Ground Heat Exchangers & Heat Pumps

An integrated design framework for ground heat exchangers and ground source heat pumps

External training | 20.09.2022 | Online

This project has received funding from the H2020 programme under Grant Agreement No. 792210

GEOFIT

GEOthermal systems for energy efficient building retroFITting

- 4 year H2020 project (May 2018-April 2022)
- 24 Partners
- Innovation Action supporting the H2020 Societal Challenge of Secure, Clean and Efficiency Energy
- Part of INEA's Energy Portfolio (Low Carbon Economy (LCE), Renewable Energy Technologies (RET)
- € 9.7 million cost / € 7.9 million funding

Tools and methods for viable and cost-effective geothermal retrofitting

Efficient geothermal systems and its components

IDDS

Integrated retrofit management framework based on IDDS

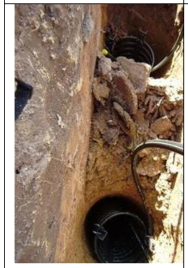
Demonstration, exploitation and innovative business models

Motivation

- Ground source heat exchangers (GHEX) and heat pumps provide highly efficient heating and cooling

- For existing building stock few solutions exist, retrofitting in non-urban areas will benefit from low-cost easy to install GHEX such as slinky, horizontal and earth basket GHEX

- BUT: no integrated advanced engineering design tools exist for e.g. slinky loop collectors, earth baskets etc. - installation depend on skills of installers – they are not trained for installing these GHEX

(a) Vertical spiral collectors	(b) Horizontal spiral collectors	(c) Horizontal (flat) slinky-loop collectors	(d) Vertical (upright) slinky loop collectors
Placed in vertical boreholes with a diameter of about 20 cm width and 5 m depth. The loop pitches (i.e. the distance between the loops) vary, but are typically several cm.	Placed in trenches with a diameter of about 20 cm width and 5 m depth. The loop pitches (i.e. the distance between the loops) vary, but are typically several cm.	Placed lying flat in loops in a ca. 2 m wide trench. After the placing of the loops, the trench is backfilled with in-situ sediment or with primarily sandy sediment ('cable sand') The loops are either not overlapping or overlapping at half or a third of the loop diameter.	Placed upright in loops in a ca. 50 cm wide trench. After the placing of the loops, the trench is backfilled with in-situ sediment or with primarily sandy sediment ('cable sand') The loops are either not overlapping or overlapping at half or a third of the loop diameter.
			
http://www.rosenthal-geothermie.de/117.html	http://www.rosenthal-geothermie.de/117.html	https://grabenkollektor.waermepumpen-verbrauchsdatenbank.de/	https://grabenkollektor.waermepumpen-verbrauchsdatenbank.de/

Content

- Design tool for ground heat exchangers
- Development of an integrated design approach

  integrated tool, iterative design, design documentation
- New calculation methods for complex GHEX topologies
  - *dealing with laminar/turbulent transition*
- Far field modelling
- Lab experiments & CFD
- Validation
- Performance analysis
- Engineering tool
- Heat pump
- Wrap-up: Field laboratory

Ground Heat Exchanger - Design Process

Ground Heat Exchanger - Design Process

Goal of the design of a ground heat exchanger is to

determine the required the size of a GHEX

As a function of

Heating and cooling energy demand

Heating and cooling capacity

Required performance

Other boundary conditions (soil thermal parameters, drilling conditions, available space)

<u>Design is not just performing the calculation, but an iterative process</u>

Ground Heat Exchanger - Design Process

- **Seasonal performance and energy savings achieved**, under different boundary conditions (such as soil thermal parameters, climate and building characteristics)

- **Technical and operational life of the system**, reflecting the life-expectancy of components depending on material properties and operational conditions (mainly temperature) as well as the temperature evolution of the activated ground volume.

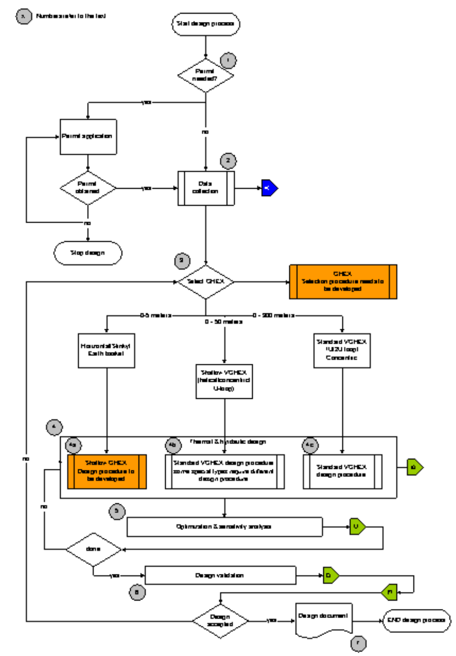
- **Balancing between installed capacity, base load and peak load operation and system size**, the relative importance of many system characteristics depends on the ratio of thermal capacity and total energy delivered and is moreover affected by the seasonal balance between heating and cooling.

- **Sensitivity analysis and validation of the final design**, as many different parameters affect the design, but the relative importance may vary very significantly, a sensitivity analysis is usually needed to determine the critical design parameters.

Ground Heat Exchanger - Design Process

Summary roadmap for project design

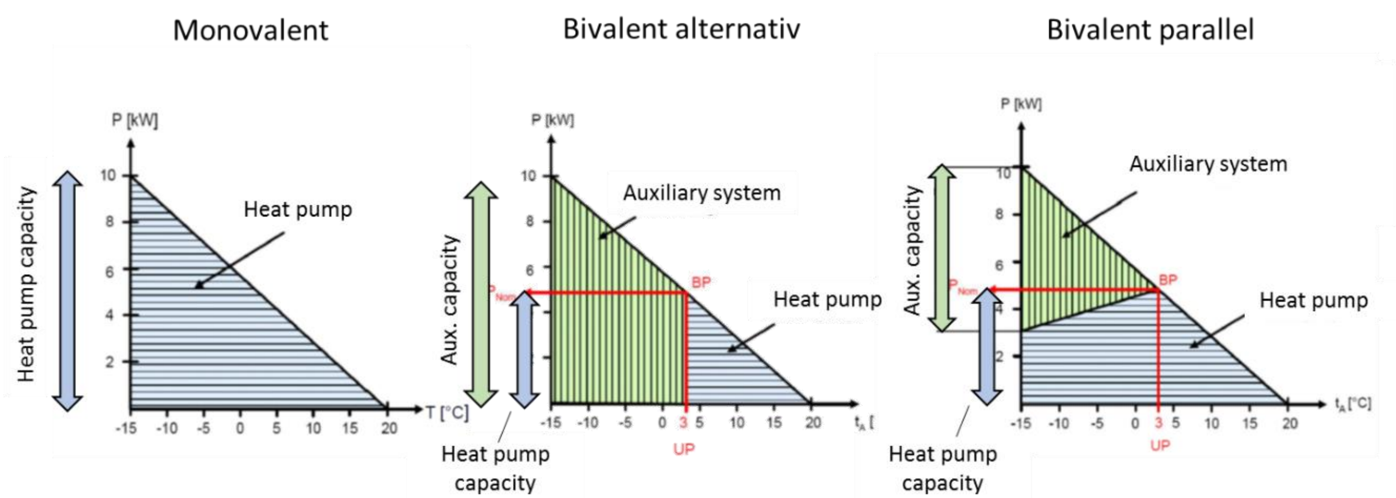
- Check feasibility and permits required
- Collecting and evaluating data needed for the design
- Thermal and hydraulic design
  - Defining design parameters and boundary conditions
  - Comparing different GHEX solutions
  - Design calculations: thermal
    - Local process: individual GHEX construction
    - Global process: GHEX thermal interactions
    - Sensitivity
  - Design calculation: hydraulic (pressure drop)
- Documenting the design process and results



Ground Heat Exchanger - Design Process

Example, energy demand profile and hybridization

Iterative design: evaluate different approaches to hybridization



- Heat pump only
- Design for 100% heat demand
- Feasible for small temperature lifts

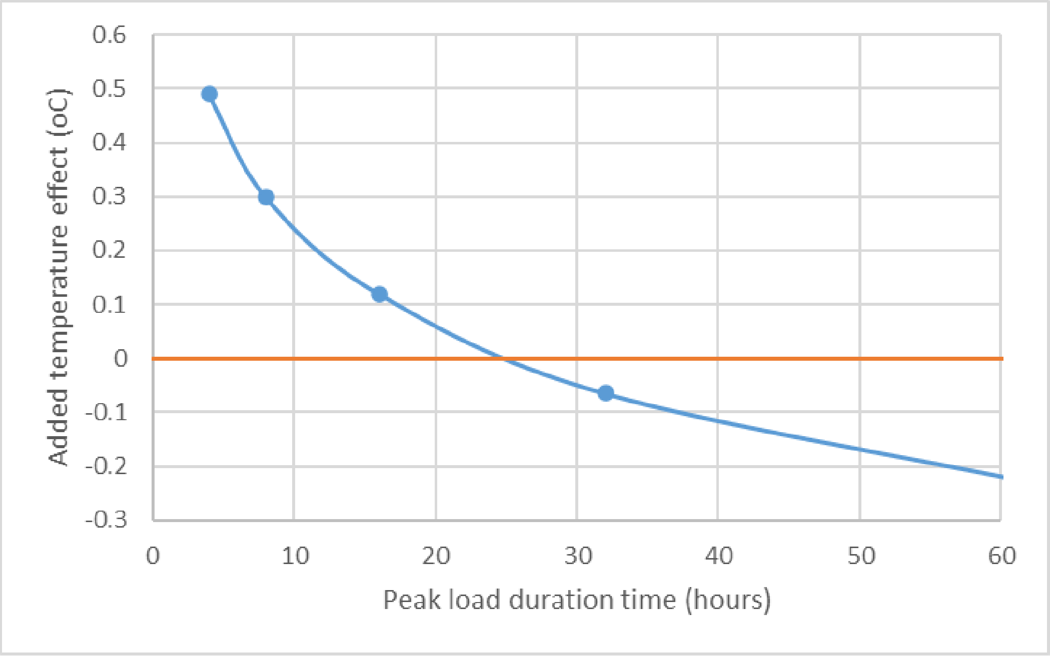
- Co-generation heat pump with aux. system
- Heat pump partly covers heat demand
- Aux. system only above BP

- Co-generation heat pump with aux. system
- Heat pump covers approx. 80% heat demand
- Base load with heat pump

Ground Heat Exchanger - Design Process

Example, peak capacity and peak load duration

Iterative design: evaluate effect of different capacities and select final capacity and peak load duration

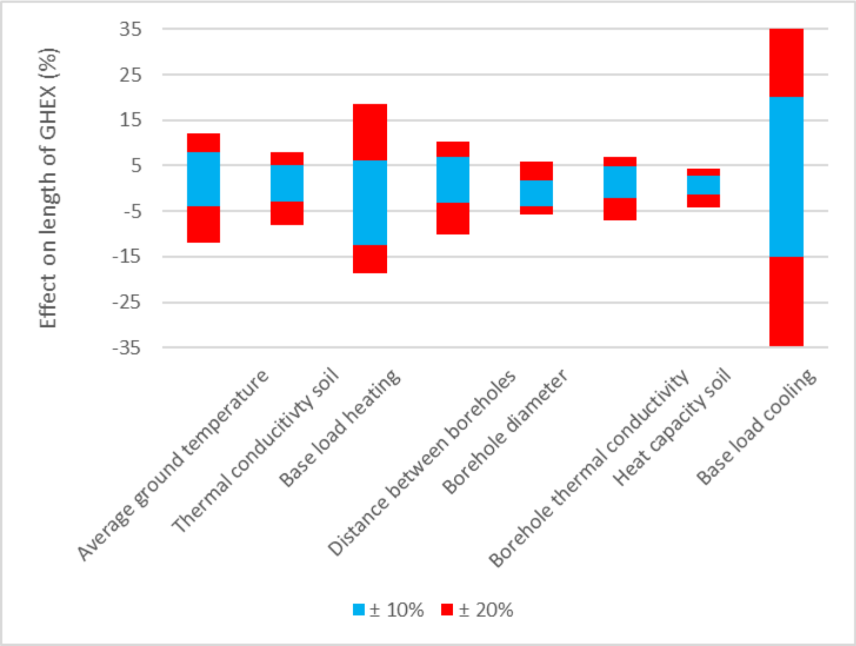


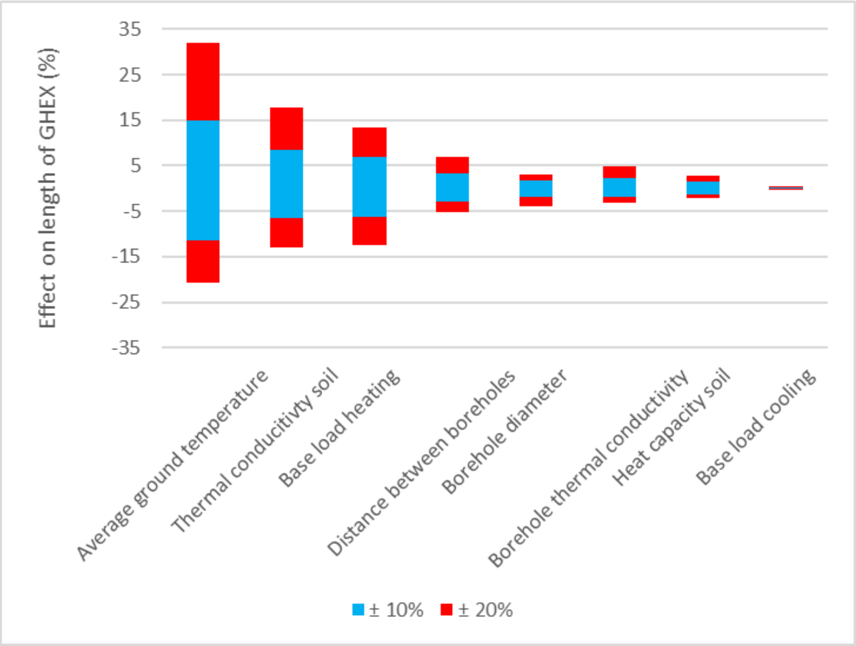
Ground Heat Exchanger - Design Process

Example, sensitivity

Iterative design: evaluate effect of different parameterizations and possibly collect and analyze additional data

