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Simulating the effect of groundwater flow and heterogeneity on Borehole Thermal Energy Storage (BTES)

Mathias POSSEMIERS, Lotte DE HENAU & Jos VAN STEENWINKEL

AGT – Advanced Groundwater Techniques

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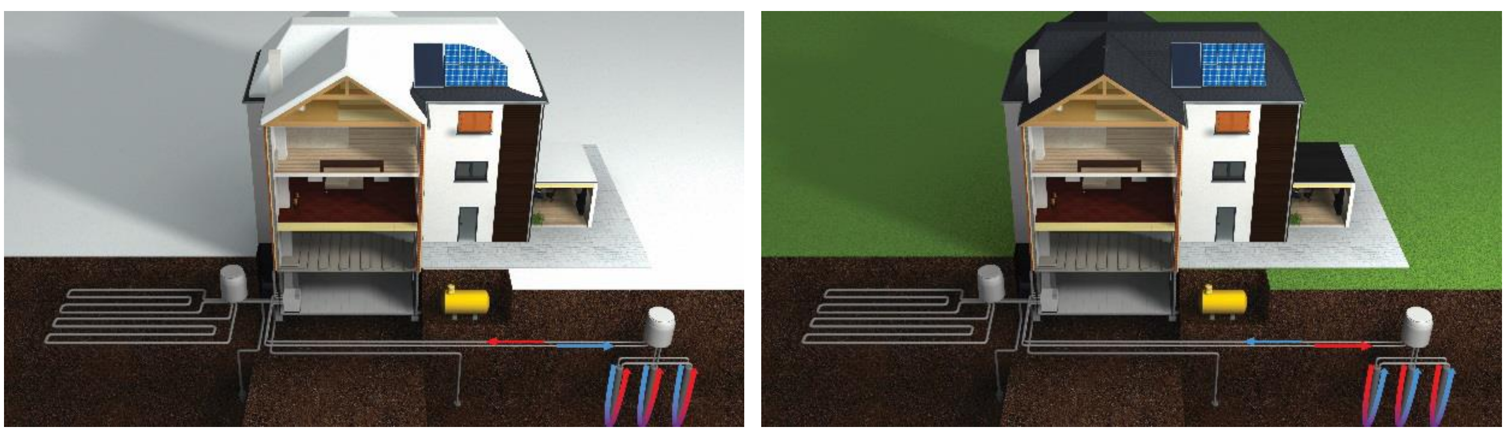
BTES

- Borehole Thermal Energy Storage (BTES), closed loop ground source heat pumps (GSHP) or closed systems
- Thermal energy is stored and recovered with a closed hydraulic circuit consisting of one or more boreholes with vertical heat exchangers.
- Heat exchangers consist of plastic tubes wherein a fluid (commonly a water-glycol mixture) is circulated and absorbs the thermal energy from the ground.



(SmartGeotherm, 2015)

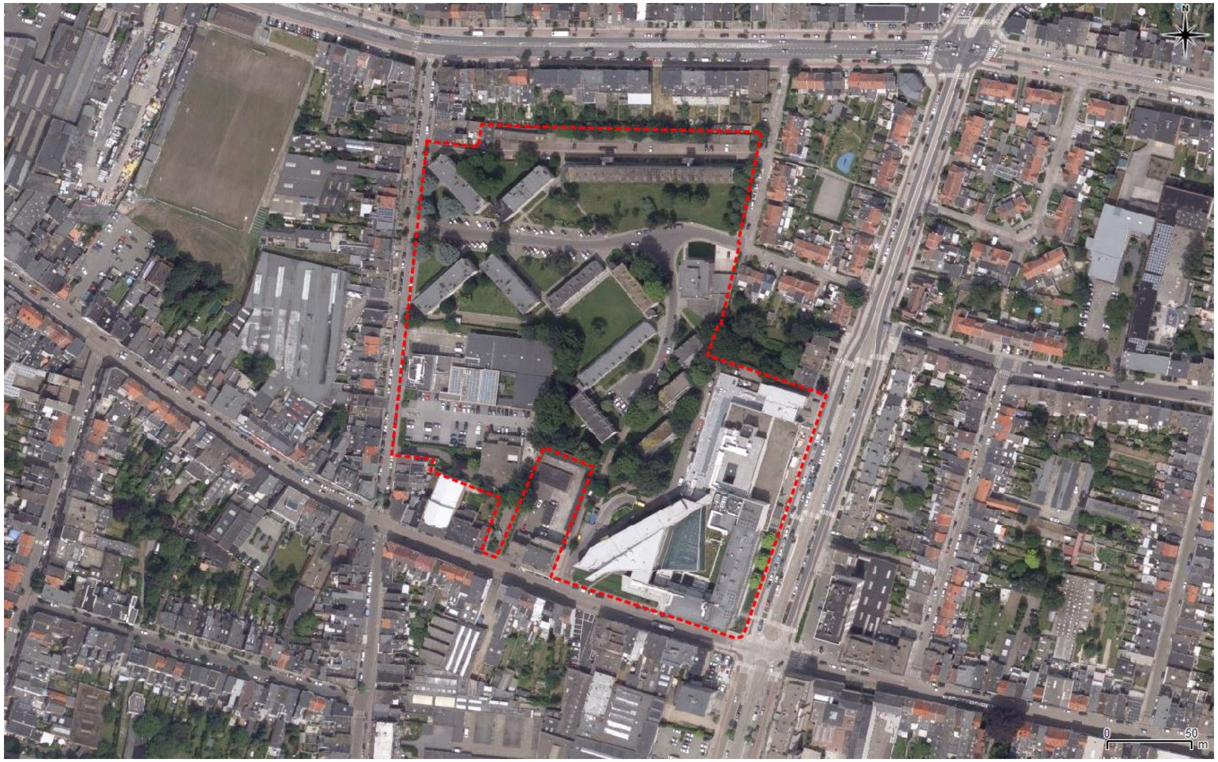
Problem

- Commonly, the number of heat exchangers is calculated using average values for the thermal properties of the subsurface
- Groundwater flow is generally not considered
- Subsurface heterogeneity and groundwater flow, however, can have an important impact on the number of required heat exchangers and the associated cost of a BTES system

- In this project the effect of both groundwater flow and heterogeneity on BTES systems is evaluated.

