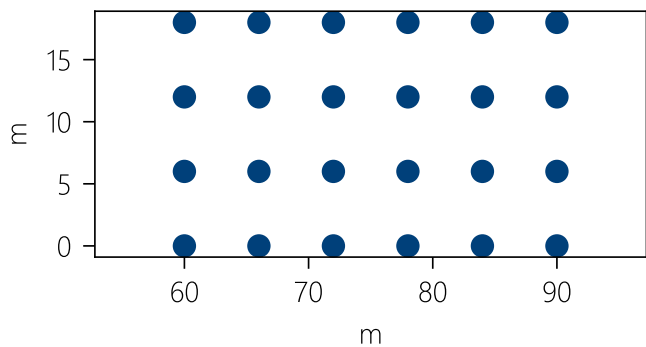
Effective borehole thermal resistance (injection): 0,1542 m·K/W, Reynolds number: 981 (laminar)

Maximum borefield inlet fluid temperature: 17,16 °C, Minimum borefield inlet fluid temperature: 0,76 °C



2.2 Building B

Input



Number of boreholes: 24
Average minimum borehole spacing: 6,0 m
Borehole depth (w.r.t. surface): 73,0 m
2 x U tube DN32 PN16
25,0 v/v% MPG

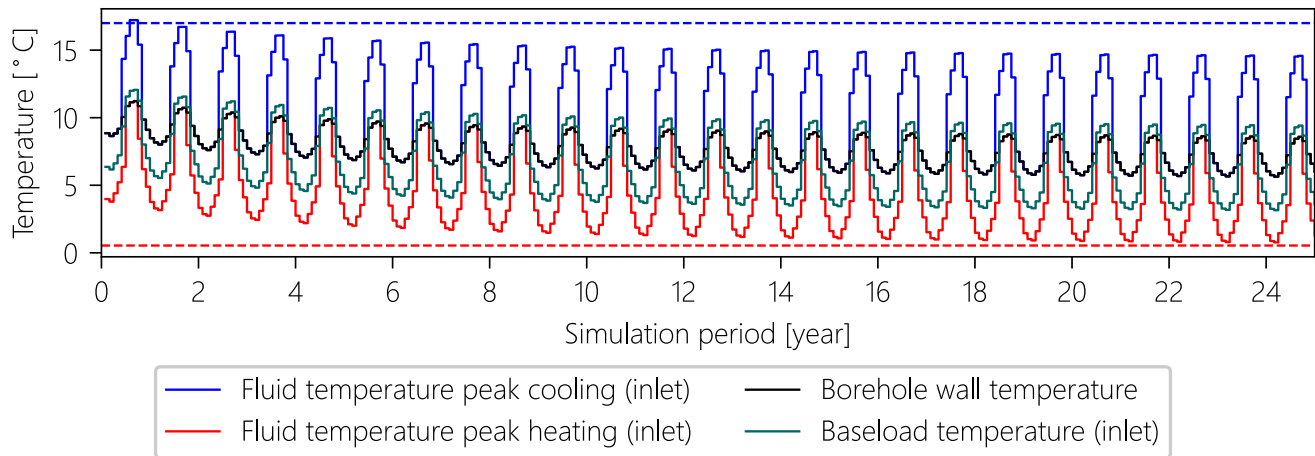
Ground demand	Yearly load	Peak power
Extraction demand	53 605 kWh/y	26,1 kW
Injection demand	12 935 kWh/y	33,6 kW

Results

Effective borehole thermal resistance (extraction): 0,1679 m·K/W, Reynolds number: 449 (laminar)

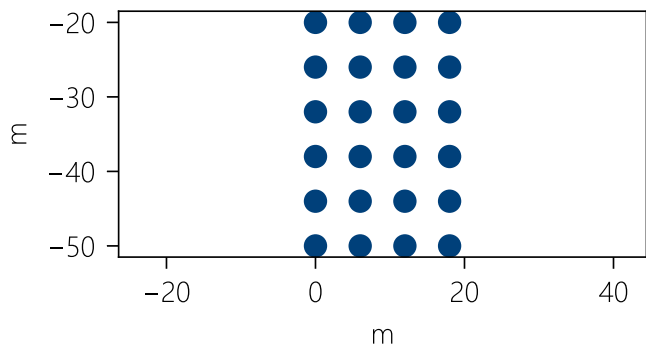
Effective borehole thermal resistance (injection): 0,1533 m·K/W, Reynolds number: 1 003 (laminar)

Maximum borefield inlet fluid temperature: 17,22 °C, Minimum borefield inlet fluid temperature: 0,77 °C



2.3 Building C

Input



Number of boreholes: 24
Average minimum borehole spacing: 6,0 m
Borehole depth (w.r.t. surface): 73,0 m
2 x U tube DN32 PN16
25,0 v/v% MPG

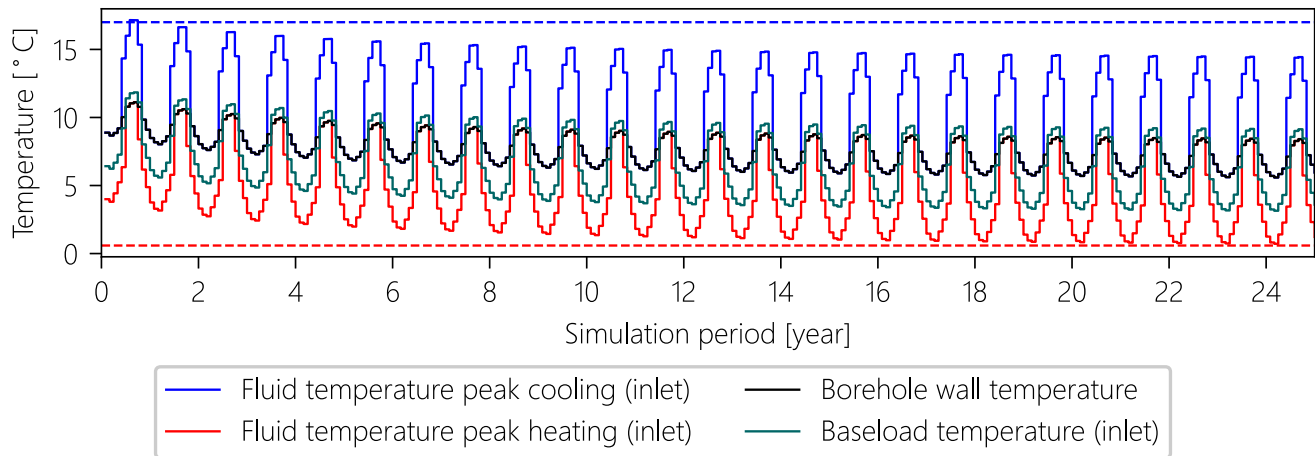
Ground demand	Yearly load	Peak power
Extraction demand	52 879 kWh/y	26,1 kW
Injection demand	11 257 kWh/y	33,6 kW

Results

Effective borehole thermal resistance (extraction): 0,1679 m·K/W, Reynolds number: 448 (laminar)

Effective borehole thermal resistance (injection): 0,1533 m·K/W, Reynolds number: 1 000 (laminar)

Maximum borefield inlet fluid temperature: 17,16 °C, Minimum borefield inlet fluid temperature: 0,72 °C



2.4 Interference

Input

Thermal conductivity of the soil	2,00 W/(m·K)
Ground volumetric heat capacity	2,40 MJ/(m ³ ·K)
Simulation period	25 years

ID	Name	Heating [MWh]	DHW [MWh]	Cooling [MWh]	SCOP heating	SCOP DHW	SEER
1	N Building A	73,93	0,00	18,97	-	-	-
2	N Building B	53,61	0,00	12,93	-	-	-
3	N Building C	52,88	0,00	11,26	-	-	-

Results

From \ To [°C]	1	2	3
1	0,00	-0,47	-0,47
2	-0,36	0,00	-0,04
3	-0,39	-0,04	0,00
Total interference [°C]	-0,74	-0,51	-0,52



2.5 Interference (20 houses)

Input

Thermal conductivity of the soil	2,00 W/(m·K)
Ground volumetric heat capacity	2,40 MJ/(m ³ ·K)
Simulation period	25 years

ID	Name	Heating [MWh]	DHW [MWh]	Cooling [MWh]	SCOP heating	SCOP DHW	SEER
1	N System 1	12,96	2,00	7,20	5,20	3,50	20,00
2	N system 2	12,96	2,00	7,20	5,10	3,50	20,00
3	N System 3	15,84	2,00	8,10	5,20	3,50	20,00
4	N System 4	17,28	2,00	9,60	5,10	3,50	20,00
5	N System 5	10,56	2,00	5,28	5,20	3,50	20,00
6	N System 6	15,84	2,00	8,10	5,20	3,50	20,00
7	N System 7	21,12	2,00	10,80	5,20	3,50	20,00
8	N System 8	15,84	2,00	8,10	5,20	3,50	20,00
9	N System 9	21,12	2,00	10,80	5,20	3,50	20,00
10	N System 10	21,12	2,00	10,80	5,20	3,50	20,00
11	N System 11	21,12	2,00	10,80	5,20	3,50	20,00
12	N System 12	10,56	2,00	5,28	5,20	3,50	20,00
13	N System 13	15,84	2,00	8,10	5,20	3,50	20,00
14	N System 14	17,28	2,00	9,60	5,10	3,50	20,00
15	N System 15	17,28	2,00	9,60	5,10	3,50	20,00
16	N System 16	21,12	2,00	10,80	5,20	3,50	20,00
17	N System 17	15,84	2,00	8,10	5,20	3,50	20,00
18	N System 18	10,56	2,00	5,28	5,20	3,50	20,00
19	N System 19	10,56	2,00	5,28	5,20	3,50	20,00
20	N System 20	15,84	2,00	8,10	5,20	3,50	20,00

Results

From \ To [°C]	1	2	3	4	5	6	7	8	9	10
1	0,00	-0,15	-0,05	-0,05	-0,01	-0,01	0,00	0,00	0,00	0,00
2	-0,15	0,00	-0,09	-0,02	-0,01	-0,01	-0,01	0,00	0,00	0,00
3	-0,07	-0,12	0,00	-0,04	-0,02	-0,04	-0,03	-0,01	0,00	0,00
4	-0,06	-0,02	-0,03	0,00	-0,07	-0,04	-0,01	-0,02	0,00	0,00
5	-0,01	-0,01	-0,02	-0,06	0,00	-0,10	-0,03	-0,09	-0,01	0,00
6	-0,01	-0,01	-0,04	-0,04	-0,14	0,00	-0,12	-0,09	-0,01	0,00