Adapt energy demand profile, e.g. re-evaluate cooling demand





Ground Heat Exchanger - Design Process

Documentation

2d – geology					
Based on information geological survey or test drilling on site					
Design goal: Intended end-depth boreholes (m)					120 m
Summary soil profile, soil thermal parameters and backfilling					
Test boreholes to end-depth, average distance to location				500 (m)	
Test boreholes, number of boreholes used				3	
top (m)	**bottom (m)**	**soil type**	**thermal conductivity (W/mK)**	**heat capacity (MJ/kgK)**	**backfill**
0	5	sand, dry	0.50 ± 0.2	1.20 ± 0.1	sealing clay
5	45	medium fine sand	1.90 ± 0.3	2.40 ± 0.2	coarse sand
45	55	clay	1.80 ± 0.4	2.20 ± 0.1	sealing clay
55	95	medium fine sand	1.90 ± 0.3	2.50 ± 0.2	coarse sand
95	120	coarse sand	2.30 ± 0.2	2.40 ± 0.2	coarse sand
		Average:	**1.92** ± 0.3	**2.37** ± 0.2	coarse sand
Average yearly surface temperature (°C)			16.2		
Average minimum monthly temperature(°C)			9.1		
Average maximum monthly temperature (°C)			24.2		
Depth of isothermal surface (m)			15		
Average temperature below isothermal surface (°C)			16.6		
Geothermal gradient (K/m)			0.0		
Geothermal flux (W/m²)			0.0		
Geohydology		Porous		Porous/fractured	
Average Darcy ground water flow aquifers (m/year)		< 10			
Total length of aquifer (m)		105			

Computational Framework

Computational framework

Global process – temperature evolution in the ground

- Temperature evolution at GHEX wall
- Interaction between all GHEX in ground volume
- Include near-surface seasonal temperature variations
- Include deep geothermal gradient

Local process – thermal resistance fluid to ground and pressure drop

- Set of equations to calculate the thermal resistance for different geometries (*dealing with turbulent/laminar boundary*)
- Set of equations to calculate the pressure drop for different geometries
- Correlations for temperature-dependent fluid properties for water, mono-ethylene and mon-propylene glycol

Computational framework

Standardized methodology for GHEX design calculations

- Conductive heat flow in the ground
- Solver for temperature effect @ distance from GHEX
- Solver for fluid temperature as function of capacity and thermal resistance

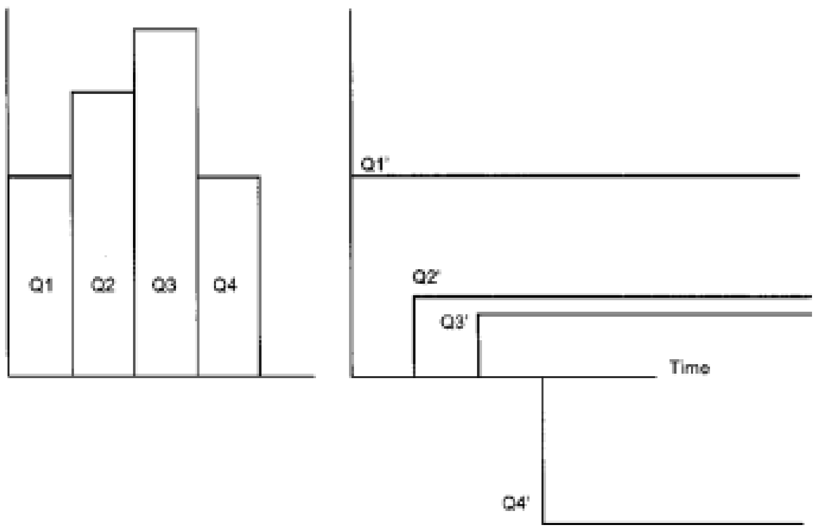
- Superposition of temperature effects in space and time
- Superposition of long term and short term response

- Decomposition of energy-demand profile
- G-function approach to speed-up calculations

Computational framework

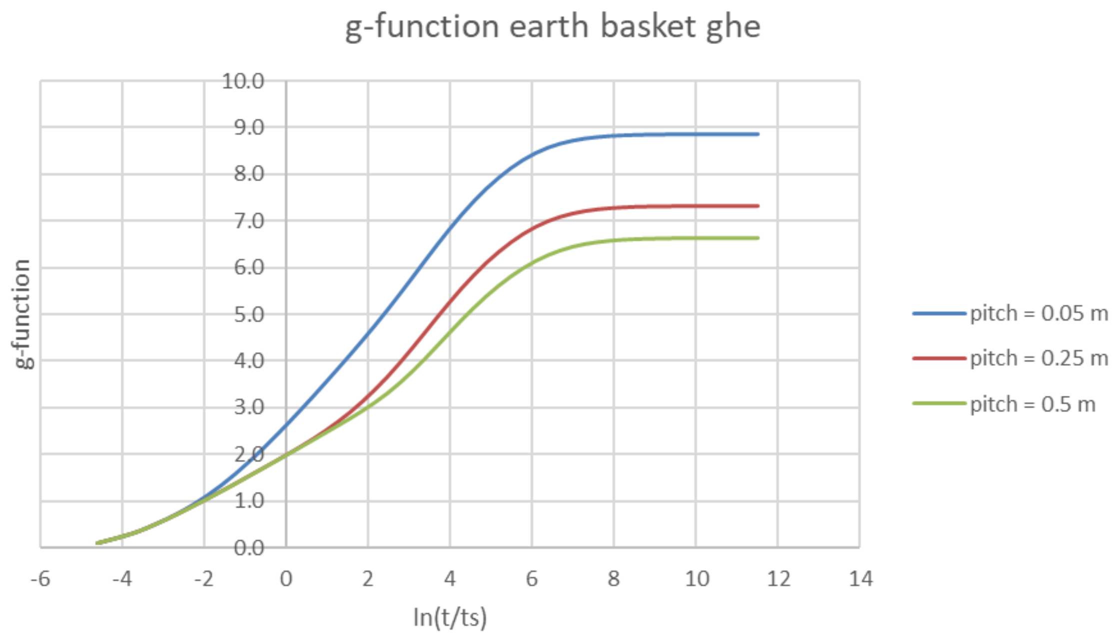
Decomposition of energy-demand profile

- Solver only calculates for contant load for total time
- Superposition of additional load steps solutions in time
- Decomposition of energy-demand profile



Computational framework

G-function



Computational framework - global process

Finite Line Source + G-function approach

FLS is the "workhorse" of conventional (vertical) GHEX

G-function is standard approach for computational efficiency

1D (Vertical Borehole Heat Exchanger

$$T(r,z,t) = \frac{q_0}{4\pi\lambda} \int_0^H \left[\frac{1}{r_1} erfc\left(\frac{r_1}{2\sqrt{\alpha t}}\right) - \frac{1}{r_2} erfc\left(\frac{r_2}{2\sqrt{\alpha t}}\right)\right] dh$$

2D (horizontal / slinky GHEX)

$$\Delta T_{j\to i}(t) = \frac{q'R}{8\pi^2\lambda} \int_0^{2\pi} \int_0^{2\pi} \left[\frac{\mathrm{erfc}\left(d(P_j,P_i)/2\sqrt{\alpha t}\right)}{d(P_j,P_i)} - \frac{\mathrm{erfc}\left(\sqrt{d(P_j,P_i)^2 + 4h^2}/2\sqrt{\alpha t}\right)}{\sqrt{d(P_j,P_i)^2 + 4h^2}}\right] d\omega d\varphi$$

3D (Earth basket type GHEX)

$$\Delta T_{j\to i}(t) = \frac{q'R}{8\pi^2\lambda} \int_0^{2\pi} \int_0^{2\pi} \left[\frac{\mathrm{erfc}\left(d(P_j,P_i)/2\sqrt{\alpha t}\right)}{d(P_j,P_i)} - \frac{\mathrm{erfc}\left(\left(d(P_j,P_i) + 2h\right)/2\sqrt{\alpha t}\right)}{\left(d(P_j,P_i) + 2h\right)}\right] d\omega d\varphi$$

Computational framework - global process

Finite line source for vertical ground heat exchangers

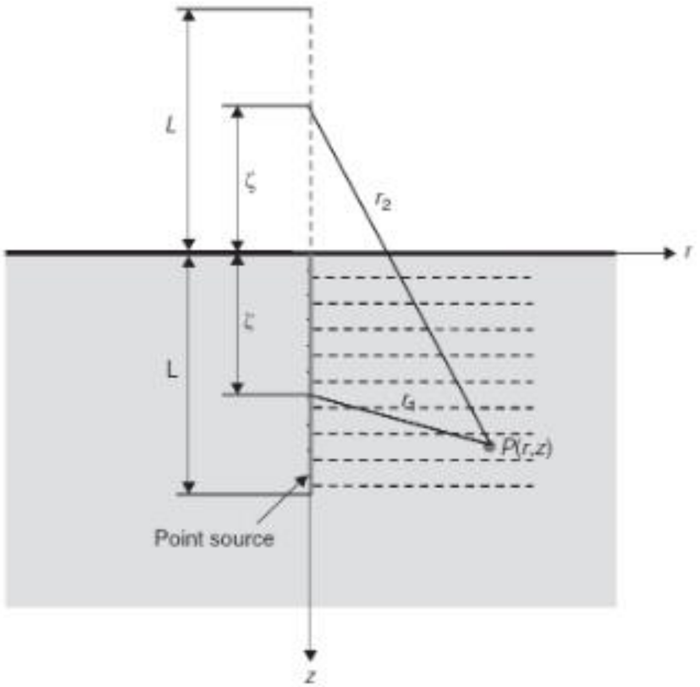


Figure 2.5: Finite Line Source method [2]

$$r_1 = \sqrt{\left(\sqrt{(r^2)} + (z-h)^2\right)} \qquad r_2 = \sqrt{\left(\sqrt{(r^2)} + (z+h)^2\right)}$$

Computational framework - global process

Finite line source for slinky ground heat exchangers

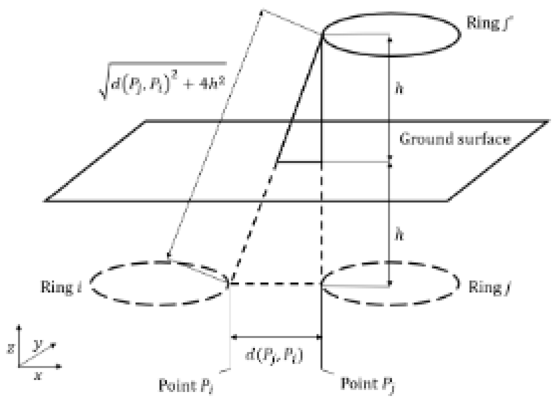


Fig. 5: 3D view of the horizontal Slinky type GHE model

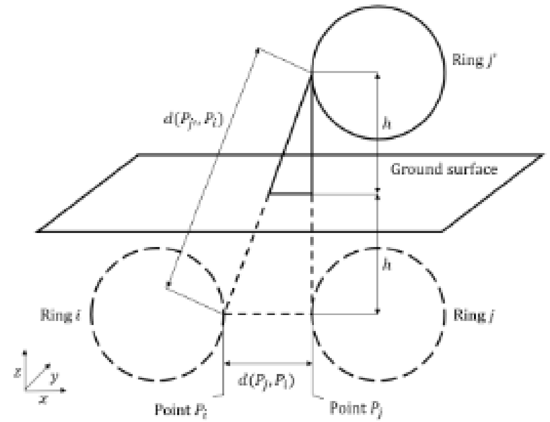


Fig. 7: 3D view of the vertical Slinky type GHE model

$$d(P_j, P_i) = \frac{d(P_{ii}, P_j) + d(P_{io}, P_j)}{2}$$

$$d(P_{ii}, P_j) = \sqrt{[x_{oi} + (R-r)\cos\varphi - x_{oj} - R\cos\omega]^2 + [y_{oi} + (R-r)\sin\varphi - y_{oj} - R\sin\omega]^2}$$

$$d(P_{io}, P_j) = \sqrt{[x_{oi} + (R+r)\cos\varphi - x_{oj} - R\cos\omega]^2 + [y_{oi} + (R+r)\sin\varphi - y_{oj} - R\sin\omega]^2}$$

$$d(P_{ii}, P_j) = \sqrt{[x_{oi} + (R-r)\cos\varphi - x_{oj} - R\cos\omega]^2 + [y_{oi} - y_{oj}]^2 + [z_{oi} + (R-r)\sin\varphi - z_{oj} - R\sin\omega]^2}$$