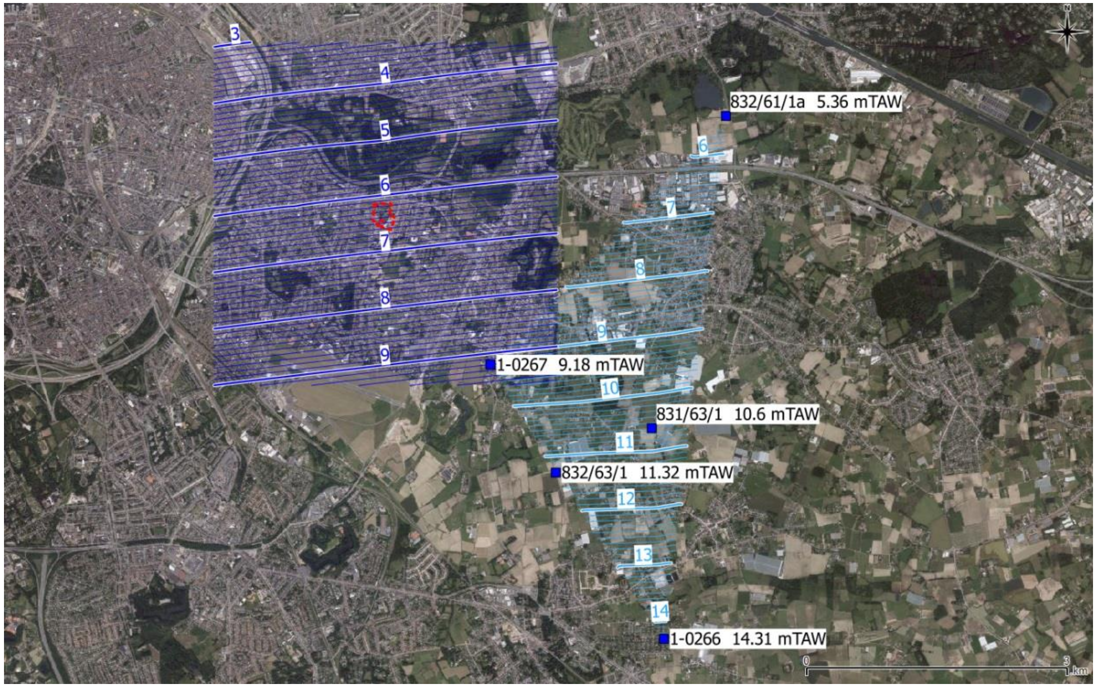
Case

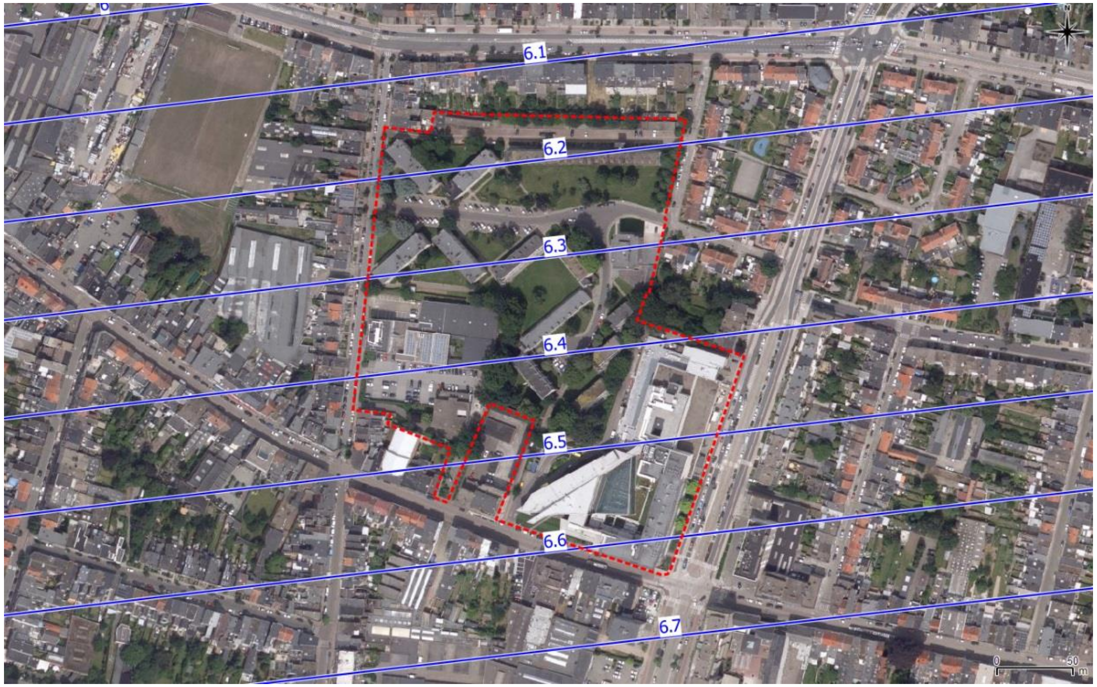
- Antwerp (Belgium)
- Hospital and public housing project