7	-0,01	-0,01	-0,04	-0,01	-0,05	-0,15	0,00	-0,05	-0,01	0,00
8	0,00	0,00	-0,01	-0,02	-0,12	-0,09	-0,04	0,00	-0,05	0,00
9	0,00	0,00	0,00	0,00	-0,01	-0,01	-0,01	-0,06	0,00	0,00
10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,04
12	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,02
13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,01
14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
16	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
17	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	0,00	0,00	0,00
18	0,00	0,00	0,00	0,00	0,00	0,00	-0,02	0,00	-0,01	0,00
19	0,00	0,00	0,00	0,00	0,00	-0,01	-0,02	-0,01	-0,03	0,00
20	0,00	0,00	0,00	0,00	-0,01	-0,01	-0,02	-0,03	-0,10	0,00
Total interference [°C]	-0,31	-0,32	-0,28	-0,24	-0,43	-0,48	-0,32	-0,36	-0,22	-0,07

From \ To [°C]	11	12	13	14	15	16	17	18	19	20
1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,01
6	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	-0,01
7	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	-0,03	-0,04	-0,03
8	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	-0,03
9	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	-0,05	-0,13
10	-0,04	-0,03	-0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00
11	0,00	-0,04	-0,04	-0,01	0,00	0,00	0,00	0,00	0,00	0,00
12	-0,03	0,00	-0,13	-0,01	0,00	0,00	0,00	0,00	0,00	0,00
13	-0,04	-0,17	0,00	-0,02	0,00	0,00	0,00	0,00	0,00	0,00
14	-0,01	-0,01	-0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	0,00	0,00	0,00	0,00	0,00	-0,10	-0,01	0,00	0,00	0,00
16	0,00	0,00	0,00	0,00	-0,14	0,00	-0,01	0,00	0,00	0,00
17	0,00	0,00	0,00	0,00	-0,01	-0,01	0,00	-0,17	-0,04	-0,01
18	0,00	0,00	0,00	0,00	0,00	0,00	-0,13	0,00	-0,14	-0,03
19	0,00	0,00	0,00	0,00	0,00	0,00	-0,03	-0,14	0,00	-0,13
20	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	-0,04	-0,17	0,00
Total interference [°C]	-0,11	-0,25	-0,21	-0,04	-0,15	-0,11	-0,22	-0,41	-0,47	-0,39

3. Shared input data

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: ground data, pipe data, and fluid data.

3.1 Ground data

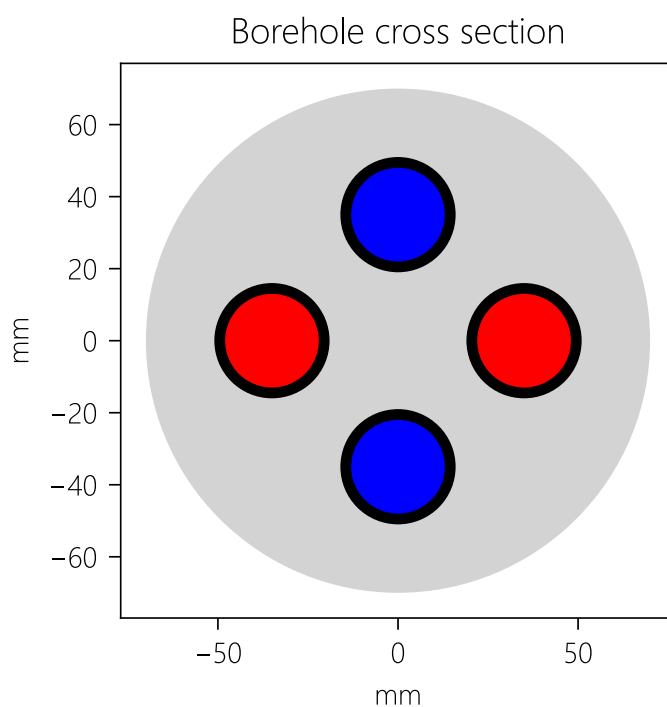
The ground is modelled as a single homogeneous layer with an average thermal conductivity of $2,00 \text{ W/(m}\cdot\text{K)}$ and a volumetric heat capacity of $2,40 \text{ MJ/(m}^3\cdot\text{K)}$. This means that the ground properties are assumed to remain constant at all depths.

A ground temperature gradient is taken into account. Using a geothermal heat flux of $0,07 \text{ W/m}^2$, a ground surface temperature of $9,60 \text{ }^\circ\text{C}$ and the ground thermal conductivity, the average ground temperature can be calculated for each borehole depth. For example, the average ground temperature is $10,23 \text{ }^\circ\text{C}$ at 36 m and $10,87 \text{ }^\circ\text{C}$ at 72 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.

3.2 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 $1,50 \text{ W/(m}\cdot\text{K)}$.



3.3 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.



4. Results

4.1 Building A

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

4.1.1 Input

General simulation settings

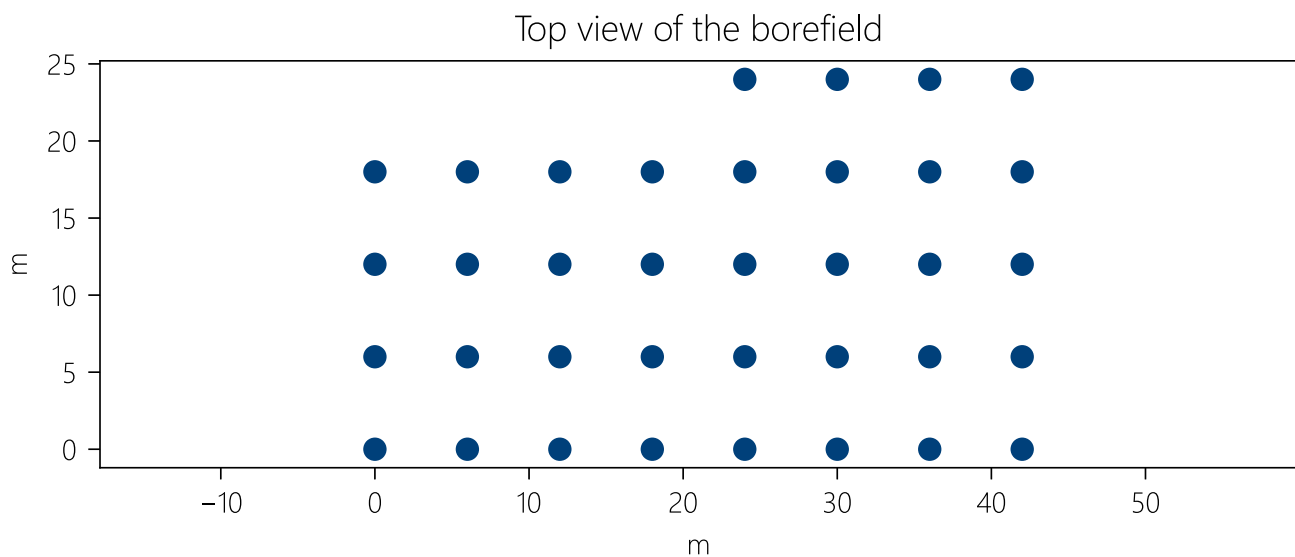
The scenarios in this report have been simulated with a simulation period of 25 years, starting in January. The minimum and maximum borefield inlet fluid temperatures were 0,80 °C and 17,00 °C respectively. The simulations were carried out with GHEtool Cloud v2.8.0.0.

Borefield configuration

The simulations were carried out with a borefield consisting of 36 boreholes, with an average buried depth of 0,70 m, an average borehole depth of 73,00 m and an average borehole length of 72,30 m. This results in a total borehole length of 2 602,80 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	72,30	73,00	0,70	0,00	0,00
0,00	6,00	72,30	73,00	0,70	0,00	0,00
0,00	12,00	72,30	73,00	0,70	0,00	0,00
0,00	18,00	72,30	73,00	0,70	0,00	0,00
6,00	0,00	72,30	73,00	0,70	0,00	0,00
6,00	6,00	72,30	73,00	0,70	0,00	0,00
6,00	12,00	72,30	73,00	0,70	0,00	0,00
6,00	18,00	72,30	73,00	0,70	0,00	0,00
12,00	0,00	72,30	73,00	0,70	0,00	0,00
12,00	6,00	72,30	73,00	0,70	0,00	0,00
12,00	12,00	72,30	73,00	0,70	0,00	0,00
12,00	18,00	72,30	73,00	0,70	0,00	0,00
18,00	0,00	72,30	73,00	0,70	0,00	0,00
18,00	6,00	72,30	73,00	0,70	0,00	0,00
18,00	12,00	72,30	73,00	0,70	0,00	0,00
18,00	18,00	72,30	73,00	0,70	0,00	0,00
24,00	0,00	72,30	73,00	0,70	0,00	0,00
24,00	6,00	72,30	73,00	0,70	0,00	0,00
24,00	12,00	72,30	73,00	0,70	0,00	0,00
24,00	18,00	72,30	73,00	0,70	0,00	0,00
24,00	24,00	72,30	73,00	0,70	0,00	0,00
30,00	0,00	72,30	73,00	0,70	0,00	0,00
30,00	6,00	72,30	73,00	0,70	0,00	0,00
30,00	12,00	72,30	73,00	0,70	0,00	0,00
30,00	18,00	72,30	73,00	0,70	0,00	0,00
30,00	24,00	72,30	73,00	0,70	0,00	0,00
36,00	0,00	72,30	73,00	0,70	0,00	0,00
36,00	6,00	72,30	73,00	0,70	0,00	0,00
36,00	12,00	72,30	73,00	0,70	0,00	0,00
36,00	18,00	72,30	73,00	0,70	0,00	0,00
36,00	24,00	72,30	73,00	0,70	0,00	0,00
42,00	0,00	72,30	73,00	0,70	0,00	0,00

42,00	6,00	72,30	73,00	0,70	0,00	0,00
42,00	12,00	72,30	73,00	0,70	0,00	0,00
42,00	18,00	72,30	73,00	0,70	0,00	0,00
42,00	24,00	72,30	73,00	0,70	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 3,26 l/s and 4,13 l/s respectively.