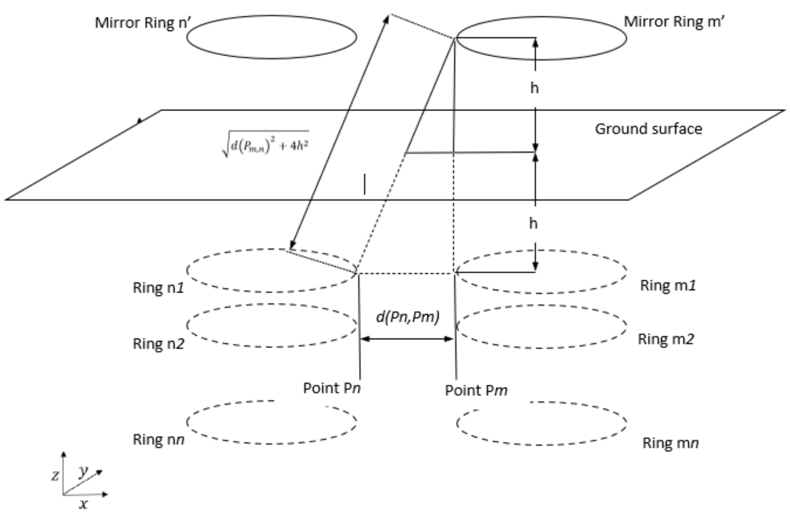
$$d(P_{io}, P_j) = \sqrt{[x_{oi} + (R+r)\cos\varphi - x_{oj} - R\cos\omega]^2 + [y_{oi} - y_{oj}]^2 + [z_{oi} + (R+r)\sin\varphi - z_{oj} - R\sin\omega]^2}$$

$$d(P_{ii}, P_{j'}) = \sqrt{[x_{oi} + (R-r)\cos\varphi - x_{oj} - R\cos\omega]^2 + [y_{oi} - y_{oj}]^2 + [z_{oi} + (R-r)\sin\varphi - z_{oj} - 2h - R\sin\omega]^2}$$

$$d(P_{io}, P_{j'}) = \sqrt{[x_{oi} + (R+r)\cos\varphi - x_{oj} - R\cos\omega]^2 + [y_{oi} - y_{oj}]^2 + [z_{oi} + (R+r)\sin\varphi - z_{oj} - 2h - R\sin\omega]^2}$$

Computational framework - global process

Finite line source for spiral ground heat exchangers



$$d(P_{ii}, P_j) = \sqrt{\left[x_{oi} + (R - r)\cos\varphi - x_{oj} - R\cos\omega\right]^2 + \left[y_{oi} + (R - r)\sin\varphi - y_{oj} - R\sin\omega\right]^2 + \left[z_{oi} - z_{oj}\right]^2}$$

$$d(P_{io}, P_j) = \sqrt{\left[x_{oi} + (R + r)\cos\varphi - x_{oj} - R\cos\omega\right]^2 + \left[y_{oi} + (R + r)\sin\varphi - y_{oj} - R\sin\omega\right]^2 + \left[z_{oi} - z_{oj}\right]^2}$$

Computational framework - local process

Thermal resistance between fluid and ground

- Vertical/horizontal GHEX: U-pipe and concentric GHEX
- Slinky and earth basket: spiral type GHEX

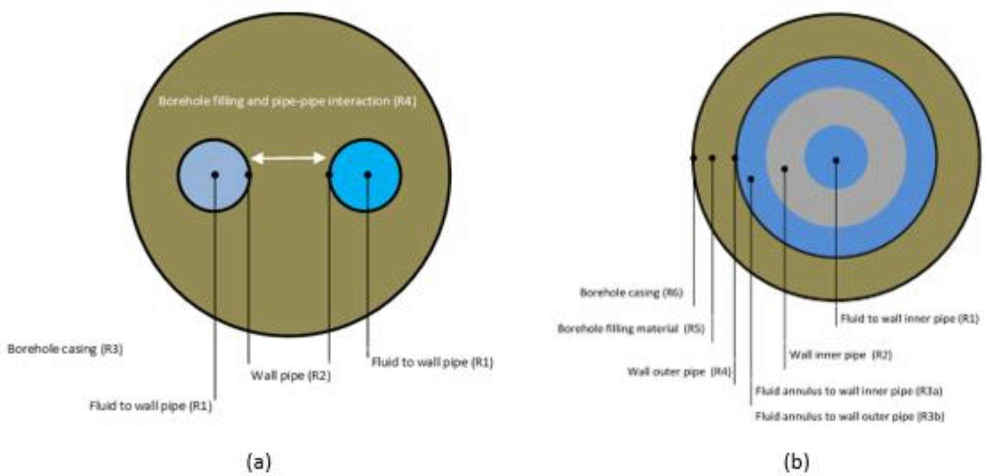


Figure 5. Schematic overview of a U-loop and concentric heat exchanger with different resistance terms.

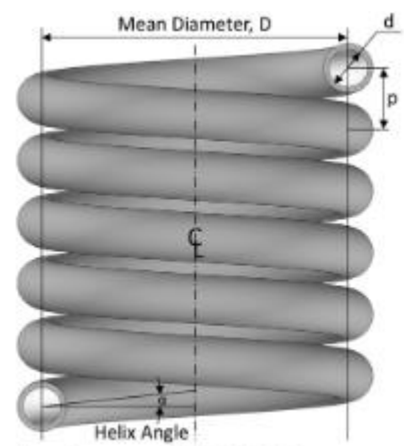


Figure 1. Isometric view of a helically coiled tube.

Computational framework - local process

Equations for

- Critical Reynolds
- Nusselt
- Pressure drop

OVERVIEW EQUATIONS	Straight pipe	Curved pipe
Critical Reynolds	2300 (2000 – 3000)	$Re_{cr} = 2300\left[1+8.6\left(\frac{d}{D}\right)^{0.45}\right]$ *Schmidt (1967)*
Nusselt	**Reynolds < Re_{cr}**	**Reynolds < Re_{cr}**
	$Nu = 3.657 + \frac{0.05565(L^*)^{-1.3335}}{1+0.08386Pr^{0.2}(L^*)^{-0.8559}}$ Where $L^* = \frac{L}{RePrD}$ *Merker (1987)*	$Nu = 3.66 + 0.08\left[1+0.8\left(\frac{d}{D}\right)^{0.9}\right]Re^m Pr^{1/3}\left(\frac{Pr}{Pr_w}\right)^{0.14}$ With m = 0.5 + 0.2903 (d/D)$^{0.194}$ *Schmidt (1967)*
	Reynolds >= Re_{cr}	**Reynolds > 2.2. 10^4**
	$0.023Re^{0.8}Pr^m$ m heating: 0.4; m cooling 0.3 *Dittus Boelter (1930)*	$Nu = \frac{\left(\xi/8\right)RePr}{1+12.7/\sqrt{\xi/8}\left(Pr^{2/3}-1\right)}\left(\frac{Pr}{Pr_w}\right)^{0.14}$ With $\xi = \left[\frac{0.3164}{Re^{0.25}} + 0.03\left(\frac{d}{D}\right)^{0.5}\right]\left(\frac{\eta_w}{\eta}\right)^{0.27}$ *Gnielinski (1986a); Mishra & Gupta (1979)* *The term (Pr/Pr2)^0.14 as well as (Nw/n)^0.27, when wall and fluid temperature are similar, is 1 and can be dropped.*
		Re_{cr} < Reynolds < 2.2 10^4
		$Nu = \gamma Nu_1(Re_c) + (1-\gamma)Nu_2(Re = 2.2 * 10^4)$ $\gamma = \frac{2.2 * 10^4 - Re}{2.2 * 10^4 - Re_c}$ *Gnielinski (1986b)*
Pressure drop	$\Delta P = f\frac{\rho_f L v_f^{2}}{D/2}$ *Fanning (Fanning friction factor = 1/4th Darcy) (1896)*	
	Reynolds < Re_c	**Reynolds < Re_c**
	$f = \frac{16}{Re}$	$f_c = f_s\left[0.556 + 0.0969\sqrt{De}\right]$ With De (Dean number): $Re\sqrt{d/D}$ *Hasson (1955)*
	Reynolds > Re_c	
	$f = \frac{0.0791}{Re}$ *Blasius (1913) The denominator is Re^(1/4) according to Fox&McDonald textbook "Introduction to Fluid Mechanics"*	
		4500 < Reynolds < 10^5 & 0 < P/d < 25.4
		$f_c = 0.0791Re^{-0.25} + 0.0075\sqrt{d/D}$ *Mishra and Gupta (1979)*

Computational framework - local process

Turbulent / laminar flow and transition zone

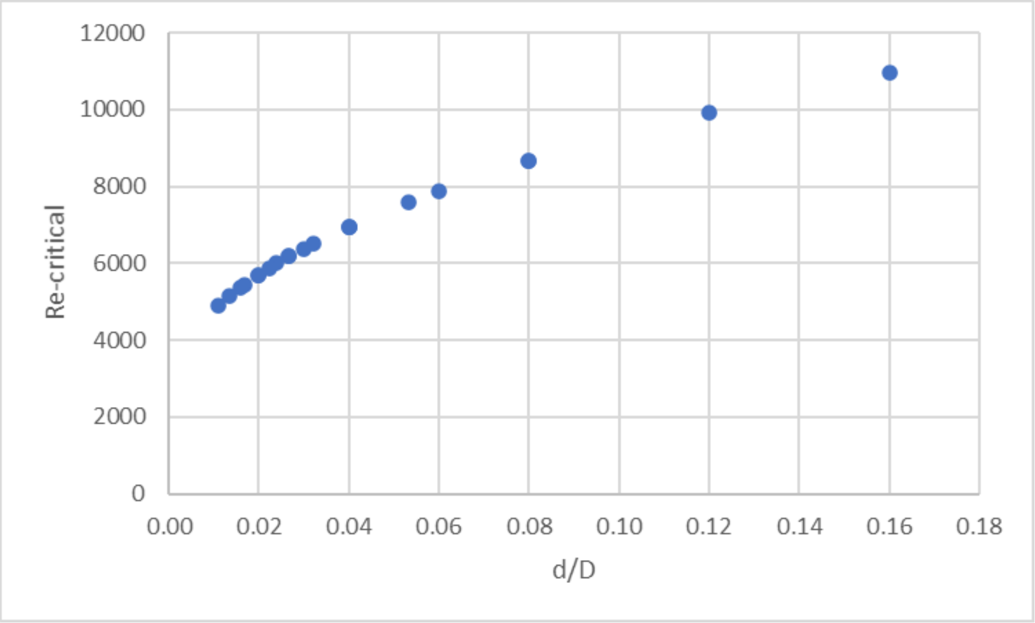
- Thermal resistance (and pressure drop) depend on fluid flow regime and especially laminar / turbulent boundary
- This boundary is characterized by the *Reynolds* number (ratio between inertial and viscous forces)