Site

- Groundwater flow
  - WNW
  - 1.5 ‰



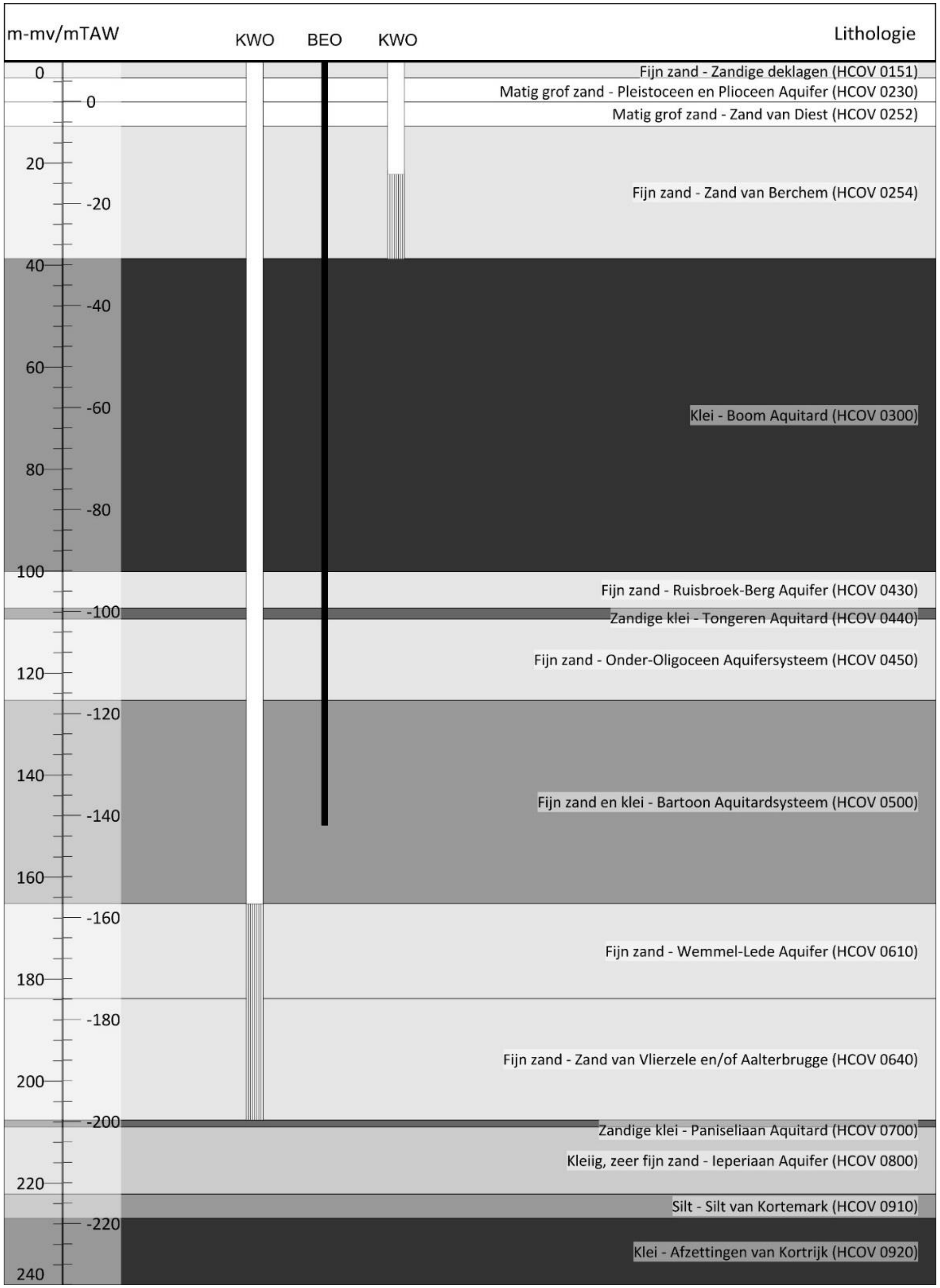


Site

- Geology
  - Sand
  - Clay

- BTES depth criterion

  = 150 m



Energy Demand

Scenario 1	Heating demand (MWh/year)	Peak load (kw)
Buildings	362	55
Subsurface (COP_{HP} 4.5)	282	43

Scenario 2	Heating demand (MWh/year)	Peak load (kw)
Buildings	3372	483
Subsurface (COP_{HP} 4.5)	2623	376

- Load duration curves not available

Model Setup

- COMSOL Multiphysics®
  - Groundwater flow (Subsurface Flow Module)
  - Heat transport in the subsurface (Heat Transfer Module)
  - The subsurface was divided into different geological layers (aquifers and aquitards), each with different hydrogeological and thermal parameters. To simulate the effect of groundwater flow, a groundwater gradient was imposed.

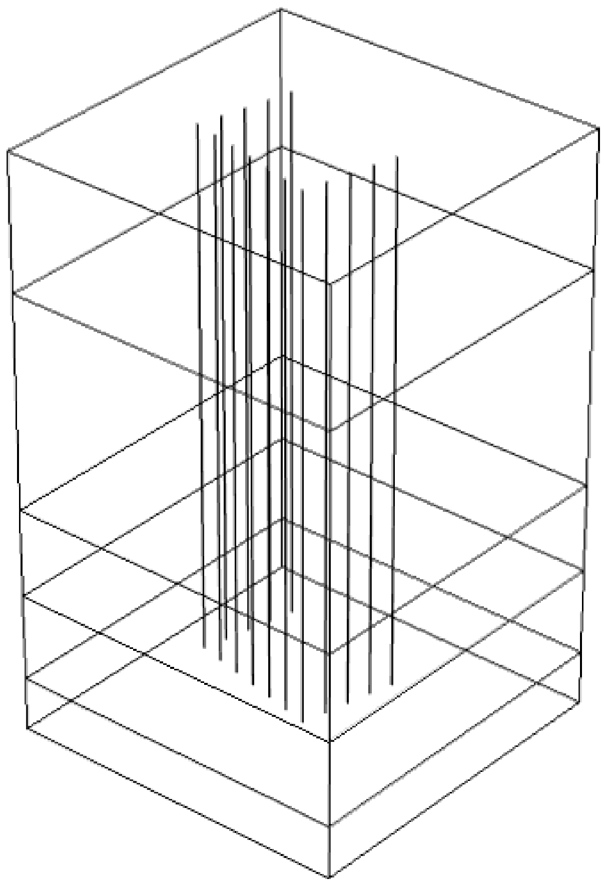
Model Setup

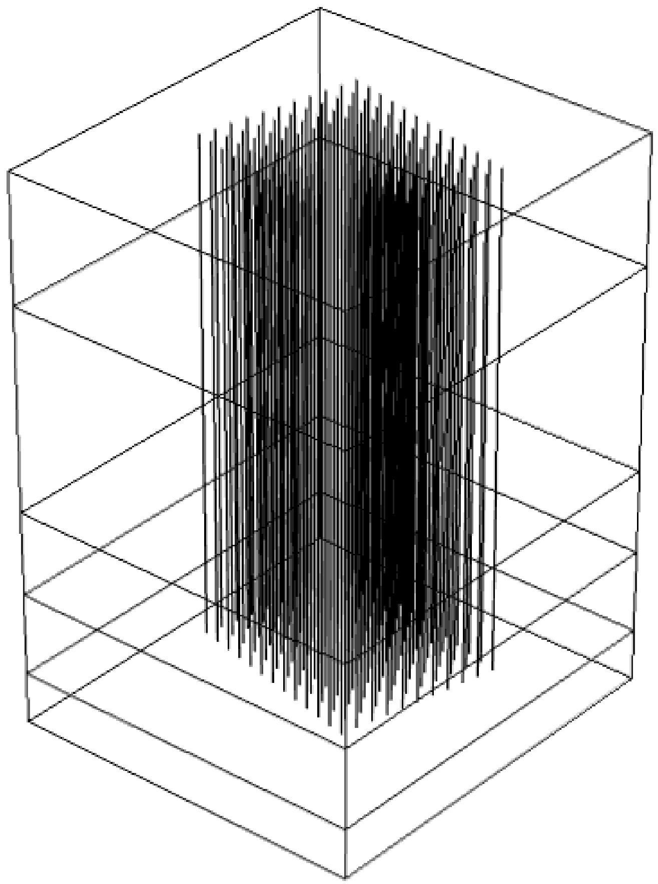
- Horizontal extensions
  - Scenario 1: 100 x 100 m
  - Scenario 2: 110 x 120 m
- Vertical extensions