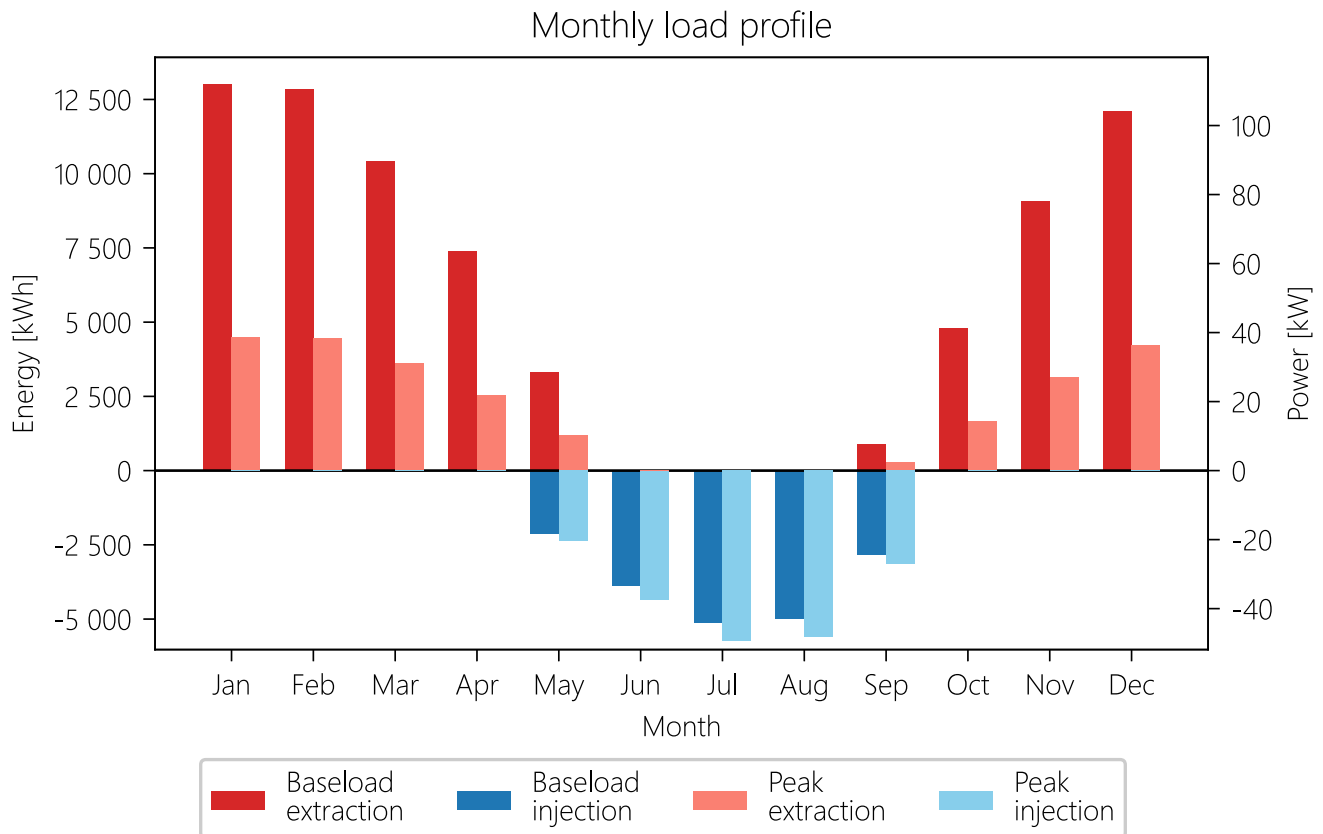
Load data

For the simulation, a geothermal load was used. This means that, instead of working with the heating and cooling demand for the building, the heat extraction and injection from and in the borefield are used directly. Below you can find a summary of the load.

Ground demand	Yearly load	Peak power
Extraction demand	73 930 kWh/y	38,8 kW
Injection demand	18 968 kWh/y	49,4 kW

The monthly distribution is given in the table below.

Month	Baseload extraction [kWh]	Baseload injection [kWh]	Peak extraction [kW]	Peak injection [kW]
January	13 012	0	38,8	0,0
February	12 864	0	38,5	0,0
March	10 424	0	31,1	0,0
April	7 393	0	22,0	0,0
May	3 327	2 124	10,2	20,5
June	0	3 888	0,0	37,3
July	0	5 121	0,0	49,4
August	0	5 008	0,0	48,2
September	887	2 826	2,6	27,1
October	4 805	0	14,3	0,0
November	9 093	0	27,1	0,0
December	12 125	0	36,2	0,0



The peak duration during extraction is 12 hours, and for injection it is 8 hours. The peak duration is defined as the longest runtime of the maximum extraction/injection 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

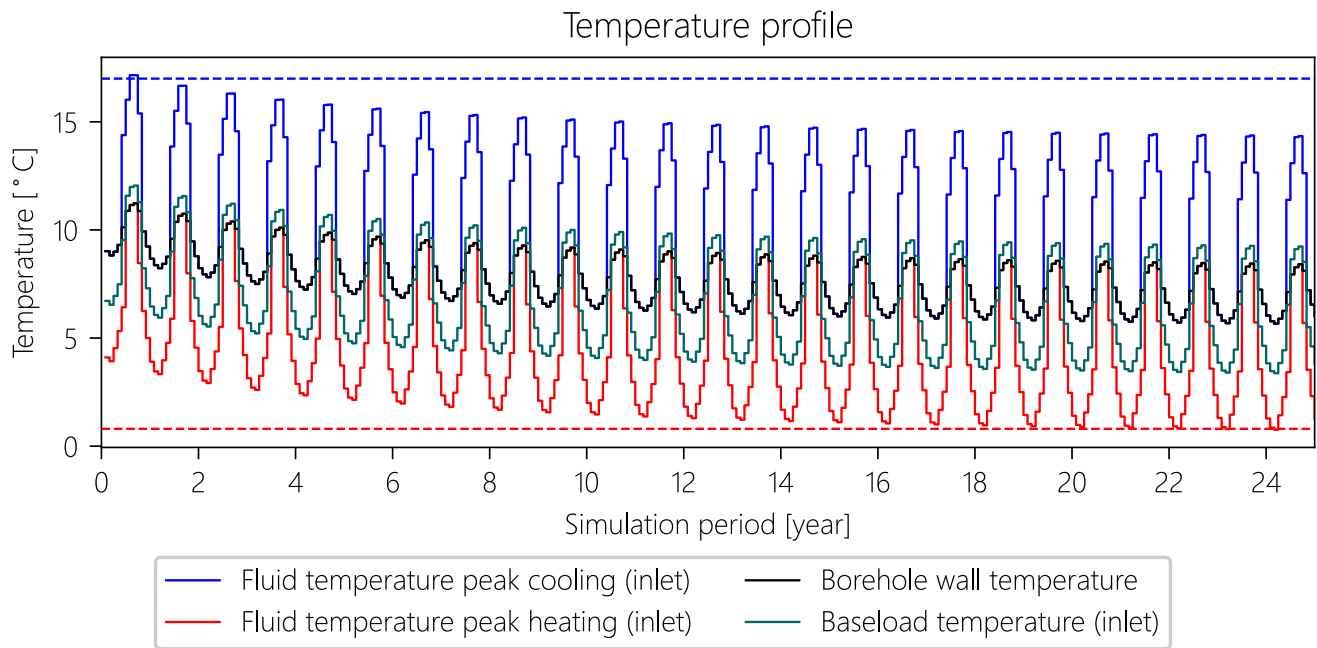
Temperature evolution of the borefield

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 445, whilst it was 981 during injection. This corresponds respectively to a laminar and laminar flow regime, with an effective borehole thermal resistance of 0,1685 m·K/W and 0,1542 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 borefield inlet fluid temperature over the whole simulation period at peak power are 17,16 °C and 0,76 °C respectively. The minimum and maximum borefield inlet fluid temperatures during the baseload are respectively 3,37 °C and 12,05 °C.

Pressure drop

The pressure drop over a single borehole is 2,98 kPa during extration and 2,17 kPa during injection.

4.2 Building B

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

4.2.1 Input

General simulation settings

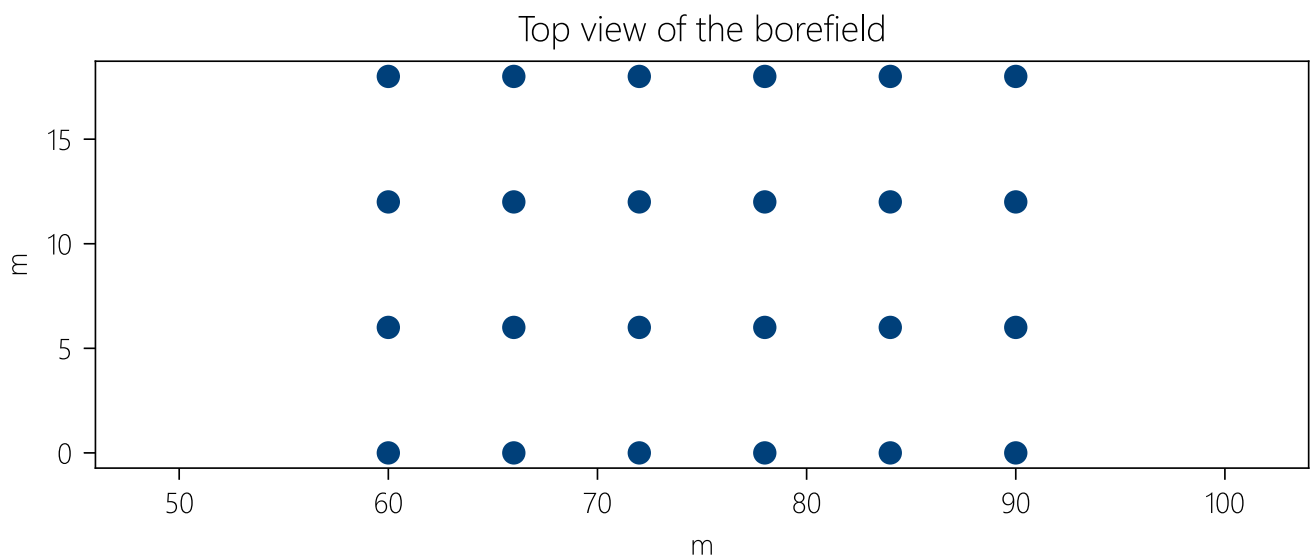
The scenarios in this report have been simulated with a simulation period of 25 years, starting in January. The minimum and maximum borefield inlet fluid temperatures were 0,54 °C and 17,00 °C respectively. The simulations were carried out with GHEtool Cloud v2.8.0.0.