- For straight pipes the critical Reynolds number is usually taken as **2300**
- For curved pipes it is more complex and depends on the ratio d/D

$$Re_{cr} = 2300\left[1 + 8.6\left(\frac{d}{D}\right)^{0.45}\right]$$

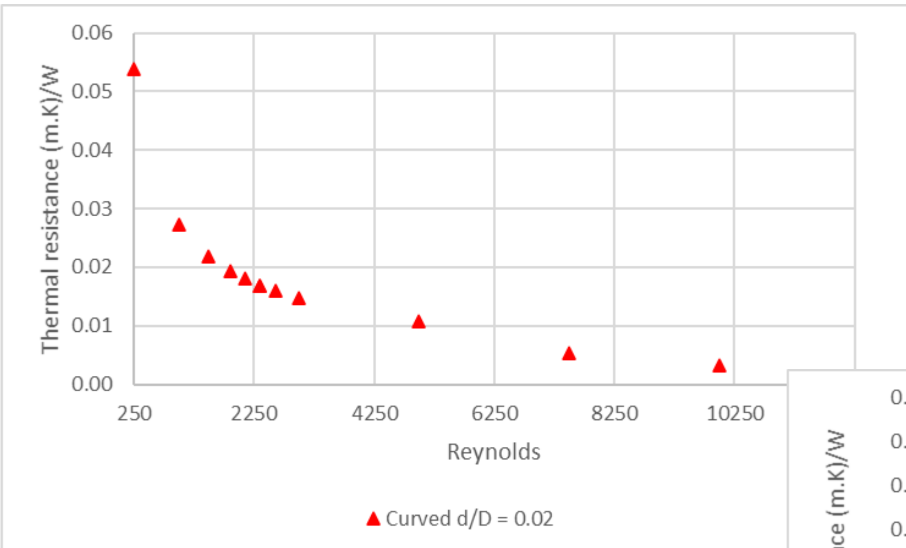
Computational framework - local process

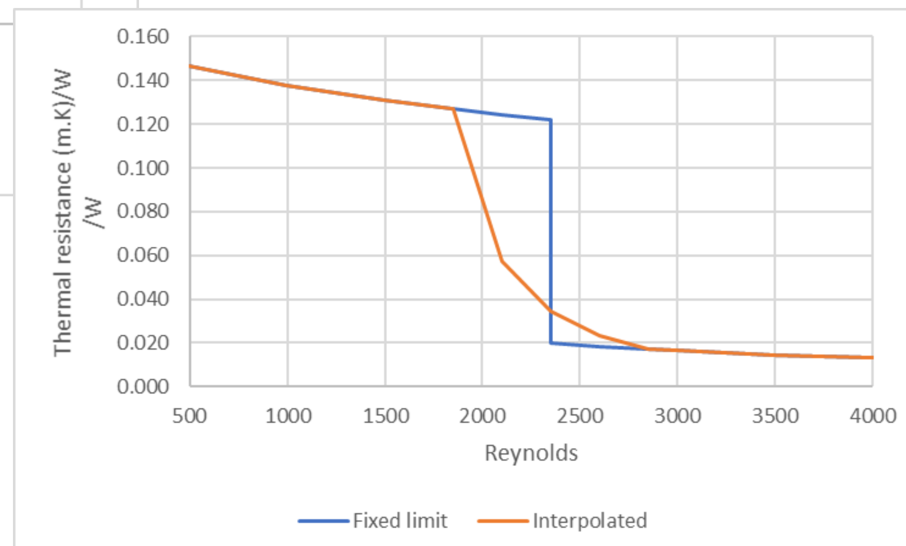
Spiral heat exchanger



Computational framework - local process

Thermal resistance Spiral / Straight pipe heat exchanger



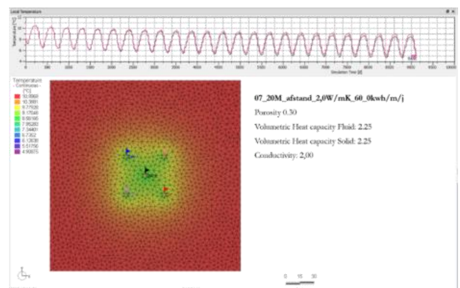


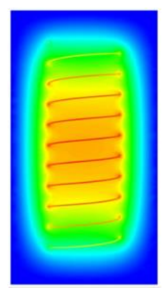
Lab experiments and CFD modelling

Method

Lab experiments spiral collectors

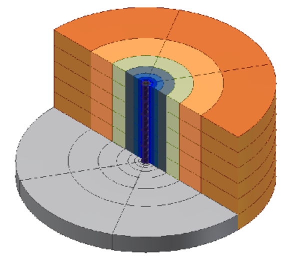
CFD simulations – thermal behavior of collectors

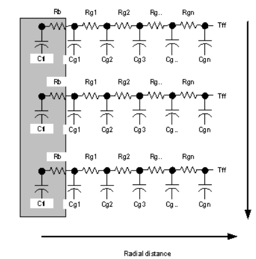


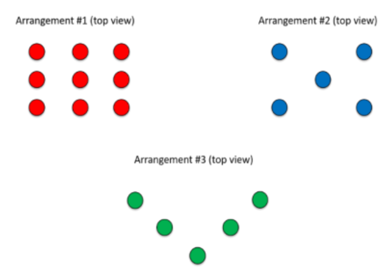


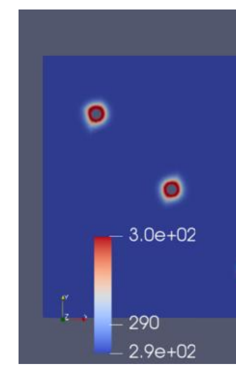
t = 800.000 s
(approx. 9,3 days)