Model-laag	Top (mTAW)	Basis (mTAW)	Top (m-mv)	Basis (m-mv)	Dikte (m)	Hydrogeologie	K_h (m/dag)	K_v (m/dag)
1	7.9	-30.8	0	38.7	38.7	Zandige deklagen (HCOV 0151) Pleistoceen en Plioceen Aquifer (HCOV 0230) Zand van Diest (HCOV 0252) Zand van Berchem (HCOV 0254)	10	3.33
2	-30.8	-92.2	38.7	100.1	61.4	Boom Aquitard (HCOV 0300)	0.001	0.0003
4	-92.2	-117.4	100.1	125.3	25.2	Ruisbroek-Berg Aquifer (HCOV0430) Tongeren Aquitard (HCOV 0440) Onder-Oligoceen Aquifersysteem (HCOV 0450)	1	0.33
7	-117.4	-157.3	125.3	165.2	39.9	Bartoon Aquitardsysteem (HCOV 0500)	0.010	0.0033

Model Setup

- Geometry





Model Setup

- Materials

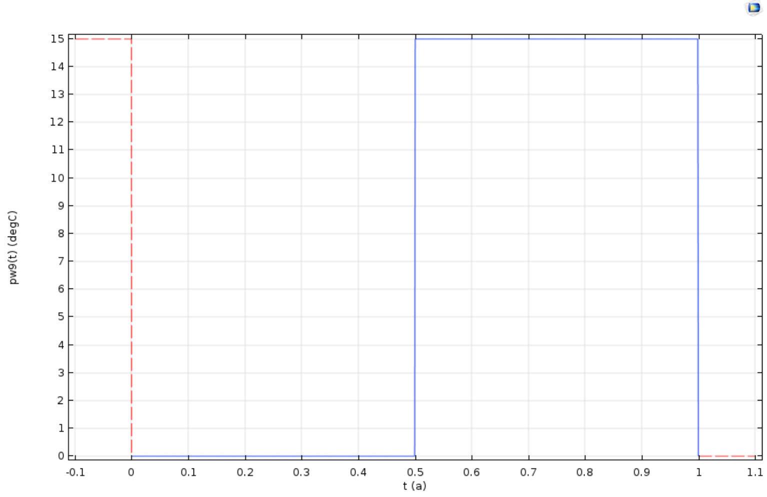
Material	Thermal conductivity (W/mK)	Heat capacity (J/kgK)	Density (kg/m³)
Sand	2.90	920	2650
Clay	2.00	1090	2650
Water	0.58	4186	1000

Model Setup

- Darcy's Law
  - Effective porosity
    - Sand: 0.15
    - Clay: 0.01
  - Hydraulic conductivity (K_h, K_v)
  - Hydraulic head > Groundwater gradient
    - Up- and downstream end

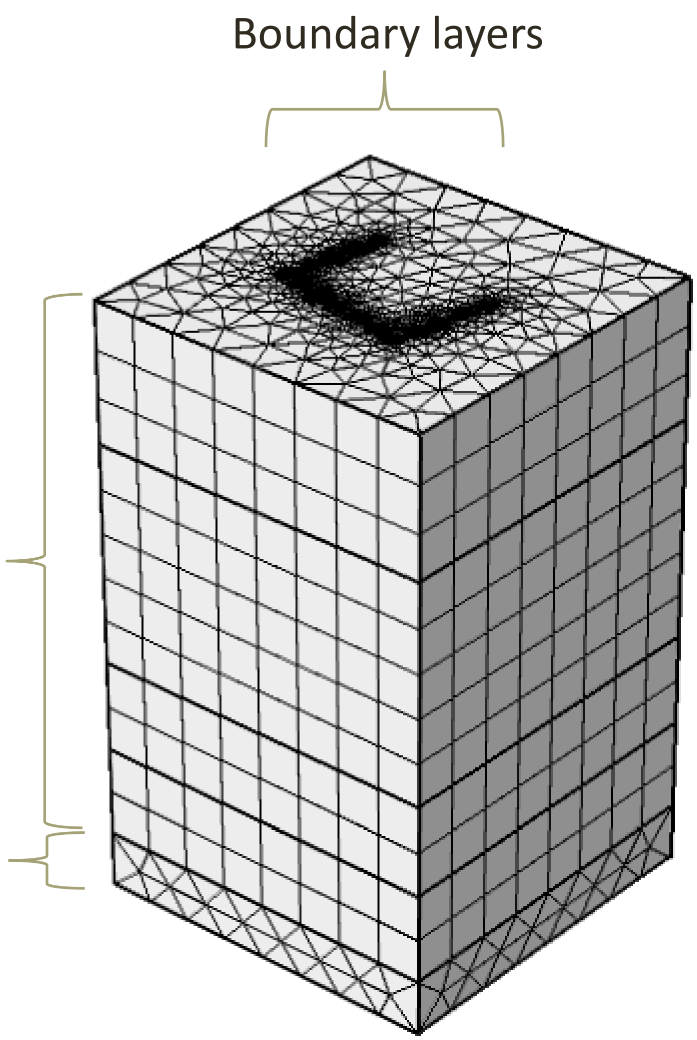
Model Setup

- Heat Transfer in Porous Media
  - Initial temperature: 12°C
  - Inflow – Outflow
  - Effective porosity: 0.35
  - Convective Heat Flux
    - Heat transfer coefficient: $1/R_b$
    - R_b: Borehole resistance = 0.1 mK/W x borehole radius (65 mm)
    - External temperature: Piecewise function
      - Heating (6 months): 0°C
      - Cooling (6 months): 15°C