Borefield configuration

The simulations were carried out with a borefield consisting of 24 boreholes, with an average buried depth of 0,70 m, an average borehole depth of 73,00 m and an average borehole length of 72,30 m. This results in a total borehole length of 1 735,20 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 [°]
60,00	0,00	72,30	73,00	0,70	0,00	0,00
60,00	6,00	72,30	73,00	0,70	0,00	0,00
60,00	12,00	72,30	73,00	0,70	0,00	0,00
60,00	18,00	72,30	73,00	0,70	0,00	0,00
66,00	0,00	72,30	73,00	0,70	0,00	0,00
66,00	6,00	72,30	73,00	0,70	0,00	0,00
66,00	12,00	72,30	73,00	0,70	0,00	0,00
66,00	18,00	72,30	73,00	0,70	0,00	0,00
72,00	0,00	72,30	73,00	0,70	0,00	0,00
72,00	6,00	72,30	73,00	0,70	0,00	0,00
72,00	12,00	72,30	73,00	0,70	0,00	0,00
72,00	18,00	72,30	73,00	0,70	0,00	0,00
78,00	0,00	72,30	73,00	0,70	0,00	0,00
78,00	6,00	72,30	73,00	0,70	0,00	0,00
78,00	12,00	72,30	73,00	0,70	0,00	0,00
78,00	18,00	72,30	73,00	0,70	0,00	0,00
84,00	0,00	72,30	73,00	0,70	0,00	0,00
84,00	6,00	72,30	73,00	0,70	0,00	0,00
84,00	12,00	72,30	73,00	0,70	0,00	0,00
84,00	18,00	72,30	73,00	0,70	0,00	0,00
90,00	0,00	72,30	73,00	0,70	0,00	0,00
90,00	6,00	72,30	73,00	0,70	0,00	0,00
90,00	12,00	72,30	73,00	0,70	0,00	0,00
90,00	18,00	72,30	73,00	0,70	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 2,19 l/s and 2,81 l/s respectively.

Load data

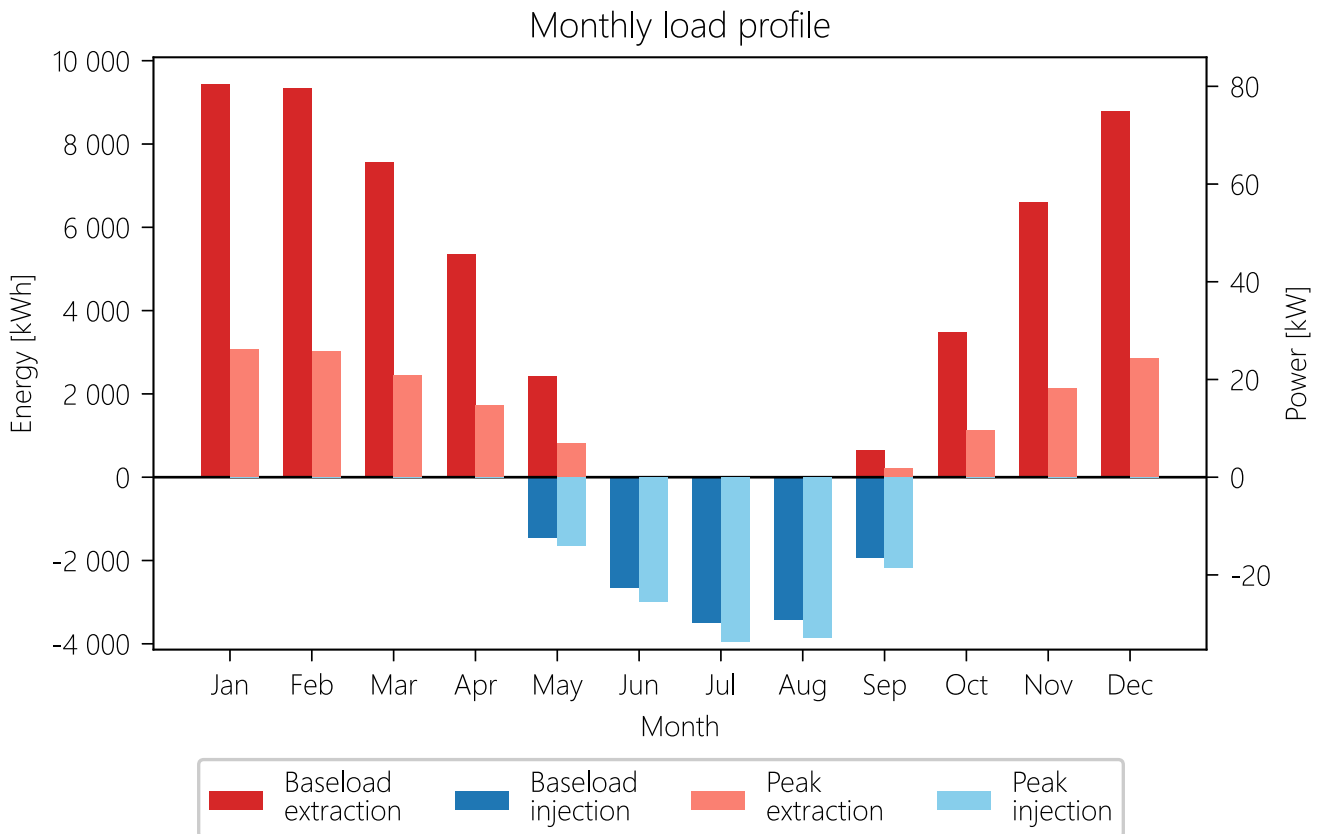
For the simulation, a geothermal load was used. This means that, instead of working with the heating and cooling demand for the building, the heat extraction and injection from and in the borefield are used directly. Below you can find a summary of the load.

Ground demand	Yearly load	Peak power
Extraction demand	53 605 kWh/y	26,1 kW
Injection demand	12 935 kWh/y	33,6 kW

The monthly distribution is given in the table below.

Month	Baseload extraction [kWh]	Baseload injection [kWh]	Peak extraction [kW]	Peak injection [kW]
January	9 434	0	26,1	0,0
February	9 327	0	25,9	0,0
March	7 558	0	20,9	0,0
April	5 360	0	14,8	0,0
May	2 412	1 449	6,9	13,9
June	0	2 652	0,0	25,4
July	0	3 492	0,0	33,6
August	0	3 415	0,0	32,8
September	643	1 927	1,7	18,4
October	3 484	0	9,6	0,0
November	6 593	0	18,2	0,0
December	8 791	0	24,4	0,0





The peak duration during extraction is 12 hours, and for injection it is 8 hours. The peak duration is defined as the longest runtime of the maximum extraction/injection 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).

4.2.2 Results

Temperature evolution of the borefield

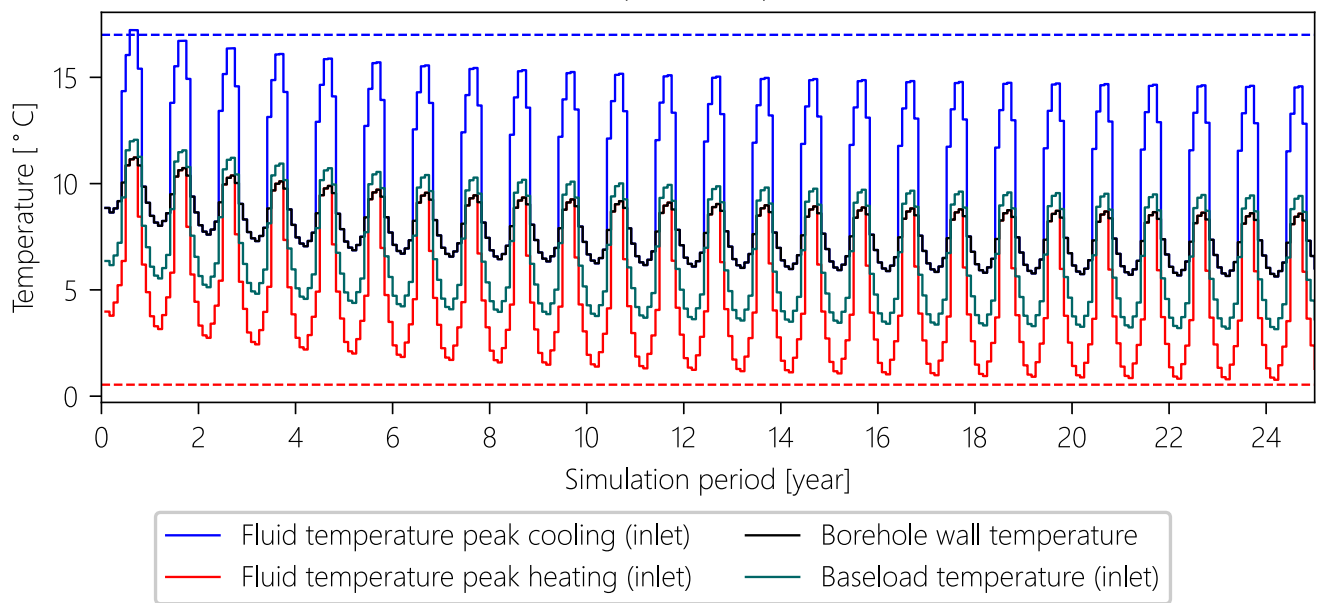
Using the pipe, fluid, and flow properties, the Reynolds number was calculated. Since this number depends on the fluid temperature and therefore varies over the simulation period, it was updated at every timestep to achieve the most accurate result possible.

Doing so, the Reynolds number during heat extraction was 449, whilst it was 1 003 during injection. This corresponds respectively to a laminar and laminar flow regime, with an effective borehole thermal resistance of 0,1679 m·K/W and 0,1533 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.

Temperature profile



The maximum and minimum borefield inlet fluid temperature over the whole simulation period at peak power are 17,22 °C and 0,77 °C respectively. The minimum and maximum borefield inlet fluid temperatures during the baseload are respectively 3,15 °C and 12,06 °C.