Development of engineering tool

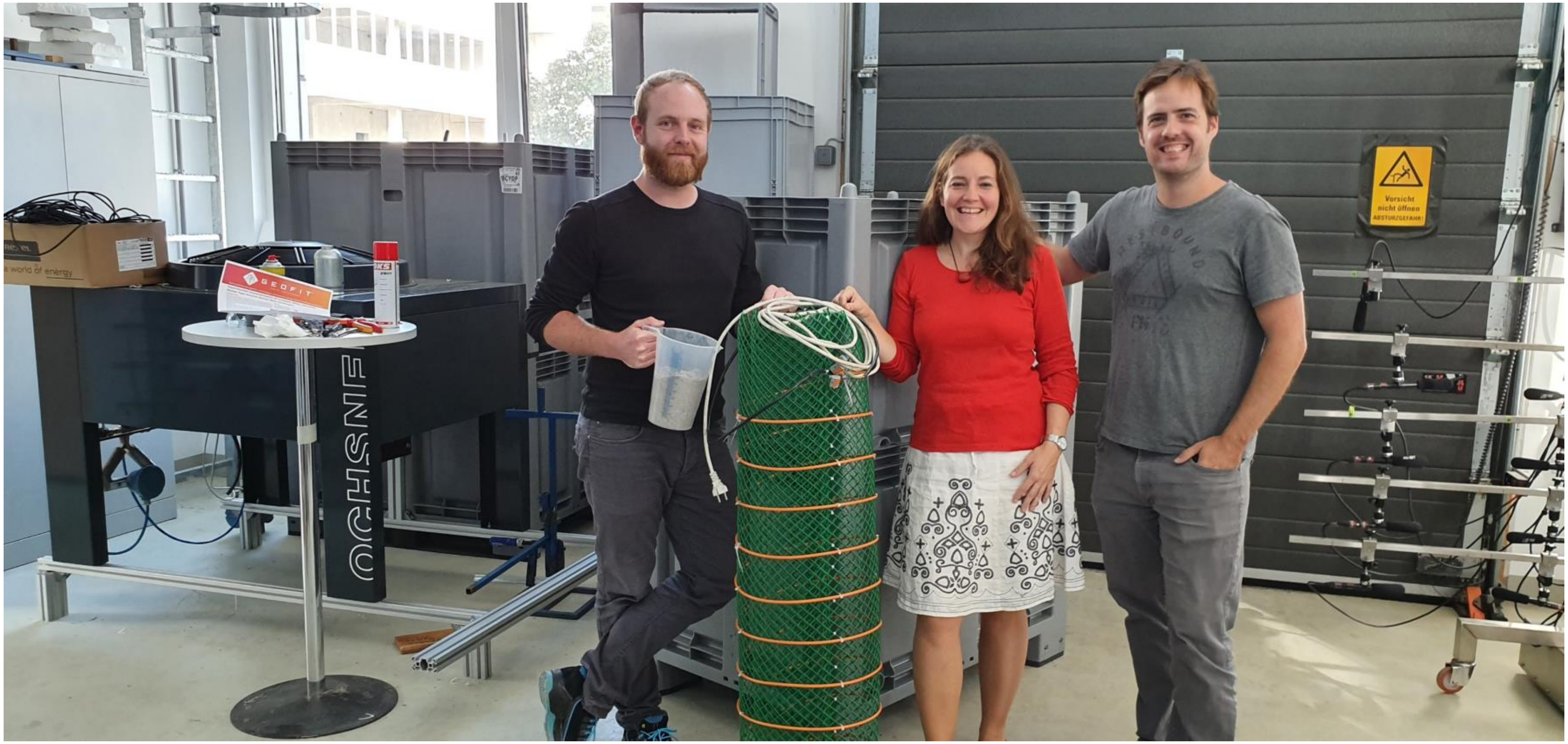






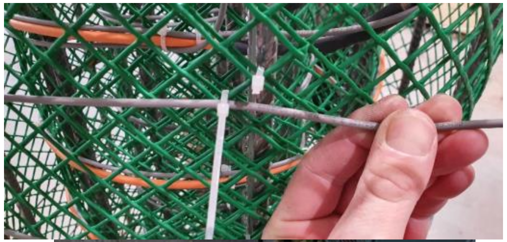


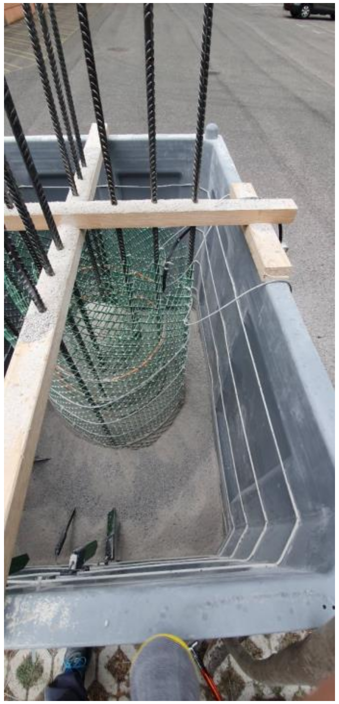
Laboratory experiments



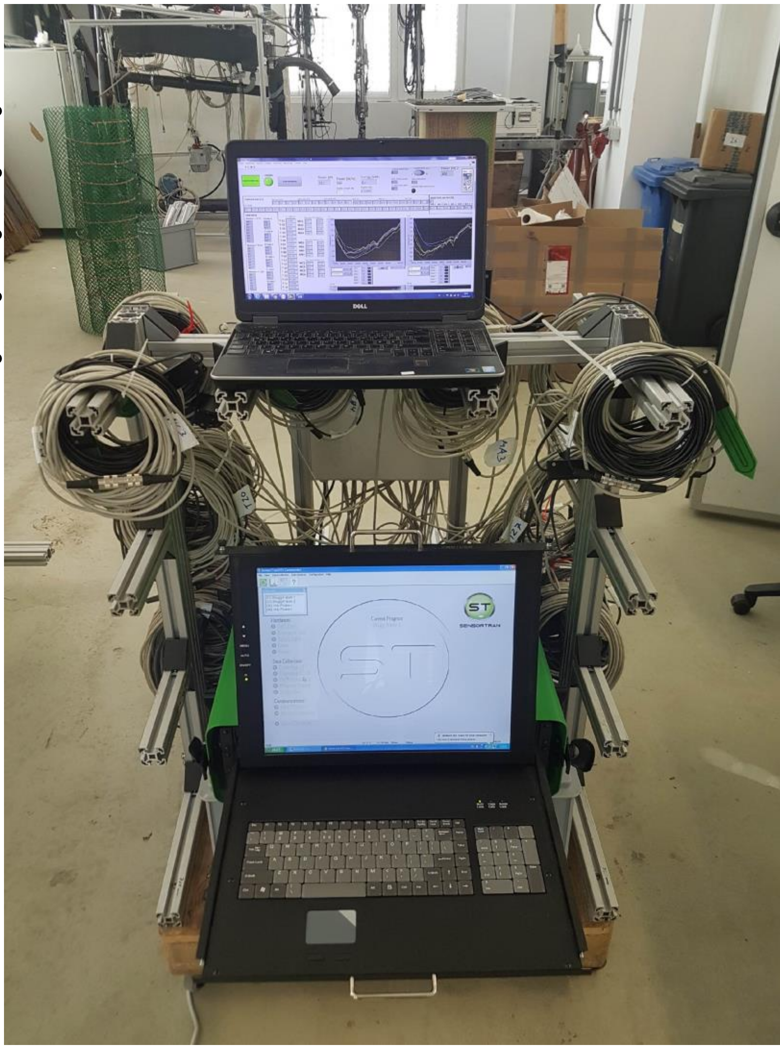
Laboratory experiments

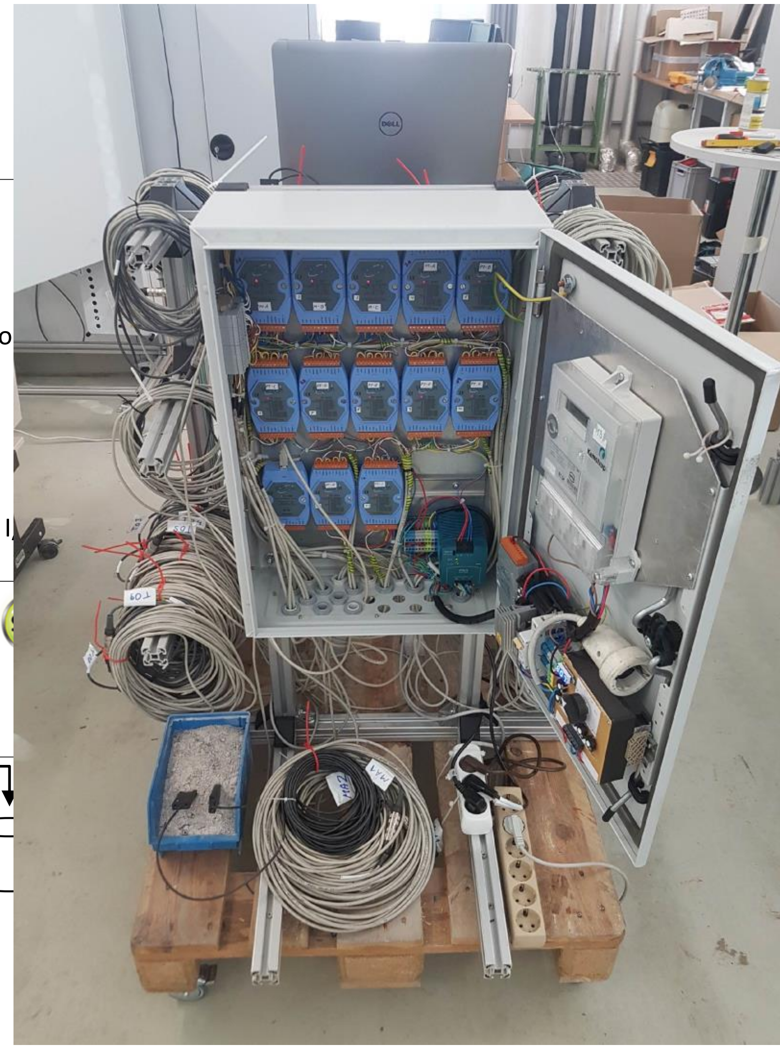
Setup of big box experiment





Data aquisition

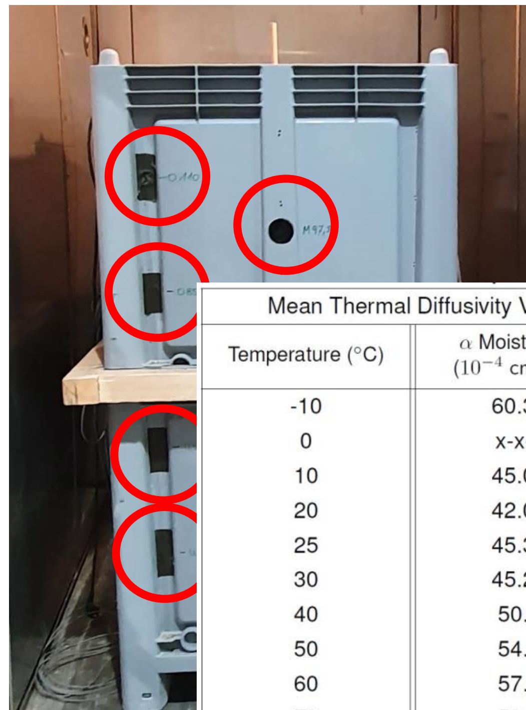




source

Moisture content

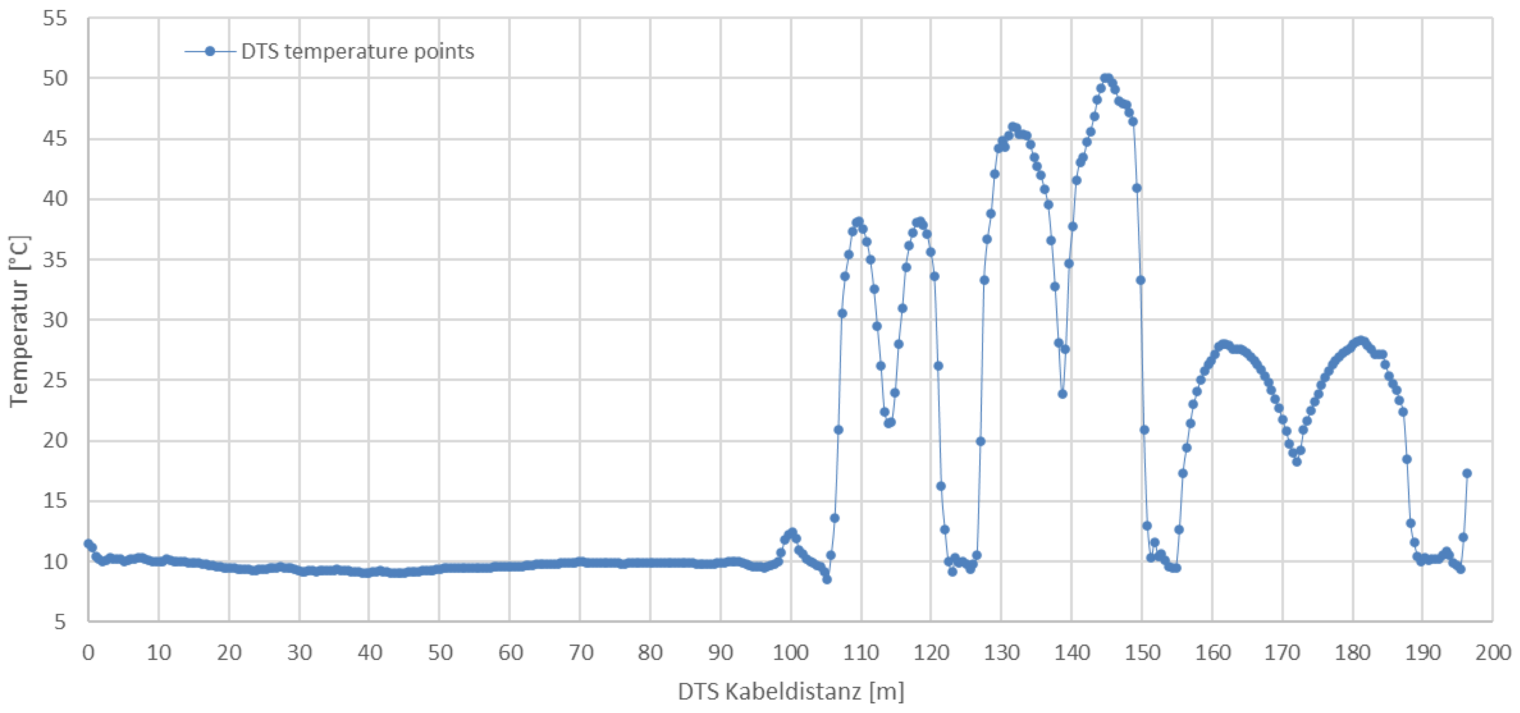
Locations of sample extraction



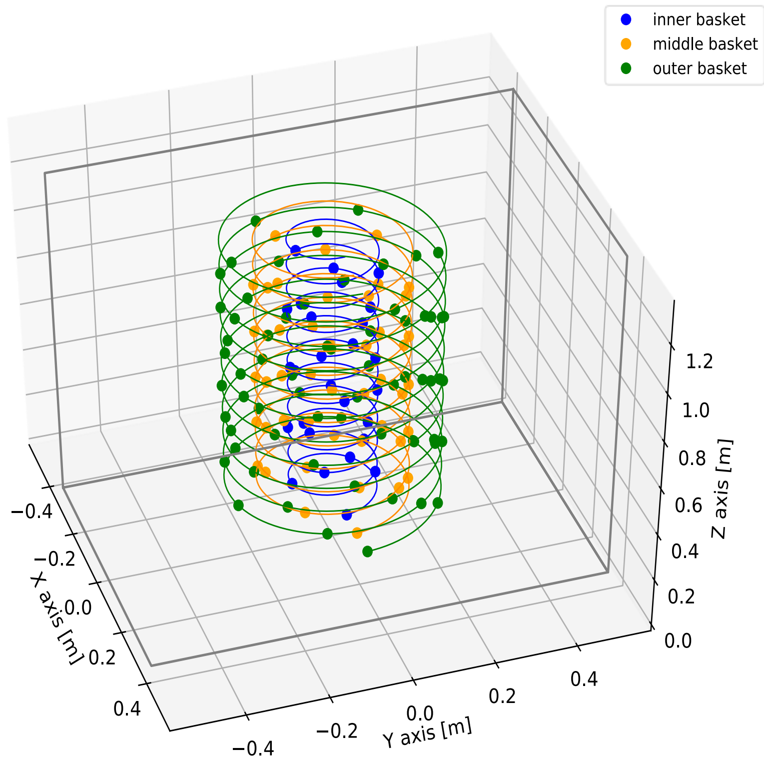
- Samples taken at start + end of experiment
- Determination of mass reduction by drying → **$\Delta m = m_{H_2O}$**

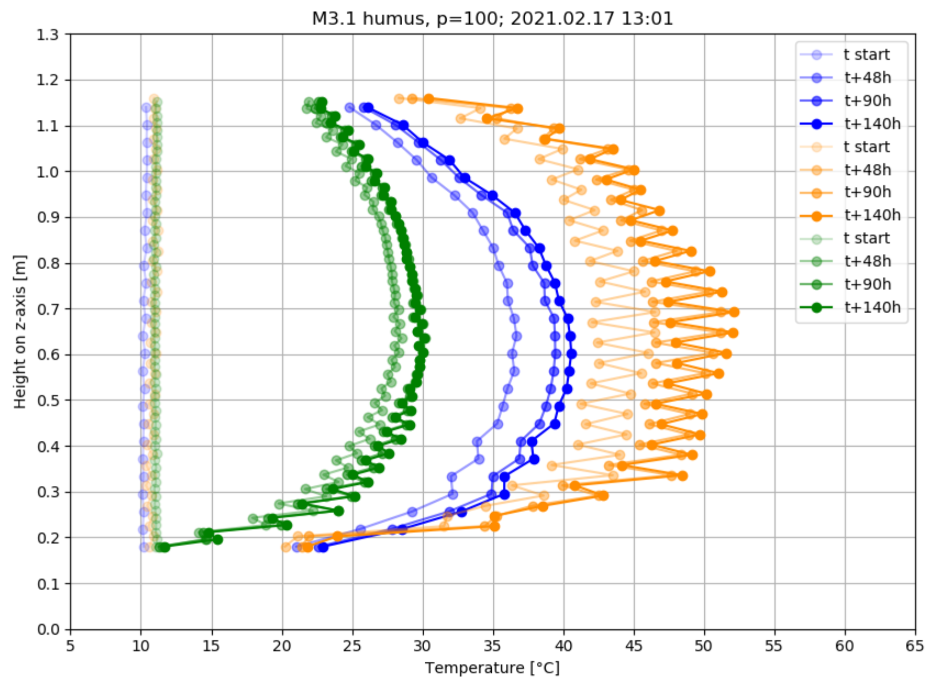
Mean Thermal Diffusivity Values for varying Materials and Temperatures			
Temperature (°C)	α Moist Sand (10^{-4} cm^2 s^{-1})	α Dry Sand (10^{-4} cm^2 s^{-1})	α Dry Humus (10^{-4} cm^2 s^{-1})
-10	60.31	23.52	22.67
0	x-x-x	21.93	21.24
10	45.09	22.13	20.33
20	42.06	21.91	19.14
25	45.34	x-x-x	x-x-x
30	45.23	21.58	17.69
40	50.1	20.82	16.77
50	54.1	20.17	17.16
60	57.2	20.78	17.18
70	58.4	20.03	16.36

Lab - results


DTS temperature points
Temperatur [°C]
55
50
45
40
35
30
25
20
15
10
5
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
DTS Kabeldistanz [m]

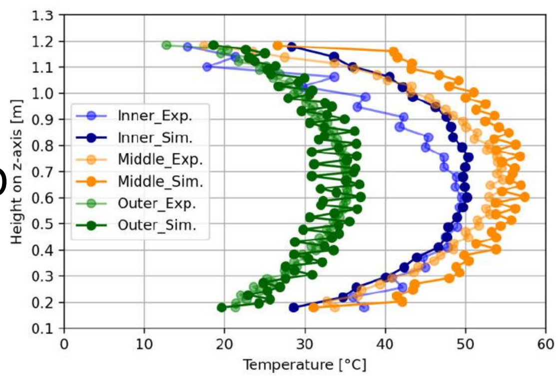
Lab - results


inner basket
middle basket
outer basket
X axis [m]
Y axis [m]
Z axis [m]

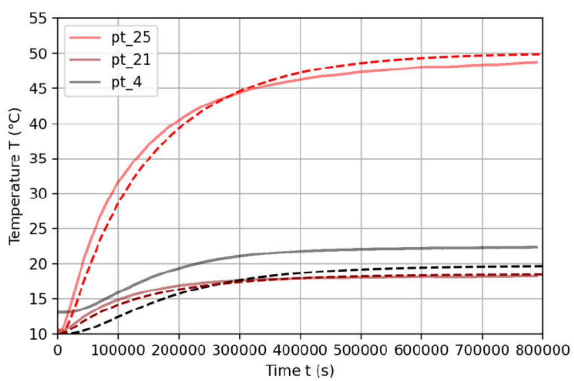

M3.1 humus, p=100; 2021.02.17 13:01
Height on z-axis [m]
Temperature [°C]
t start
t+48h
t+90h
t+140h

Experiment vs. Simulation

RTD

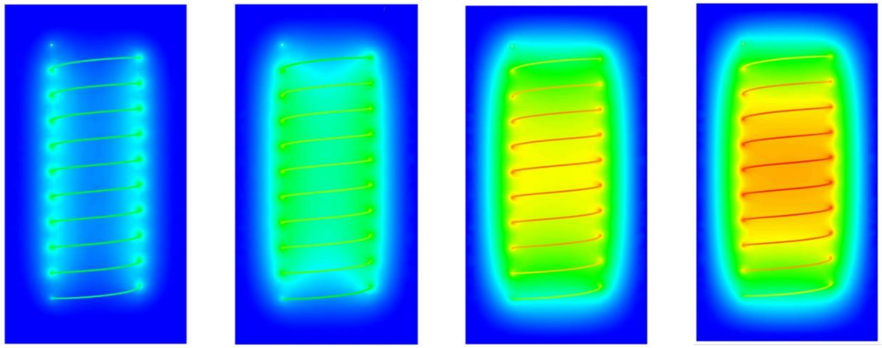


DTS



Dörr, C. J. (2020). Master thesis *CFD Analysis of Ground Source Heat Exchangers*.