Model Setup

- Mesh



Model Setup

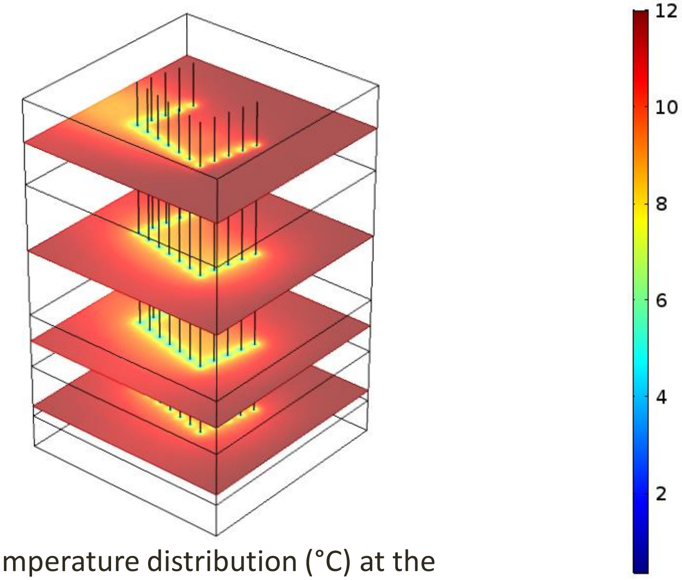
- Study
  - Study 1: Stationary > Darcy’s Law
  - Study 2: Time Dependent > Heat Transfer in Porous Media

Results

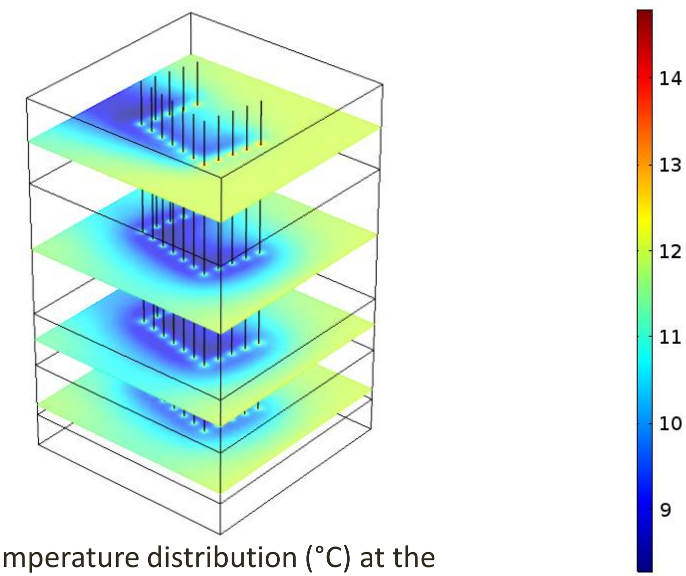
- Scenario 1
  - 55 kW
  - 362 MWh

  - 15 vertical heat exchangers
  - U-shaped configuration

  - Influence of groundwater flow
    >> in aquifers than aquitards



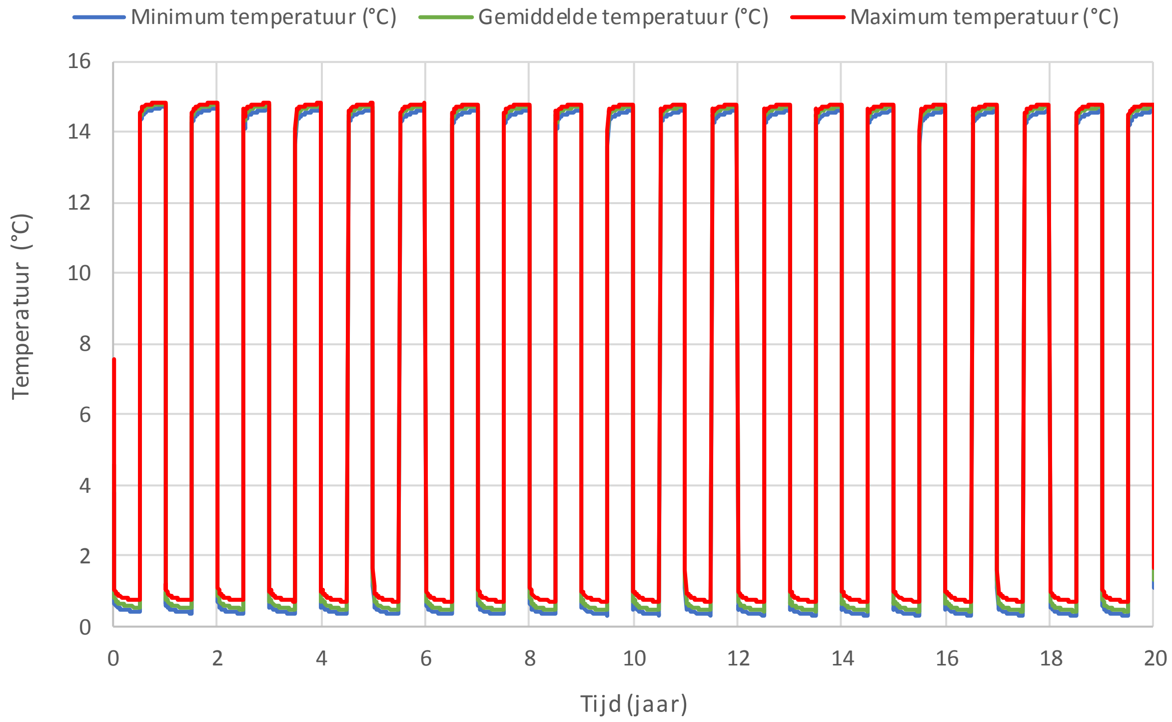
Temperature distribution (°C) at the end of the heating cycle after 20 years