Pressure drop

The pressure drop over a single borehole is 3,01 kPa during extration and 2,20 kPa during injection.

4.3 Building C

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

4.3.1 Input

General simulation settings

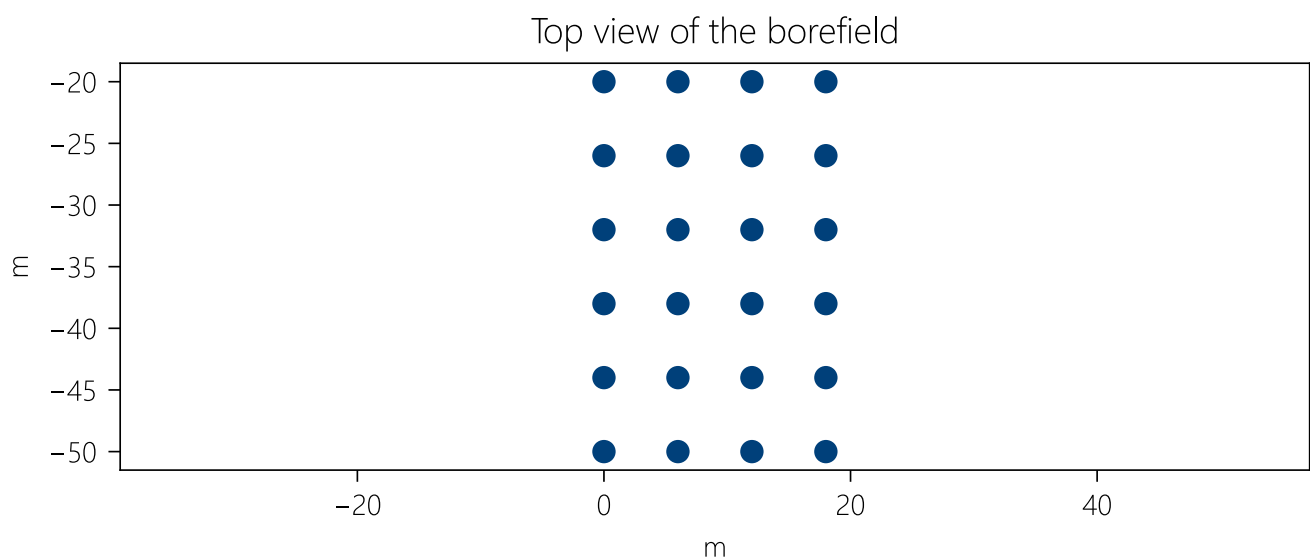
The scenarios in this report have been simulated with a simulation period of 25 years, starting in January. The minimum and maximum borefield inlet fluid temperatures were 0,59 °C and 17,00 °C respectively. The simulations were carried out with GHEtool Cloud v2.8.0.0.

Borefield configuration

The simulations were carried out with a borefield consisting of 24 boreholes, with an average buried depth of 0,70 m, an average borehole depth of 73,00 m and an average borehole length of 72,30 m. This results in a total borehole length of 1 735,20 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	-20,00	72,30	73,00	0,70	0,00	0,00
6,00	-20,00	72,30	73,00	0,70	0,00	0,00
12,00	-20,00	72,30	73,00	0,70	0,00	0,00
18,00	-20,00	72,30	73,00	0,70	0,00	0,00
0,00	-26,00	72,30	73,00	0,70	0,00	0,00
6,00	-26,00	72,30	73,00	0,70	0,00	0,00
12,00	-26,00	72,30	73,00	0,70	0,00	0,00
18,00	-26,00	72,30	73,00	0,70	0,00	0,00
0,00	-32,00	72,30	73,00	0,70	0,00	0,00
6,00	-32,00	72,30	73,00	0,70	0,00	0,00
12,00	-32,00	72,30	73,00	0,70	0,00	0,00
18,00	-32,00	72,30	73,00	0,70	0,00	0,00
0,00	-38,00	72,30	73,00	0,70	0,00	0,00
6,00	-38,00	72,30	73,00	0,70	0,00	0,00
12,00	-38,00	72,30	73,00	0,70	0,00	0,00
18,00	-38,00	72,30	73,00	0,70	0,00	0,00
0,00	-44,00	72,30	73,00	0,70	0,00	0,00
6,00	-44,00	72,30	73,00	0,70	0,00	0,00
12,00	-44,00	72,30	73,00	0,70	0,00	0,00
18,00	-44,00	72,30	73,00	0,70	0,00	0,00
0,00	-50,00	72,30	73,00	0,70	0,00	0,00
6,00	-50,00	72,30	73,00	0,70	0,00	0,00
12,00	-50,00	72,30	73,00	0,70	0,00	0,00
18,00	-50,00	72,30	73,00	0,70	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 2,19 l/s and 2,81 l/s respectively.

Load data

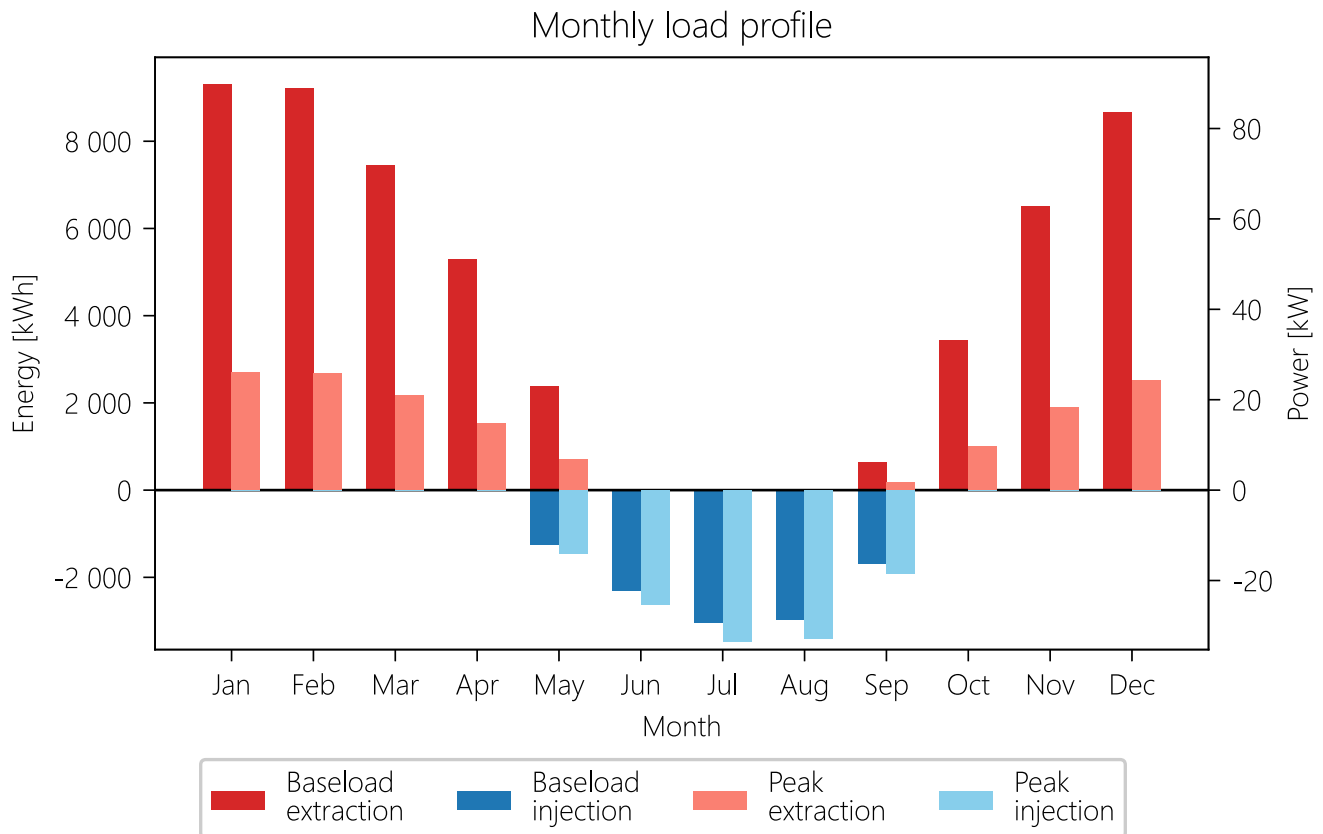
For the simulation, a geothermal load was used. This means that, instead of working with the heating and cooling demand for the building, the heat extraction and injection from and in the borefield are used directly. Below you can find a summary of the load.

Ground demand	Yearly load	Peak power
Extraction demand	52 879 kWh/y	26,1 kW
Injection demand	11 257 kWh/y	33,6 kW

The monthly distribution is given in the table below.

Month	Baseload extraction [kWh]	Baseload injection [kWh]	Peak extraction [kW]	Peak injection [kW]
January	9 307	0	26,1	0,0
February	9 201	0	25,9	0,0
March	7 456	0	20,9	0,0
April	5 288	0	14,8	0,0
May	2 380	1 261	6,9	13,9
June	0	2 308	0,0	25,4
July	0	3 039	0,0	33,6
August	0	2 972	0,0	32,8
September	635	1 677	1,7	18,4
October	3 437	0	9,6	0,0
November	6 504	0	18,2	0,0
December	8 672	0	24,4	0,0





The peak duration during extraction is 12 hours, and for injection it is 8 hours. The peak duration is defined as the longest runtime of the maximum extraction/injection 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