Reference basket



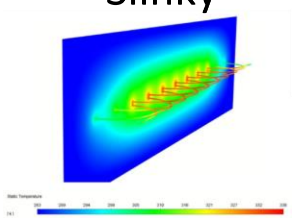
t = 50.000 s (approx. 13,8 hours)

t = 100.000 s (approx. 27,8 hours)

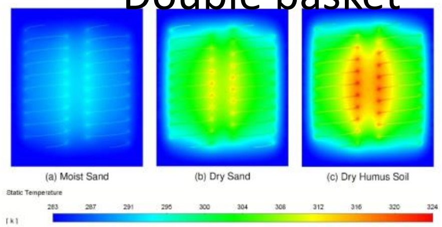
t = 300.000 s (approx. 3,5 days)

t = 800.000 s (approx. 9,3 days)

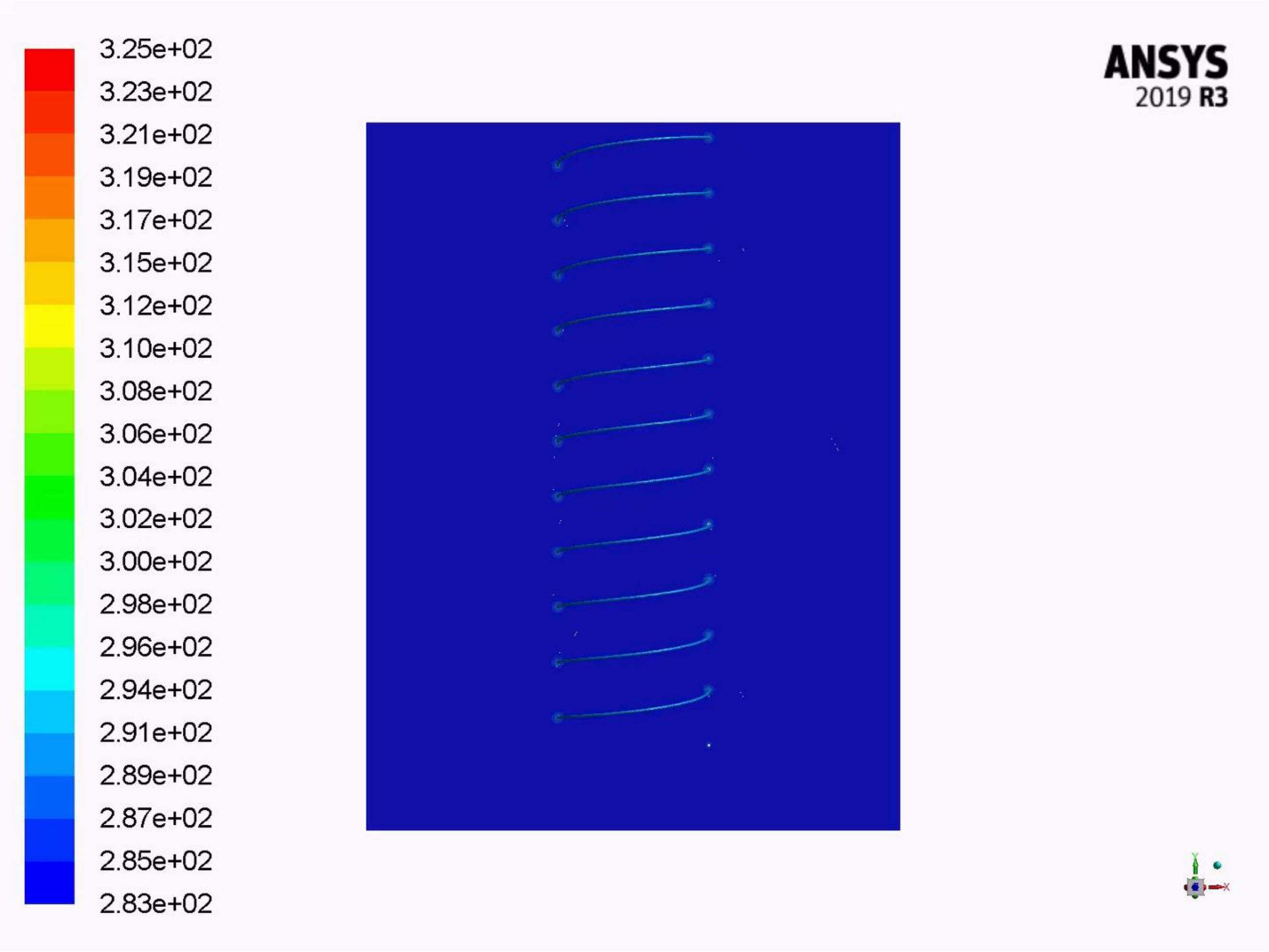
Slinky



Double basket



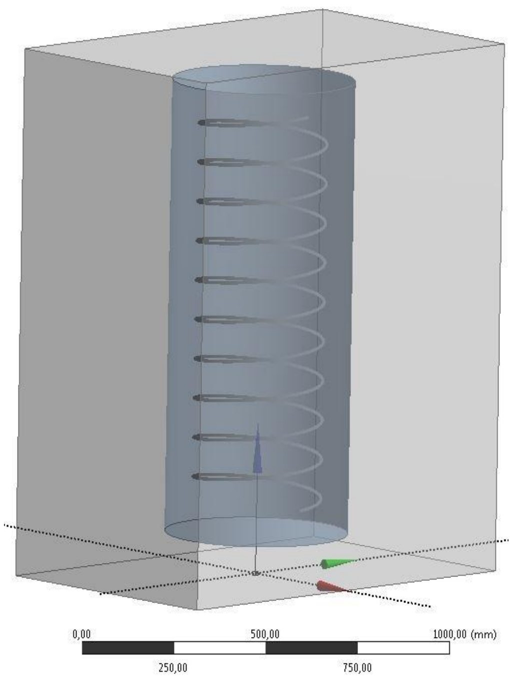
CFD temperature evolution

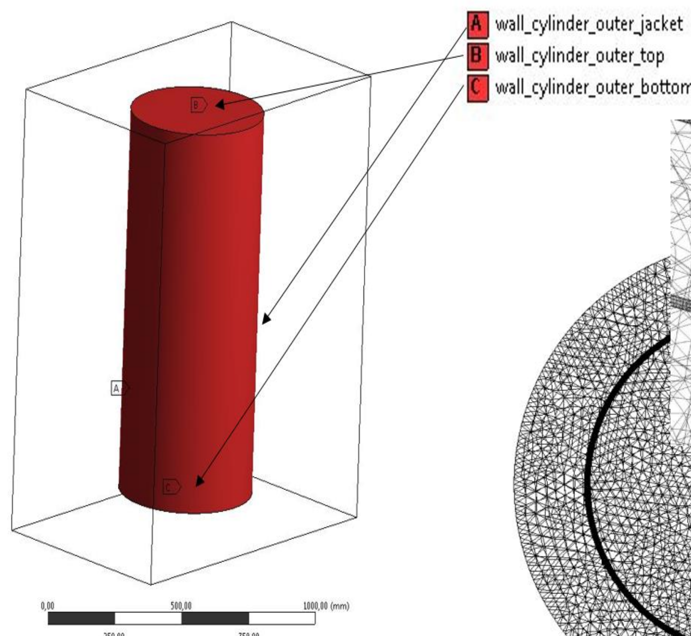


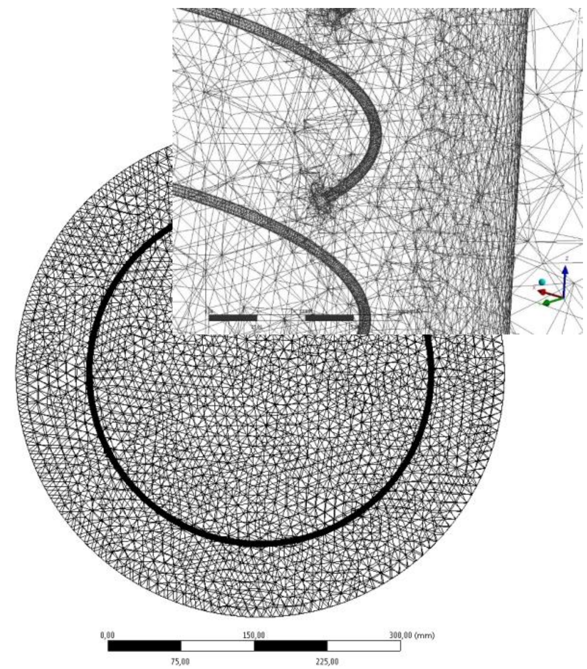
From CFD to Far Field analysis

Far field simulations: optimized spatial distribution and thermal interactions

AIT's model (detailed Computational Fluid Dynamics model) used to generate boundary conditions for the far-field simulations







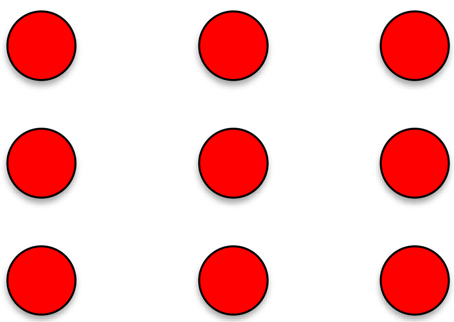
From CFD to Far Field analysis

- **Extended domain numerical simulations in order to determine the interaction between GHEX under different spatial arrangements and their thermal impact on the surrounding media**
  - Definition of three different sets of GHEX arrangements
  - Numerical simulation of the three arrangements using the soil properties and thermal parameters of the experimental facilities at AIT
  - Numerical simulation of the effect of GHEX spacing for one arrangement
  - Numerical simulation of one arrangement considering different types of soil, both dry and wet
  - Long term numerical simulations of one arrangement for three different climate zones (ongoing, only presenting one)

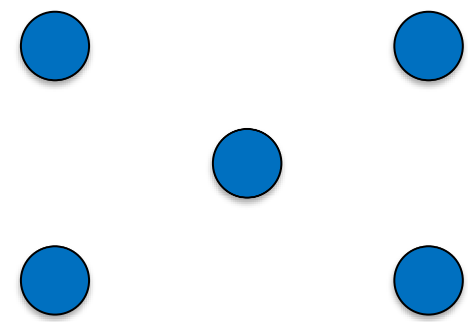
From CFD to Far Field analysis

Far field simulations: optimized spatial distribution and thermal interactions

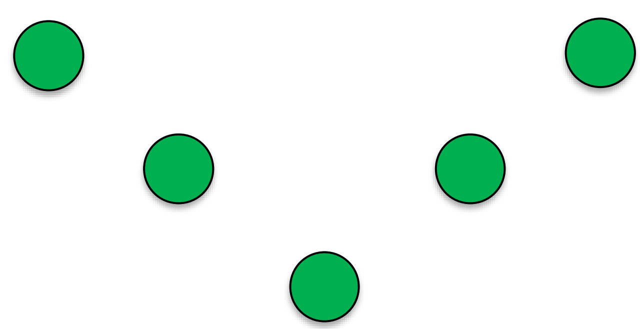
Arrangement #1 (top view)



Arrangement #2 (top view)