Temperature distribution (°C) at the end of the cooling cycle after 20 years

Results

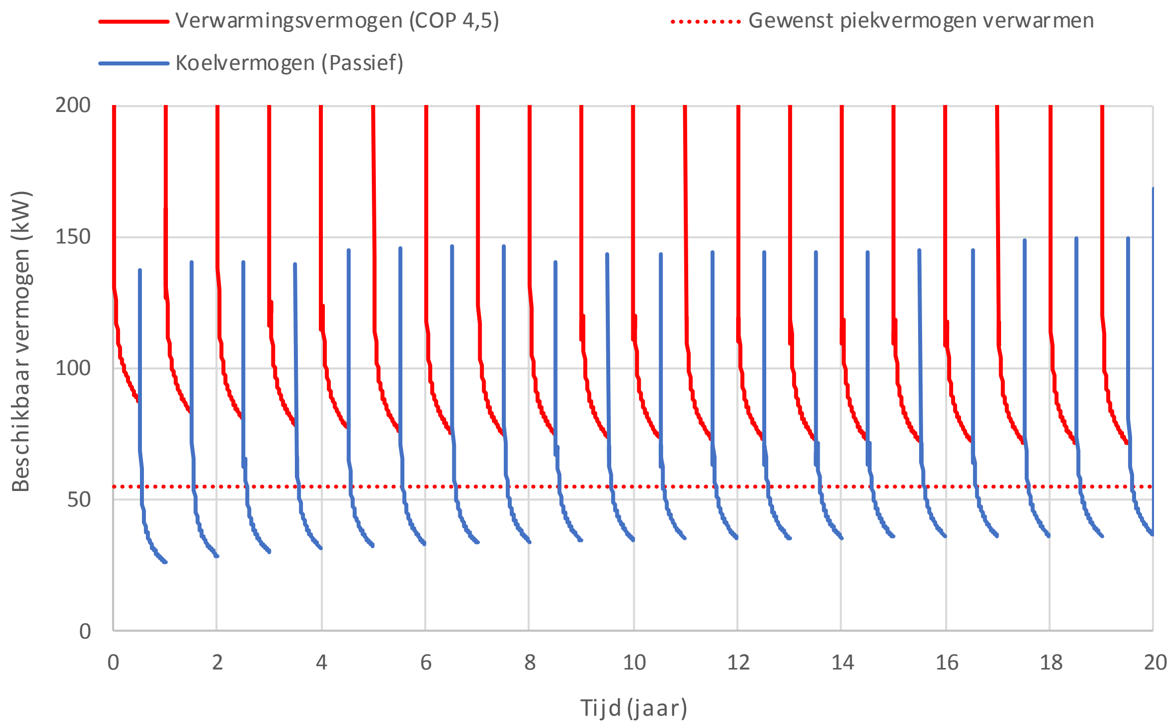
- Scenario 1



Evolution of the average, minimum and maximum temperature on the borehole wall

Results

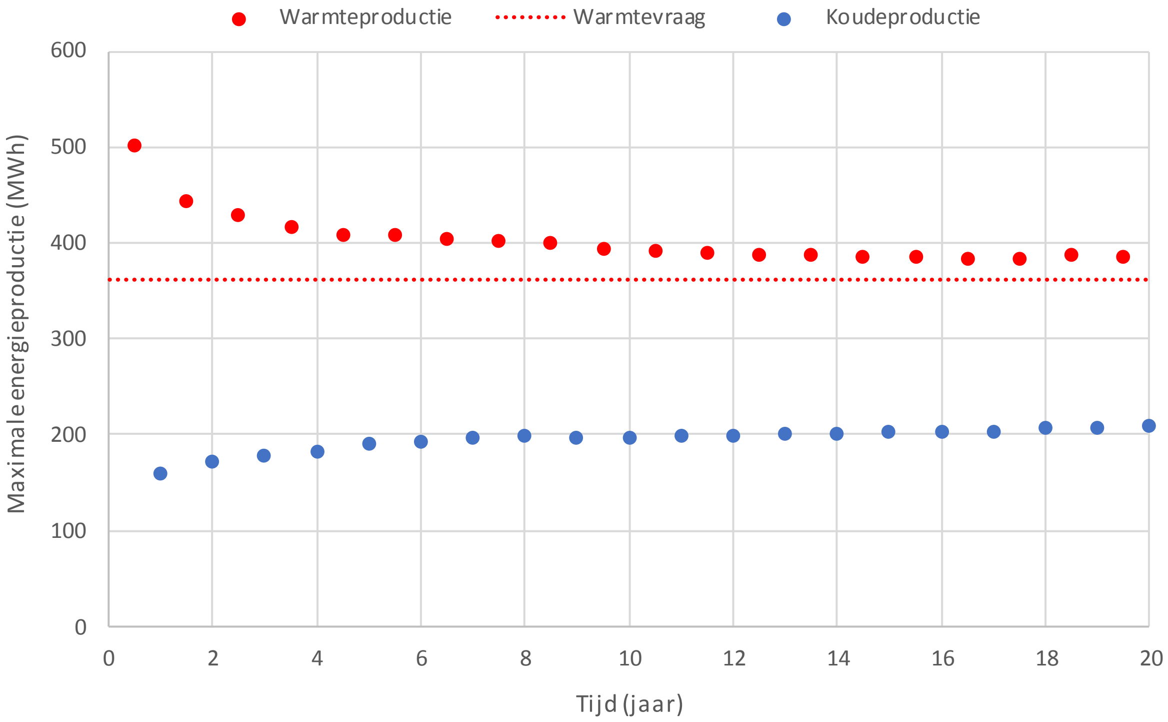
- Scenario 1



Evolution of the available power

Results

- Scenario 1



Evolution of the maximal energy production