Temperature evolution of the borefield

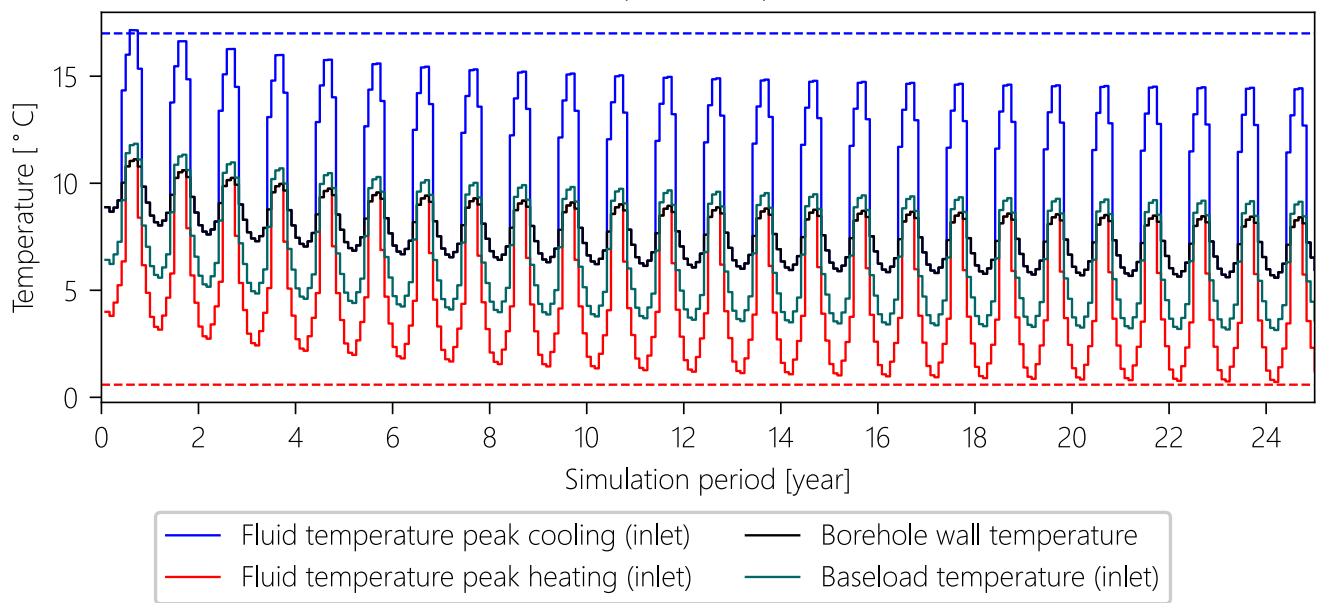
Using the pipe, fluid, and flow properties, the Reynolds number was calculated. Since this number depends on the fluid temperature and therefore varies over the simulation period, it was updated at every timestep to achieve the most accurate result possible.

Doing so, the Reynolds number during heat extraction was 448, whilst it was 1 000 during injection. This corresponds respectively to a laminar and laminar flow regime, with an effective borehole thermal resistance of 0,1679 m·K/W and 0,1533 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.

Temperature profile



The maximum and minimum borefield inlet fluid temperature over the whole simulation period at peak power are 17,16 °C and 0,72 °C respectively. The minimum and maximum borefield inlet fluid temperatures during the baseload are respectively 3,14 °C and 11,84 °C.

Pressure drop

The pressure drop over a single borehole is 3,02 kPa during extration and 2,21 kPa during injection.

4.4 Interference

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

4.4.1 Input

Interference

When multiple boreholes or borefields are close together, they influence each other in what we call thermal interference. To simulate this effect, the following parameters were used.

Thermal conductivity of the soil	2,00 W/(m·K)
Ground volumetric heat capacity	2,40 MJ/(m ³ ·K)
Simulation period	25 years

In the table below, the different systems are listed with their yearly demand for heating, domestic hot water (DHW) and cooling and their corresponding efficiencies. The new systems are shown as 'N', whereas the existing ones are marked as 'E'.

ID	Name	Heating [MWh]	DHW [MWh]	Cooling [MWh]	SCOP heating	SCOP DHW	SEER
1	N Building A	73,93	0,00	18,97	-	-	-
2	N Building B	53,61	0,00	12,93	-	-	-
3	N Building C	52,88	0,00	11,26	-	-	-

The table below contains all the boreholes for each system above. When the total length is larger than the borehole depth, this indicates that the entire borefield is modelled as a single borehole, where the (x,y) position is taken as the centre of the borefield. This approximation is valid up to six boreholes (source: Report GHNL 180760). For all other systems, the individual boreholes are used for the interference calculation, leading to the most accurate results.

ID	x [m]	y [m]	Total length [m]	Depth [m]
1	0,000	0,000	72,30	72,30
1	0,000	6,000	72,30	72,30
1	0,000	12,000	72,30	72,30
1	0,000	18,000	72,30	72,30
1	6,000	0,000	72,30	72,30
1	6,000	6,000	72,30	72,30
1	6,000	12,000	72,30	72,30
1	6,000	18,000	72,30	72,30
1	12,000	0,000	72,30	72,30
1	12,000	6,000	72,30	72,30
1	12,000	12,000	72,30	72,30
1	12,000	18,000	72,30	72,30
1	18,000	0,000	72,30	72,30
1	18,000	6,000	72,30	72,30

1	18,000	12,000	72,30	72,30
1	18,000	18,000	72,30	72,30
1	24,000	0,000	72,30	72,30
1	24,000	6,000	72,30	72,30
1	24,000	12,000	72,30	72,30
1	24,000	18,000	72,30	72,30
1	24,000	24,000	72,30	72,30
1	30,000	0,000	72,30	72,30
1	30,000	6,000	72,30	72,30
1	30,000	12,000	72,30	72,30
1	30,000	18,000	72,30	72,30
1	30,000	24,000	72,30	72,30
1	36,000	0,000	72,30	72,30
1	36,000	6,000	72,30	72,30
1	36,000	12,000	72,30	72,30
1	36,000	18,000	72,30	72,30
1	36,000	24,000	72,30	72,30
1	42,000	0,000	72,30	72,30
1	42,000	6,000	72,30	72,30
1	42,000	12,000	72,30	72,30
1	42,000	18,000	72,30	72,30
1	42,000	24,000	72,30	72,30
2	60,000	0,000	72,30	72,30
2	60,000	6,000	72,30	72,30
2	60,000	12,000	72,30	72,30
2	60,000	18,000	72,30	72,30
2	66,000	0,000	72,30	72,30
2	66,000	6,000	72,30	72,30
2	66,000	12,000	72,30	72,30
2	66,000	18,000	72,30	72,30
2	72,000	0,000	72,30	72,30
2	72,000	6,000	72,30	72,30
2	72,000	12,000	72,30	72,30
2	72,000	18,000	72,30	72,30
2	78,000	0,000	72,30	72,30
2	78,000	6,000	72,30	72,30
2	78,000	12,000	72,30	72,30
2	78,000	18,000	72,30	72,30
2	84,000	0,000	72,30	72,30

2	84,000	6,000	72,30	72,30
2	84,000	12,000	72,30	72,30
2	84,000	18,000	72,30	72,30
2	90,000	0,000	72,30	72,30
2	90,000	6,000	72,30	72,30
2	90,000	12,000	72,30	72,30
2	90,000	18,000	72,30	72,30
3	0,000	-20,000	72,30	72,30
3	6,000	-20,000	72,30	72,30
3	12,000	-20,000	72,30	72,30
3	18,000	-20,000	72,30	72,30
3	0,000	-26,000	72,30	72,30
3	6,000	-26,000	72,30	72,30
3	12,000	-26,000	72,30	72,30
3	18,000	-26,000	72,30	72,30
3	0,000	-32,000	72,30	72,30
3	6,000	-32,000	72,30	72,30
3	12,000	-32,000	72,30	72,30
3	18,000	-32,000	72,30	72,30
3	0,000	-38,000	72,30	72,30
3	6,000	-38,000	72,30	72,30
3	12,000	-38,000	72,30	72,30
3	18,000	-38,000	72,30	72,30
3	0,000	-44,000	72,30	72,30
3	6,000	-44,000	72,30	72,30
3	12,000	-44,000	72,30	72,30
3	18,000	-44,000	72,30	72,30
3	0,000	-50,000	72,30	72,30
3	6,000	-50,000	72,30	72,30
3	12,000	-50,000	72,30	72,30
3	18,000	-50,000	72,30	72,30

4.4.2 Results

The interference between the different systems was calculated using the finite line source (FLS) solution. Based on the yearly heating and cooling load, the net yearly heat extraction is calculated for each system. When this is divided by the borehole depth, the specific heat extraction per metre of borehole is obtained. Using this power, the ground properties, and the distance between each pair of systems, their thermal interference can be calculated.

From \ To [°C]

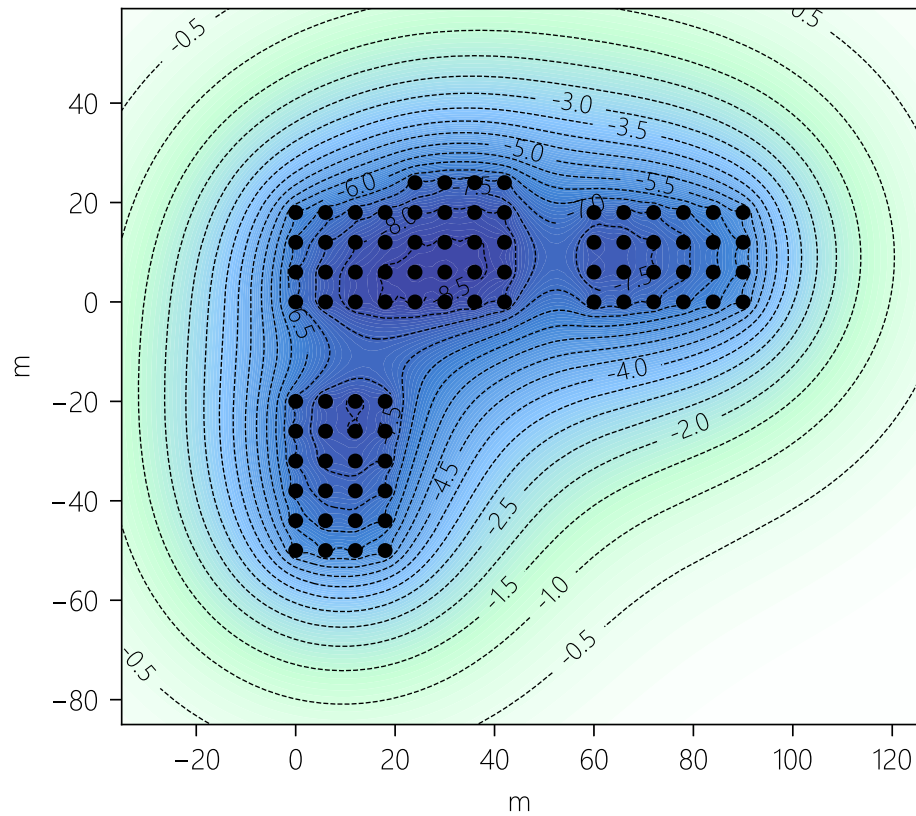
1

2

3

1	0,00	-0,47	-0,47
2	-0,36	0,00	-0,04
3	-0,39	-0,04	0,00
Total interference [°C]	-0,74	-0,51	-0,52

In the graph below, the temperature distribution in and around the borefield is shown at the end of the simulation period. This graph is a 2D approximation based on the yearly imbalance of the borefield.