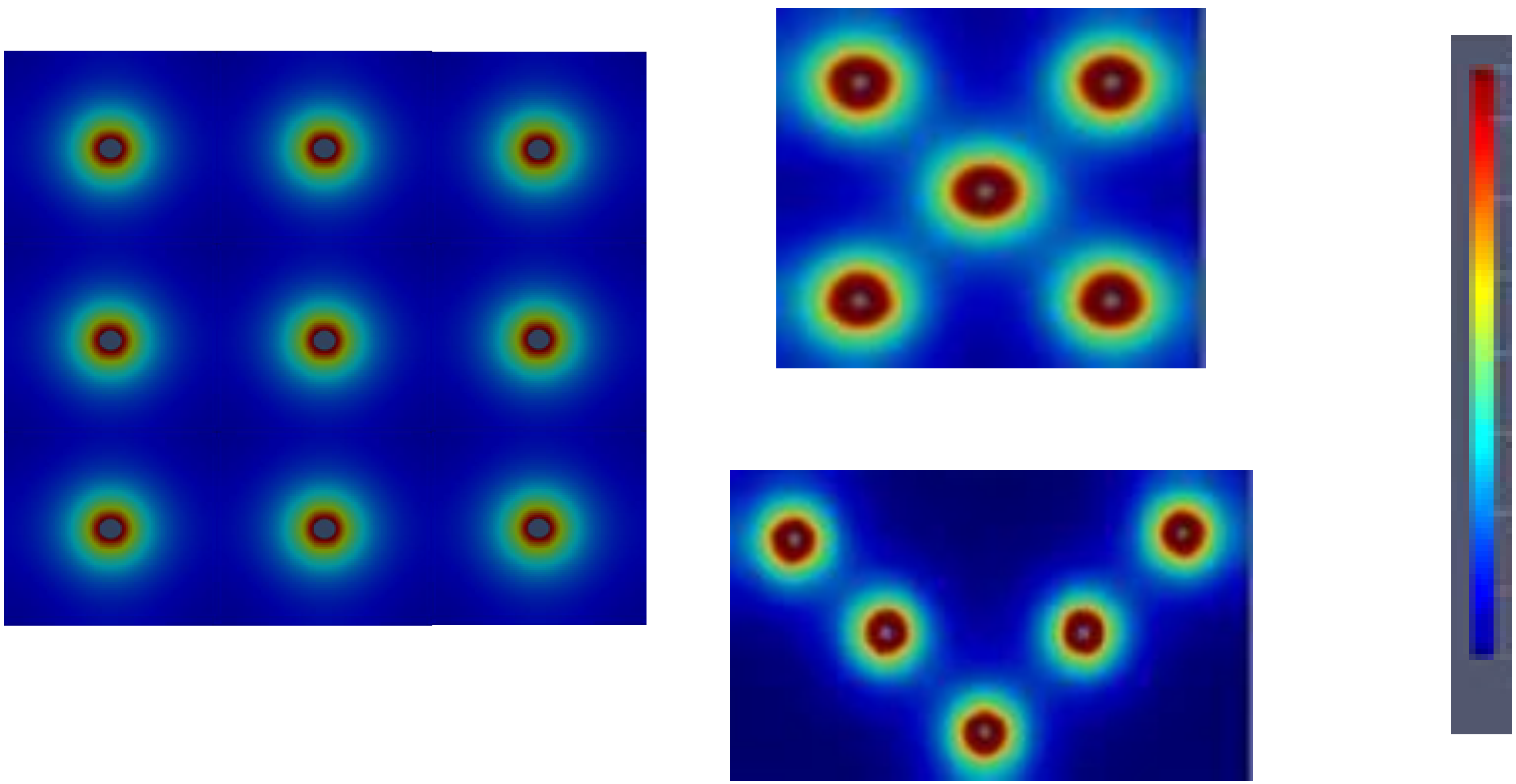


Arrangement #3 (top view)



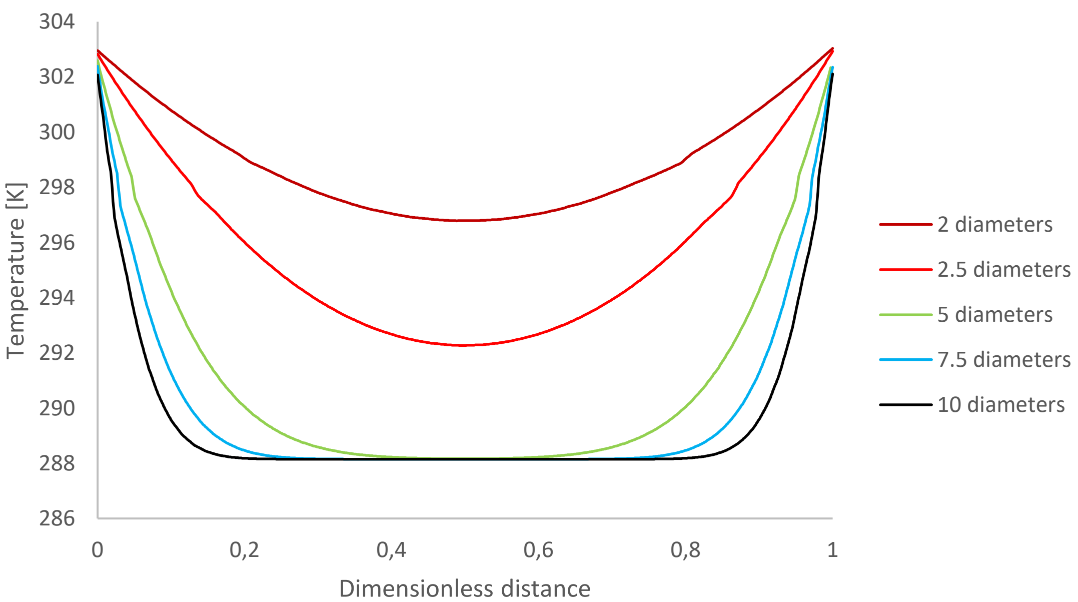
From CFD to Far Field analysis

Far field simulations, temperature contours after 100 days



From CFD to Far Field analysis

Far field simulations, temperature after 7 days with different spacing (arrangement #2)



Validation

Validation – spiral (earth basket) GHEX

Real helical shape in FLS simplified to stack of rings

First validation with reference case and point cloud around GHEX

Table 1: Overview of soil thermal parameters and earth basket spiral heat exchanger dimensions used for the validation.

Parameter	Value
Soil thermal conductivity (W/mK)	2.0
Soil heat capacity (J/kgK)	2500
Soil density (kg/m³)	1000
Soil temperature (°C)	10.0
Buried depth (m)	1.5
Ring diameter (m)	0.35
Pipe outer diameter (m)	0.06
Number of rings	10
Total pipe length (m)	11.04
Pitch (m)	0.1
Thermal load (W/m)	10.24

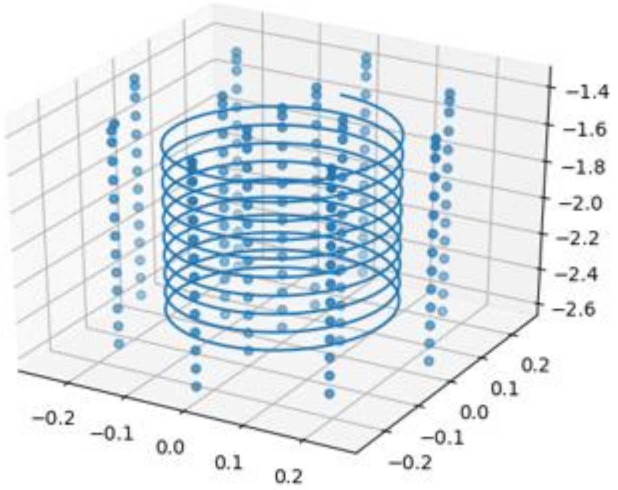
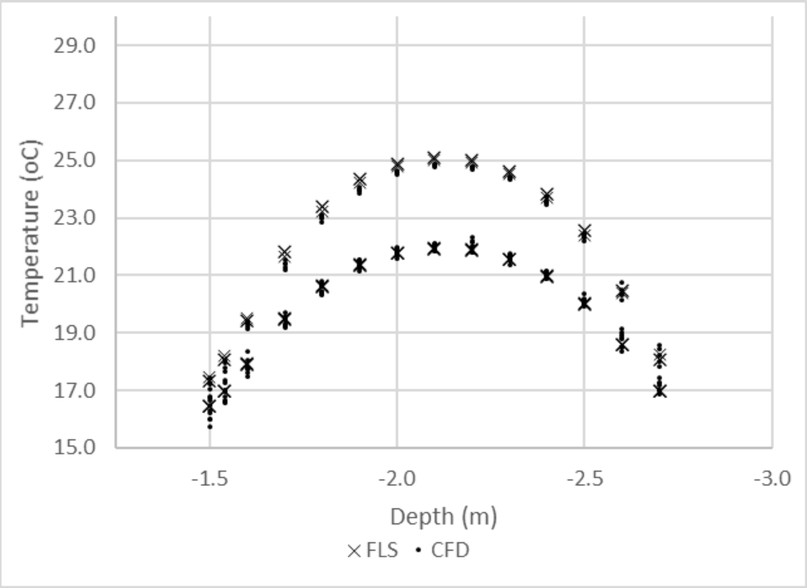


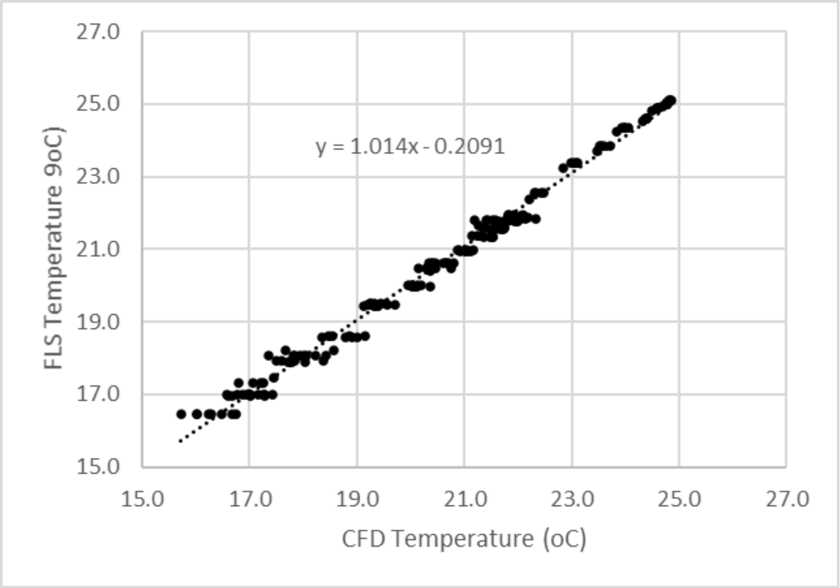
Figure 10: 3D view of the helical coil and points used for comparison between FLS and CFD simulations.

Validation – spiral (earth basket) GHEX

Real helical shape in FLS simplified to stack of rings

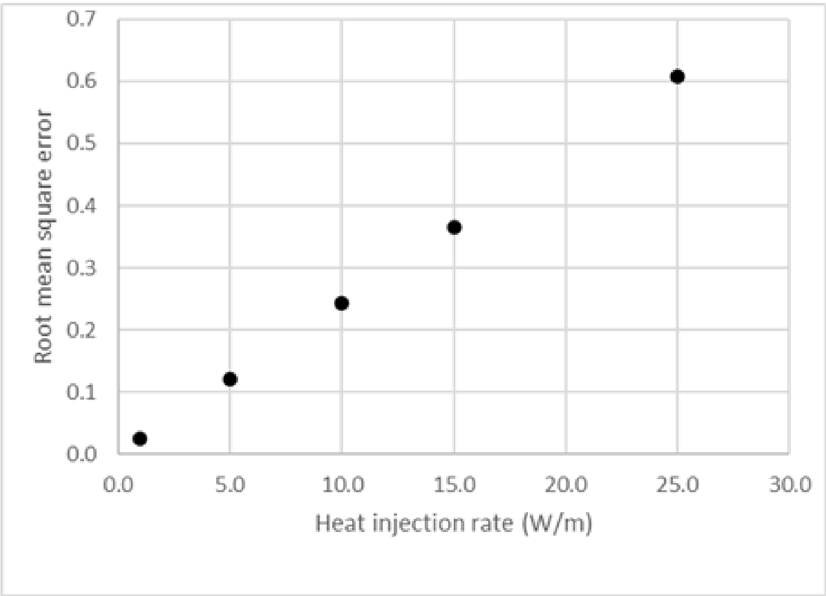
Check match of topology

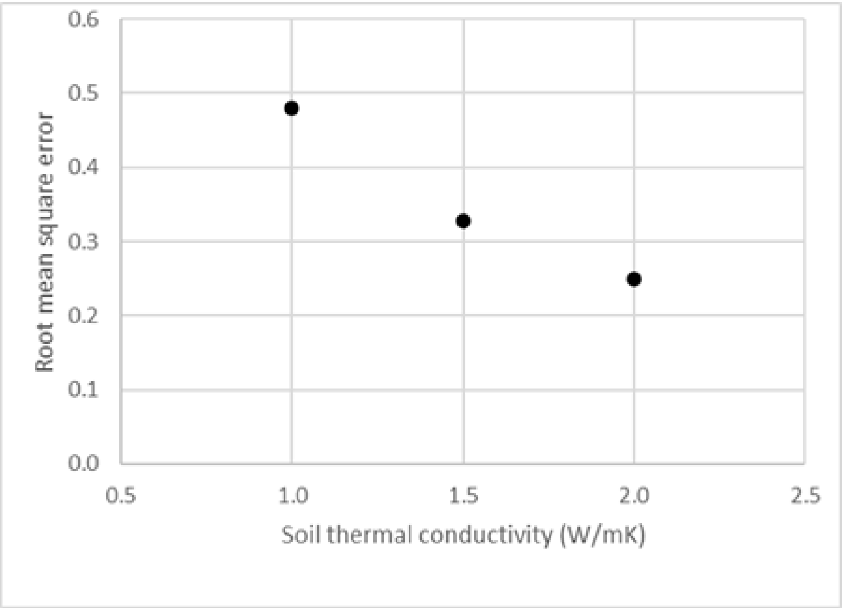




Validation – steady state

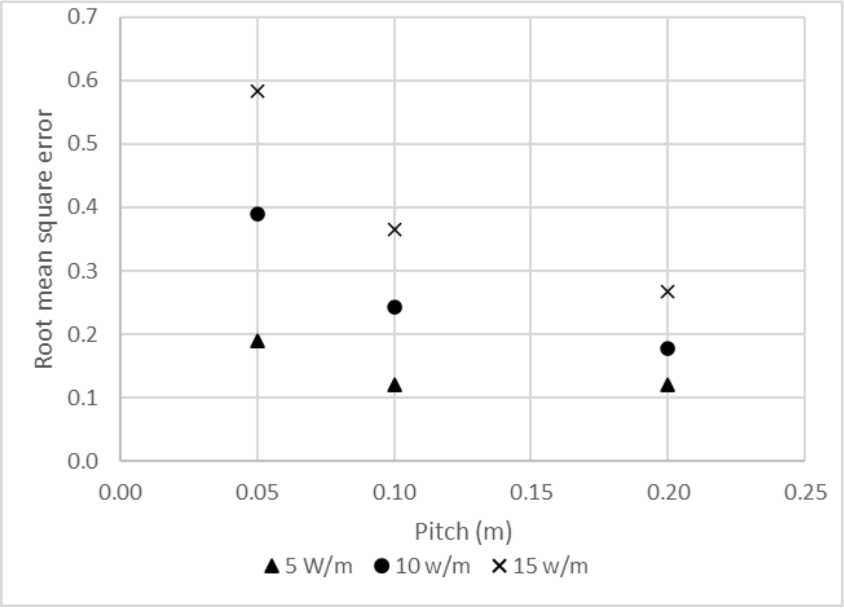
Variations of heat injection rate, soil thermal conductivity