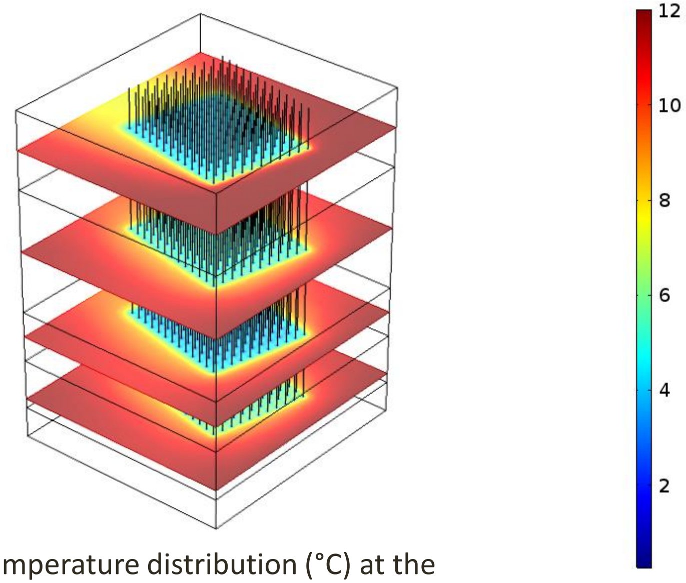
Results

- Scenario 2
  - 483 kW
  - 3372 MWh

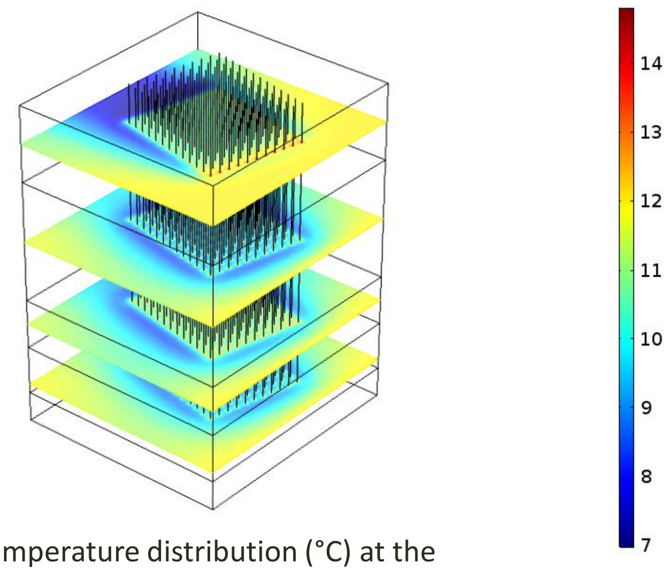
  - 143 vertical heat exchangers
  - Rectangle 11 x 13

  - Influence of groundwater flow

    >> in aquifers than aquitards



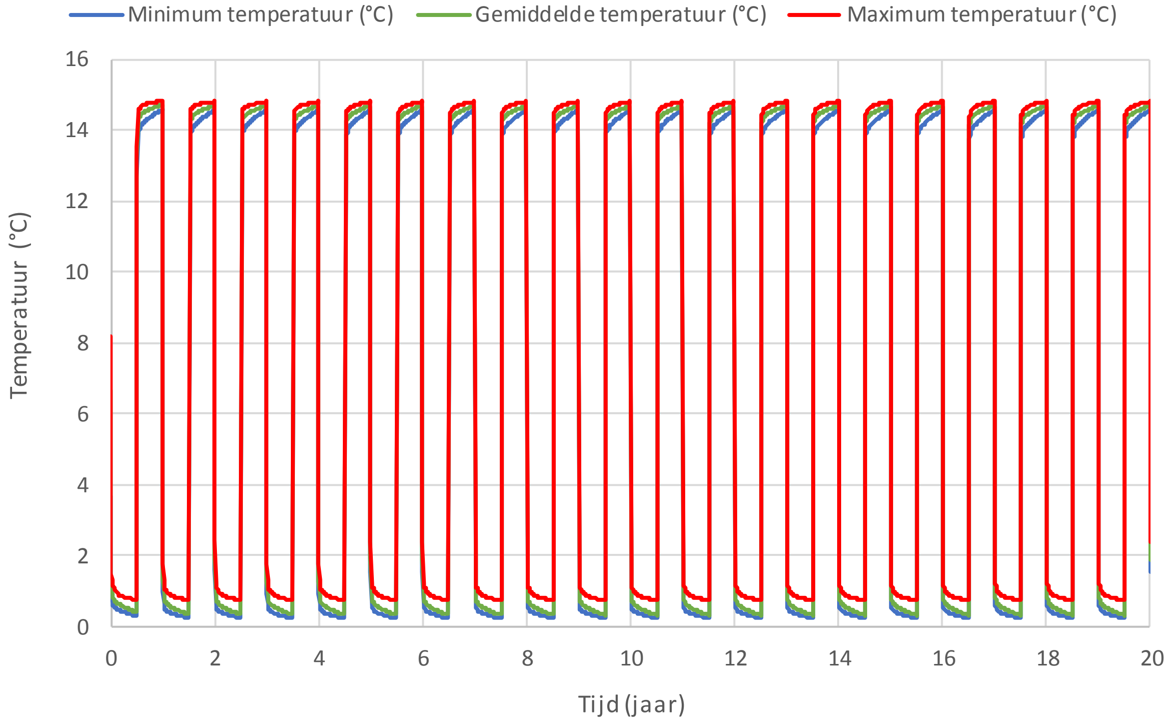
Temperature distribution (°C) at the end of the heating cycle after 20 years