4.5 Interference (20 houses)

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

4.5.1 Input

Interference

When multiple boreholes or borefields are close together, they influence each other in what we call thermal interference. To simulate this effect, the following parameters were used.

Thermal conductivity of the soil	2,00 W/(m·K)
Ground volumetric heat capacity	2,40 MJ/(m ³ ·K)
Simulation period	25 years

In the table below, the different systems are listed with their yearly demand for heating, domestic hot water (DHW) and cooling and their corresponding efficiencies. The new systems are shown as 'N', whereas the existing ones are marked as 'E'.

ID	Name	Heating [MWh]	DHW [MWh]	Cooling [MWh]	SCOP heating	SCOP DHW	SEER
1	N System 1	12,96	2,00	7,20	5,20	3,50	20,00
2	N system 2	12,96	2,00	7,20	5,10	3,50	20,00
3	N System 3	15,84	2,00	8,10	5,20	3,50	20,00
4	N System 4	17,28	2,00	9,60	5,10	3,50	20,00
5	N System 5	10,56	2,00	5,28	5,20	3,50	20,00
6	N System 6	15,84	2,00	8,10	5,20	3,50	20,00
7	N System 7	21,12	2,00	10,80	5,20	3,50	20,00
8	N System 8	15,84	2,00	8,10	5,20	3,50	20,00
9	N System 9	21,12	2,00	10,80	5,20	3,50	20,00
10	N System 10	21,12	2,00	10,80	5,20	3,50	20,00
11	N System 11	21,12	2,00	10,80	5,20	3,50	20,00
12	N System 12	10,56	2,00	5,28	5,20	3,50	20,00
13	N System 13	15,84	2,00	8,10	5,20	3,50	20,00
14	N System 14	17,28	2,00	9,60	5,10	3,50	20,00
15	N System 15	17,28	2,00	9,60	5,10	3,50	20,00
16	N System 16	21,12	2,00	10,80	5,20	3,50	20,00
17	N System 17	15,84	2,00	8,10	5,20	3,50	20,00
18	N System 18	10,56	2,00	5,28	5,20	3,50	20,00
19	N System 19	10,56	2,00	5,28	5,20	3,50	20,00
20	N System 20	15,84	2,00	8,10	5,20	3,50	20,00

The table below contains all the boreholes for each system above. When the total length is larger than the borehole depth, this indicates that the entire borefield is modelled as a single borehole, where the (x,y) position is taken as the centre of the borefield. This approximation is valid up to six boreholes (source: Report

GHNL 180760). For all other systems, the individual boreholes are used for the interference calculation, leading to the most accurate results.

ID	x [m]	y [m]	Total length [m]	Depth [m]
1	2,380	151,605	165,00	165,00
1	4,880	154,105	165,00	165,00
2	0,000	132,884	165,00	165,00
2	2,500	135,384	165,00	165,00
3	23,085	126,075	215,00	215,00
3	25,585	128,575	215,00	215,00
4	33,119	168,318	215,00	215,00
4	35,619	170,818	215,00	215,00
5	62,362	159,816	140,00	140,00
5	64,862	162,316	140,00	140,00
6	61,213	138,254	215,00	215,00
6	63,713	140,754	215,00	215,00
7	67,878	115,077	185,00	185,00
7	70,378	117,577	185,00	185,00
8	85,078	153,645	215,00	215,00
8	87,578	156,145	215,00	215,00
9	123,500	147,583	185,00	185,00
9	126,000	150,083	185,00	185,00
10	205,986	120,905	185,00	185,00
10	208,486	123,405	185,00	185,00
11	200,749	73,034	185,00	185,00
11	203,249	75,534	185,00	185,00
12	244,665	88,698	140,00	140,00
12	247,165	91,198	140,00	140,00
13	244,394	70,507	215,00	215,00
13	246,894	73,007	215,00	215,00
14	233,586	22,244	215,00	215,00
14	236,086	24,744	215,00	215,00
15	106,292	0,000	215,00	215,00
15	108,792	2,500	215,00	215,00
16	81,502	4,898	185,00	185,00
16	84,002	7,398	185,00	185,00
17	105,695	64,793	215,00	215,00
17	108,195	67,293	215,00	215,00
18	110,684	81,729	140,00	140,00
18	113,184	84,229	140,00	140,00

19	115,220	103,724	140,00	140,00
19	117,720	106,224	140,00	140,00
20	117,393	121,419	215,00	215,00
20	119,893	123,919	215,00	215,00

4.5.2 Results

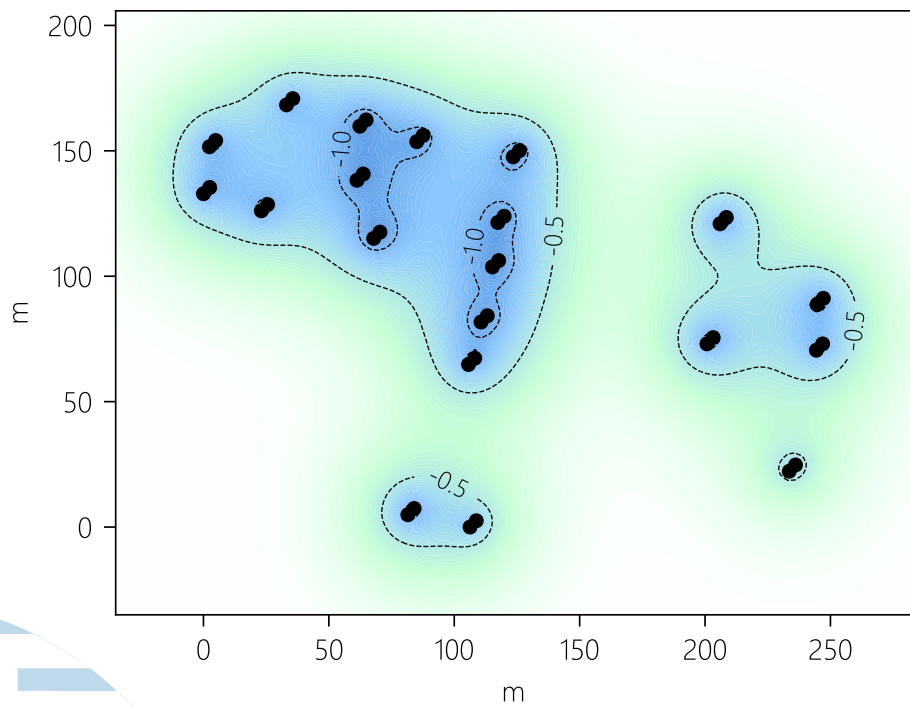
The interference between the different systems was calculated using the finite line source (FLS) solution. Based on the yearly heating and cooling load, the net yearly heat extraction is calculated for each system. When this is divided by the borehole depth, the specific heat extraction per metre of borehole is obtained. Using this power, the ground properties, and the distance between each pair of systems, their thermal interference can be calculated.

From \ To [°C]	1	2	3	4	5	6	7	8	9	10
1	0,00	-0,15	-0,05	-0,05	-0,01	-0,01	0,00	0,00	0,00	0,00
2	-0,15	0,00	-0,09	-0,02	-0,01	-0,01	-0,01	0,00	0,00	0,00
3	-0,07	-0,12	0,00	-0,04	-0,02	-0,04	-0,03	-0,01	0,00	0,00
4	-0,06	-0,02	-0,03	0,00	-0,07	-0,04	-0,01	-0,02	0,00	0,00
5	-0,01	-0,01	-0,02	-0,06	0,00	-0,10	-0,03	-0,09	-0,01	0,00
6	-0,01	-0,01	-0,04	-0,04	-0,14	0,00	-0,12	-0,09	-0,01	0,00
7	-0,01	-0,01	-0,04	-0,01	-0,05	-0,15	0,00	-0,05	-0,01	0,00
8	0,00	0,00	-0,01	-0,02	-0,12	-0,09	-0,04	0,00	-0,05	0,00
9	0,00	0,00	0,00	0,00	-0,01	-0,01	-0,01	-0,06	0,00	0,00
10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,04
12	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,02
13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,01
14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
16	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
17	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	0,00	0,00	0,00
18	0,00	0,00	0,00	0,00	0,00	0,00	-0,02	0,00	-0,01	0,00
19	0,00	0,00	0,00	0,00	0,00	-0,01	-0,02	-0,01	-0,03	0,00
20	0,00	0,00	0,00	0,00	-0,01	-0,01	-0,02	-0,03	-0,10	0,00
Total interference [°C]	-0,31	-0,32	-0,28	-0,24	-0,43	-0,48	-0,32	-0,36	-0,22	-0,07

From \ To [°C]	11	12	13	14	15	16	17	18	19	20
1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,01

6	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	-0,01
7	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	-0,03	-0,04	-0,03
8	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	-0,03
9	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	-0,05	-0,13
10	-0,04	-0,03	-0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
11	0,00	-0,04	-0,04	-0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00
12	-0,03	0,00	-0,13	-0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00
13	-0,04	-0,17	0,00	-0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14	-0,01	-0,01	-0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	0,00	0,00	0,00	0,00	0,00	-0,10	-0,01	0,00	0,00	0,00	0,00
16	0,00	0,00	0,00	0,00	-0,14	0,00	-0,01	0,00	0,00	0,00	0,00
17	0,00	0,00	0,00	0,00	-0,01	-0,01	0,00	-0,17	-0,04	-0,01	-0,01
18	0,00	0,00	0,00	0,00	0,00	0,00	-0,13	0,00	-0,14	-0,03	-0,03
19	0,00	0,00	0,00	0,00	0,00	0,00	-0,03	-0,14	0,00	-0,13	-0,13
20	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	-0,04	-0,17	0,00	0,00
Total interference [°C]	-0,11	-0,25	-0,21	-0,04	-0,15	-0,11	-0,22	-0,41	-0,47	-0,39	-0,39

In the graph below, the temperature distribution in and around the borefield is shown at the end of the simulation period. This graph is a 2D approximation based on the yearly imbalance of the borefield.



5.1 Design Data - Building A

Design parameters

- Maximum borefield inlet fluid temperature: 17 °C
- Minimum borefield inlet fluid temperature: 0,8 °C
- First month of simulation: 1
- Simulation period: 25 years

Ground parameters

- Homogeneous ground conductivity: 2 W/(m·K)
- Homogeneous volumetric heat capacity: 2,4 MJ/(m³·K)
- Ground surface temperature: 9,6 °C
- Ground flux: 0,07 W/m²

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: 3,26 l/s
- Flow rate through borefield in injection: 4,13 l/s
- Number of boreholes in series: 1

Thermal demand

Baseload extraction [kWh]	Baseload injection [kWh]	Peak extraction [kW]	Peak injection [kW]
13 011,68	0,00	38,80	0,00
12 863,82	0,00	38,45	0,00
10 424,13	0,00	31,12	0,00
7 393,00	0,00	21,96	0,00
3 326,85	2 124,42	10,24	20,50
0,00	3 888,44	0,00	37,35
0,00	5 121,36	0,00	49,40
0,00	5 007,55	0,00	48,21
887,16	2 826,23	2,56	27,12
4 805,45	0,00	14,28	0,00
9 093,39	0,00	27,08	0,00
12 124,52	0,00	36,24	0,00

- Peak extraction duration: 12 hours

- Peak injection duration: 8 hours

Borefield parameters

x [m]	y [m]	Length [m]	Depth [m]	Buried depth [m]	Tilt [°]	Orientation [°]
0,00	0,00	72,30	73,00	0,70	0,00	0,00
0,00	6,00	72,30	73,00	0,70	0,00	0,00
0,00	12,00	72,30	73,00	0,70	0,00	0,00
0,00	18,00	72,30	73,00	0,70	0,00	0,00
6,00	0,00	72,30	73,00	0,70	0,00	0,00
6,00	6,00	72,30	73,00	0,70	0,00	0,00
6,00	12,00	72,30	73,00	0,70	0,00	0,00
6,00	18,00	72,30	73,00	0,70	0,00	0,00
12,00	0,00	72,30	73,00	0,70	0,00	0,00
12,00	6,00	72,30	73,00	0,70	0,00	0,00
12,00	12,00	72,30	73,00	0,70	0,00	0,00
12,00	18,00	72,30	73,00	0,70	0,00	0,00
18,00	0,00	72,30	73,00	0,70	0,00	0,00
18,00	6,00	72,30	73,00	0,70	0,00	0,00
18,00	12,00	72,30	73,00	0,70	0,00	0,00
18,00	18,00	72,30	73,00	0,70	0,00	0,00
24,00	0,00	72,30	73,00	0,70	0,00	0,00
24,00	6,00	72,30	73,00	0,70	0,00	0,00
24,00	12,00	72,30	73,00	0,70	0,00	0,00

24,00	18,00	72,30	73,00	0,70	0,00	0,00
24,00	24,00	72,30	73,00	0,70	0,00	0,00
30,00	0,00	72,30	73,00	0,70	0,00	0,00
30,00	6,00	72,30	73,00	0,70	0,00	0,00
30,00	12,00	72,30	73,00	0,70	0,00	0,00
30,00	18,00	72,30	73,00	0,70	0,00	0,00
30,00	24,00	72,30	73,00	0,70	0,00	0,00
36,00	0,00	72,30	73,00	0,70	0,00	0,00
36,00	6,00	72,30	73,00	0,70	0,00	0,00
36,00	12,00	72,30	73,00	0,70	0,00	0,00
36,00	18,00	72,30	73,00	0,70	0,00	0,00
36,00	24,00	72,30	73,00	0,70	0,00	0,00
42,00	0,00	72,30	73,00	0,70	0,00	0,00
42,00	6,00	72,30	73,00	0,70	0,00	0,00
42,00	12,00	72,30	73,00	0,70	0,00	0,00
42,00	18,00	72,30	73,00	0,70	0,00	0,00
42,00	24,00	72,30	73,00	0,70	0,00	0,00



5.2 Design Data - Building B

Design parameters

- Maximum borefield inlet fluid temperature: 17 °C
- Minimum borefield inlet fluid temperature: 0,54 °C
- First month of simulation: 1
- Simulation period: 25 years

Ground parameters

- Homogeneous ground conductivity: 2 W/(m·K)
- Homogeneous volumetric heat capacity: 2,4 MJ/(m³·K)
- Ground surface temperature: 9,6 °C
- Ground flux: 0,07 W/m²

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: 2,19 l/s
- Flow rate through borefield in injection: 2,81 l/s
- Number of boreholes in series: 1



Thermal demand

Baseload extraction [kWh]	Baseload injection [kWh]	Peak extraction [kW]	Peak injection [kW]
9 434,48	0,00	26,10	0,00
9 327,27	0,00	25,87	0,00
7 558,30	0,00	20,93	0,00
5 360,50	0,00	14,77	0,00
2 412,22	1 448,72	6,89	13,94
0,00	2 651,67	0,00	25,40
0,00	3 492,45	0,00	33,60
0,00	3 414,84	0,00	32,79
643,26	1 927,32	1,72	18,45
3 484,32	0,00	9,60	0,00
6 593,41	0,00	18,22	0,00
8 791,22	0,00	24,38	0,00

- Peak extraction duration: 12 hours

- Peak injection duration: 8 hours

Borefield parameters

x [m]	y [m]	Length [m]	Depth [m]	Buried depth [m]	Tilt [°]	Orientation [°]
60,00	0,00	72,30	73,00	0,70	0,00	0,00
60,00	6,00	72,30	73,00	0,70	0,00	0,00
60,00	12,00	72,30	73,00	0,70	0,00	0,00
60,00	18,00	72,30	73,00	0,70	0,00	0,00
66,00	0,00	72,30	73,00	0,70	0,00	0,00
66,00	6,00	72,30	73,00	0,70	0,00	0,00
66,00	12,00	72,30	73,00	0,70	0,00	0,00
66,00	18,00	72,30	73,00	0,70	0,00	0,00
72,00	0,00	72,30	73,00	0,70	0,00	0,00
72,00	6,00	72,30	73,00	0,70	0,00	0,00
72,00	12,00	72,30	73,00	0,70	0,00	0,00
72,00	18,00	72,30	73,00	0,70	0,00	0,00
78,00	0,00	72,30	73,00	0,70	0,00	0,00
78,00	6,00	72,30	73,00	0,70	0,00	0,00
78,00	12,00	72,30	73,00	0,70	0,00	0,00
78,00	18,00	72,30	73,00	0,70	0,00	0,00
84,00	0,00	72,30	73,00	0,70	0,00	0,00
84,00	6,00	72,30	73,00	0,70	0,00	0,00
84,00	12,00	72,30	73,00	0,70	0,00	0,00

84,00	18,00	72,30	73,00	0,70	0,00	0,00
90,00	0,00	72,30	73,00	0,70	0,00	0,00
90,00	6,00	72,30	73,00	0,70	0,00	0,00
90,00	12,00	72,30	73,00	0,70	0,00	0,00
90,00	18,00	72,30	73,00	0,70	0,00	0,00



5.3 Design Data - Building C

Design parameters

- Maximum borefield inlet fluid temperature: 17 °C
- Minimum borefield inlet fluid temperature: 0,59 °C
- First month of simulation: 1
- Simulation period: 25 years

Ground parameters

- Homogeneous ground conductivity: 2 W/(m·K)
- Homogeneous volumetric heat capacity: 2,4 MJ/(m³·K)
- Ground surface temperature: 9,6 °C
- Ground flux: 0,07 W/m²

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: 2,19 l/s
- Flow rate through borefield in injection: 2,81 l/s
- Number of boreholes in series: 1



Thermal demand

Baseload extraction [kWh]	Baseload injection [kWh]	Peak extraction [kW]	Peak injection [kW]
9 306,70	0,00	26,10	0,00
9 200,95	0,00	25,87	0,00
7 455,94	0,00	20,93	0,00
5 287,90	0,00	14,77	0,00
2 379,55	1 260,78	6,89	13,94
0,00	2 307,68	0,00	25,40
0,00	3 039,39	0,00	33,60
0,00	2 971,85	0,00	32,79
634,55	1 677,29	1,72	18,45
3 437,13	0,00	9,60	0,00
6 504,12	0,00	18,22	0,00
8 672,16	0,00	24,38	0,00

- Peak extraction duration: 12 hours

- Peak injection duration: 8 hours

Borefield parameters

x [m]	y [m]	Length [m]	Depth [m]	Buried depth [m]	Tilt [°]	Orientation [°]
0,00	-20,00	72,30	73,00	0,70	0,00	0,00
6,00	-20,00	72,30	73,00	0,70	0,00	0,00
12,00	-20,00	72,30	73,00	0,70	0,00	0,00
18,00	-20,00	72,30	73,00	0,70	0,00	0,00
0,00	-26,00	72,30	73,00	0,70	0,00	0,00
6,00	-26,00	72,30	73,00	0,70	0,00	0,00
12,00	-26,00	72,30	73,00	0,70	0,00	0,00
18,00	-26,00	72,30	73,00	0,70	0,00	0,00
0,00	-32,00	72,30	73,00	0,70	0,00	0,00
6,00	-32,00	72,30	73,00	0,70	0,00	0,00
12,00	-32,00	72,30	73,00	0,70	0,00	0,00
18,00	-32,00	72,30	73,00	0,70	0,00	0,00
0,00	-38,00	72,30	73,00	0,70	0,00	0,00
6,00	-38,00	72,30	73,00	0,70	0,00	0,00
12,00	-38,00	72,30	73,00	0,70	0,00	0,00
18,00	-38,00	72,30	73,00	0,70	0,00	0,00
0,00	-44,00	72,30	73,00	0,70	0,00	0,00
6,00	-44,00	72,30	73,00	0,70	0,00	0,00
12,00	-44,00	72,30	73,00	0,70	0,00	0,00

18,00	-44,00	72,30	73,00	0,70	0,00	0,00
0,00	-50,00	72,30	73,00	0,70	0,00	0,00
6,00	-50,00	72,30	73,00	0,70	0,00	0,00
12,00	-50,00	72,30	73,00	0,70	0,00	0,00
18,00	-50,00	72,30	73,00	0,70	0,00	0,00





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