Temperature distribution (°C) at the end of the cooling cycle after 20 years

Results

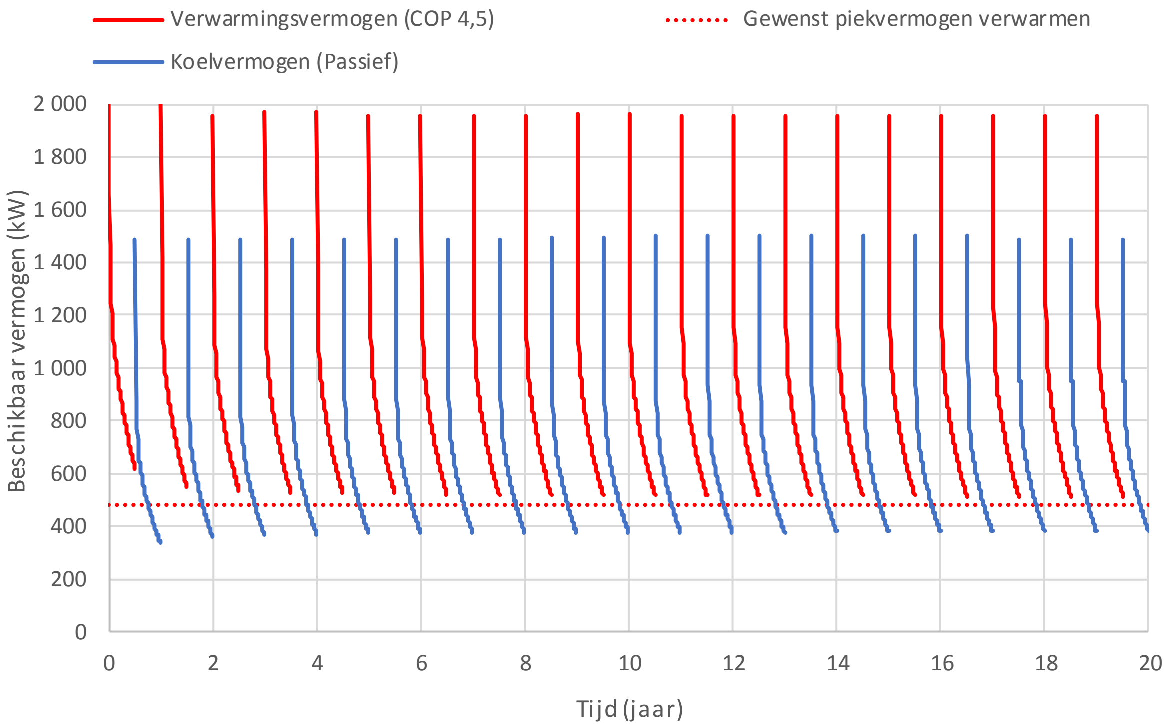
- Scenario 2



Evolution of the average, minimum and maximum temperature on the borehole wall

Results

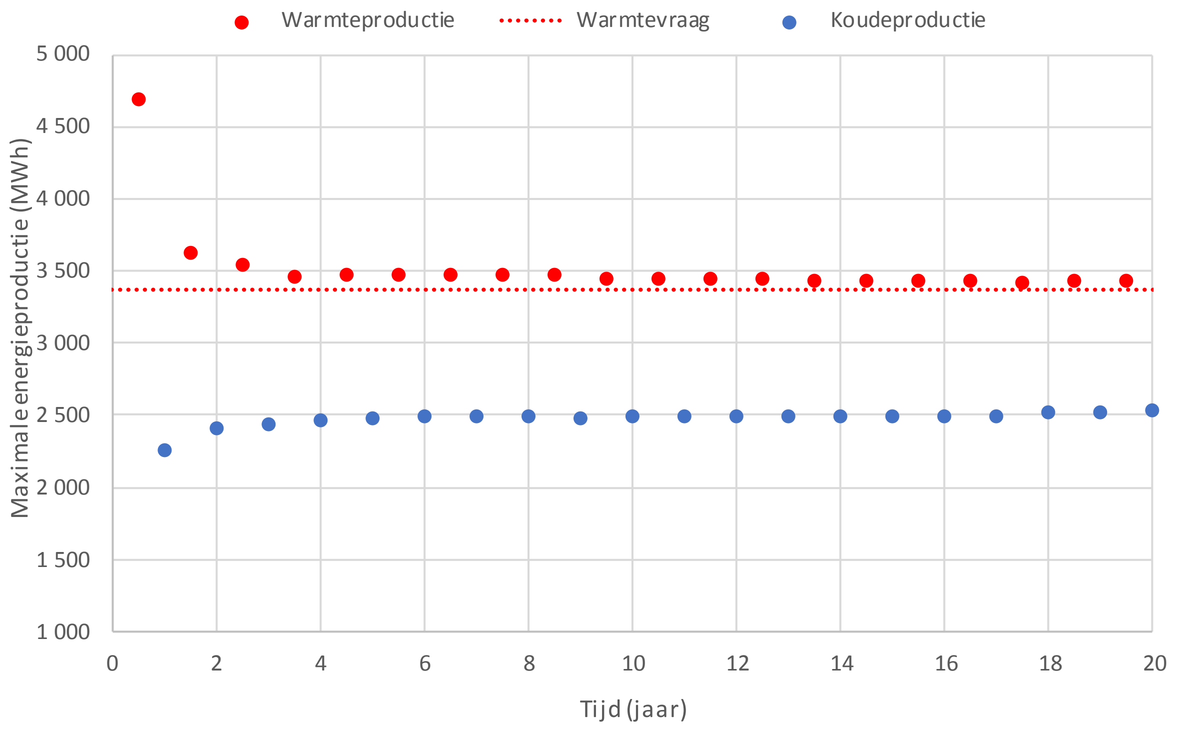
- Scenario 2



Evolution of the available power

Results

- Scenario 2



Evolution of the maximal energy production

Conclusion

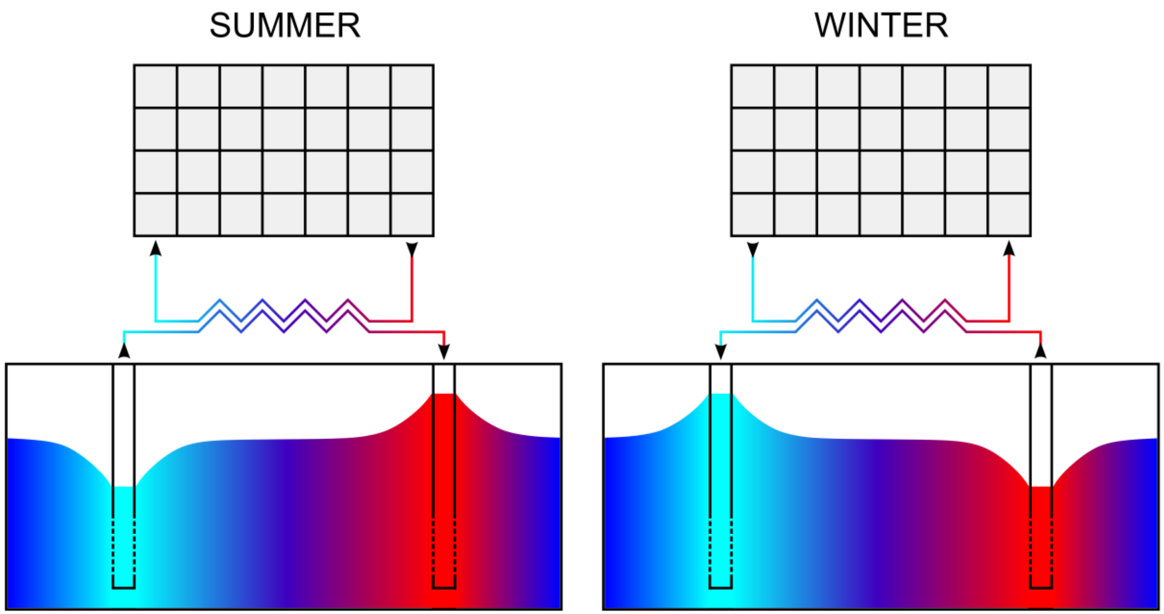
- Clear effect of both heterogeneity and groundwater flow on the temperature distribution around the borehole heat exchangers

- In the aquifers, the effect of the groundwater flow is much larger than in the aquitards.

- Particularly in the case of the presence of aquifers, it is important to consider groundwater flow and subsurface heterogeneity for dimensioning a BTES system.

Future

- Modeling interaction between BTES and ATES



(Possemiers et al., 2014)

ATES concept

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