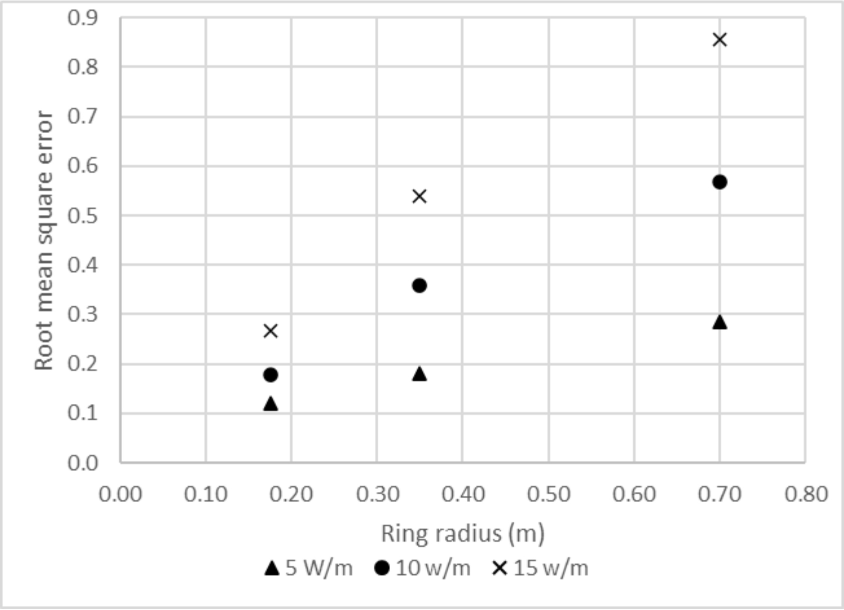




Validation – steady state

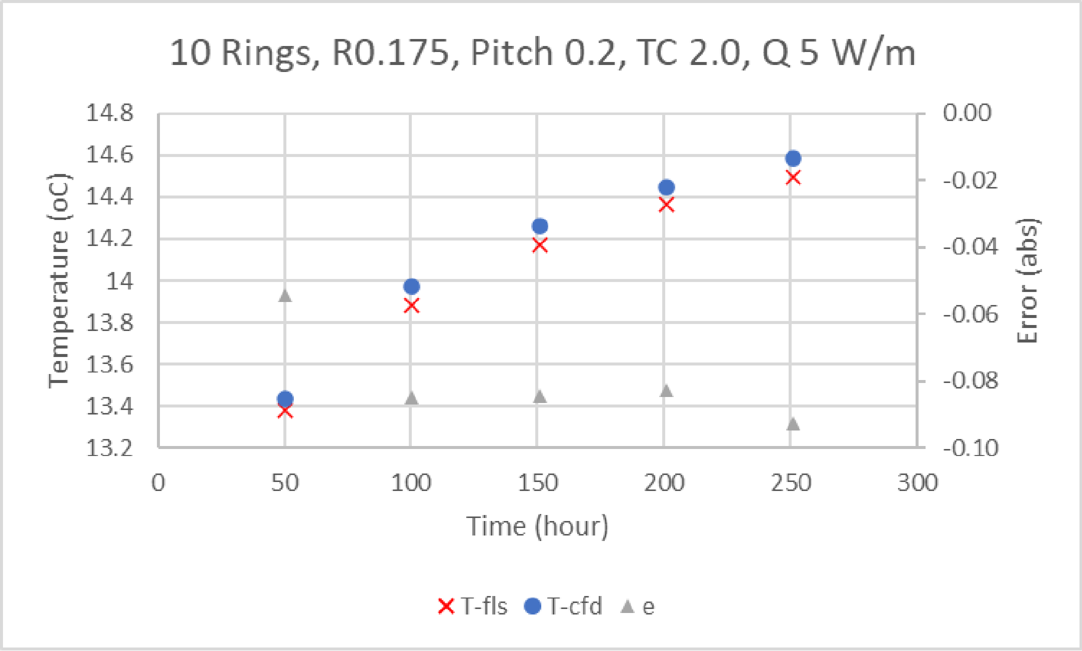
Variations of pitch, ring diameter





Validation – transient

Many variations



Performance Analysis

Performance analysis

Using the toolkit performance analysis was conducted for

- Vertical (borehole) type ground heat exchangers
- Slinky type ground heat exchangers
- Spiral/earth basket type ground heat exchangers

Investigated was GHEX construction parameters and operational (system) behaviour for different standardized building and climate types

Modern office, Retrofit office, Modern residential, Retrofit residential

Cold, average and warm climate

Performance analysis

Construction parameters in vertical GHEX

Conclusion: Shank spacing and backfilling thermal conductivity are important. Flow rate is important, depending on antifreeze mix used

The effect of different parameters may also depend on flow regime

Parameter	Laminar flow regime		Turbulent flow regime	
	Absolute	Fractional	Absolute	Fractional
Length	1.00	0.01	0.01	0.00
Borehole diameter	0.15	1.50	0.08	0.80
Shank spacing	-0.20	-4.00	-0.07	-1.40
Pipe therm. cond.	-0.05	-0.13	-0.08	-0.20
Backfilling thermal cond.	-0.22	-0.11	-0.21	-0.11
Soil thermal cond.	0.10	0.05	0.00	0.00

Performance analysis

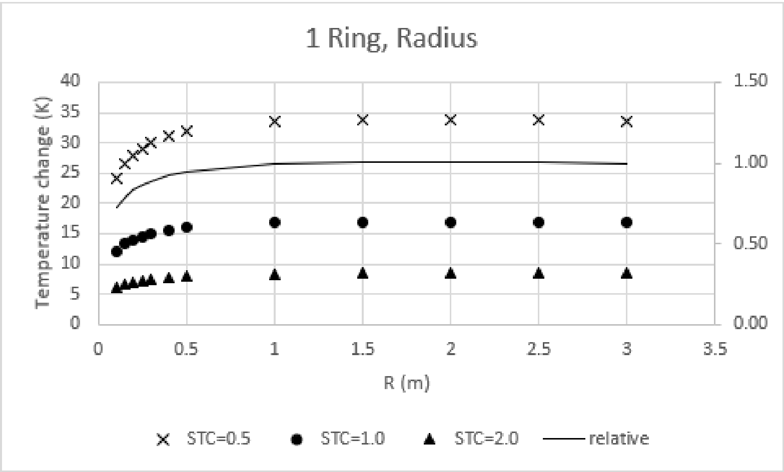
Effect of thermal resistance introduced by the pipe wall

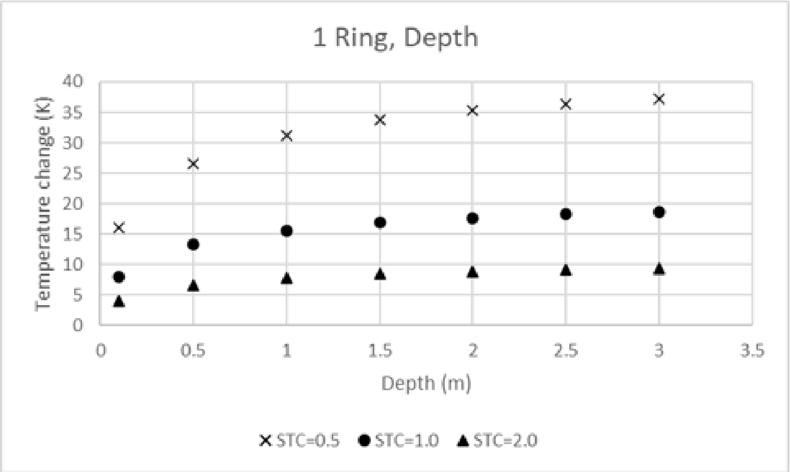
Conclusion: effects of pipe wall thickness is negligible (< 2%) for typical heat flux rates in shallow GHEX and small (<4%) in medium heat flux rates (vertical GHEX)

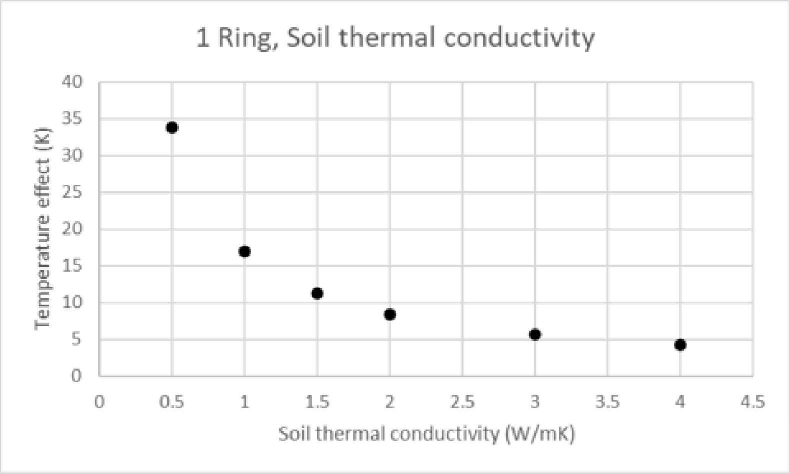
Pipe OD & SDR	Pipe ID (m)	R_{pipe} (m.K)/W))	Temperature difference (K) @ Heat flux (W/m)			
			5	10	20	40
PE 100 OD40 SDR11,0	0.033	0.076	0.4	0.8	1.5	3.0
PE 100 OD40 SDR13,6	0.034	0.060	0.3	0.6	1.2	2.4
PE 100 OD40 SDR17,6	0.035	0.046	0.2	0.5	0.9	1.8
PE 100 OD32 SDR11,0	0.026	0.076	0.4	0.8	1.5	3.0
PE 100 OD32 SDR13,6	0.027	0.060	0.3	0.6	1.2	2.4
PE 100 OD32 SDR17,6	0.028	0.046	0.2	0.5	0.9	1.8
PE 100 OD25 SDR11,0	0.020	0.076	0.4	0.8	1.5	3.0
PE 100 OD25 SDR13,6	0.021	0.060	0.3	0.6	1.2	2.4
PE 100 OD25 SDR17,6	0.022	0.046	0.2	0.5	0.9	1.8

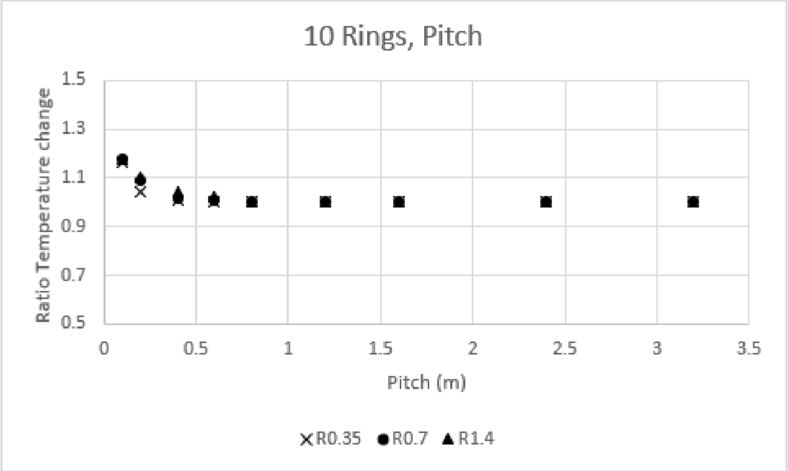
Performance analysis

Slinky GHEX, ring radius, depth, soil thermal conductivity and pitch



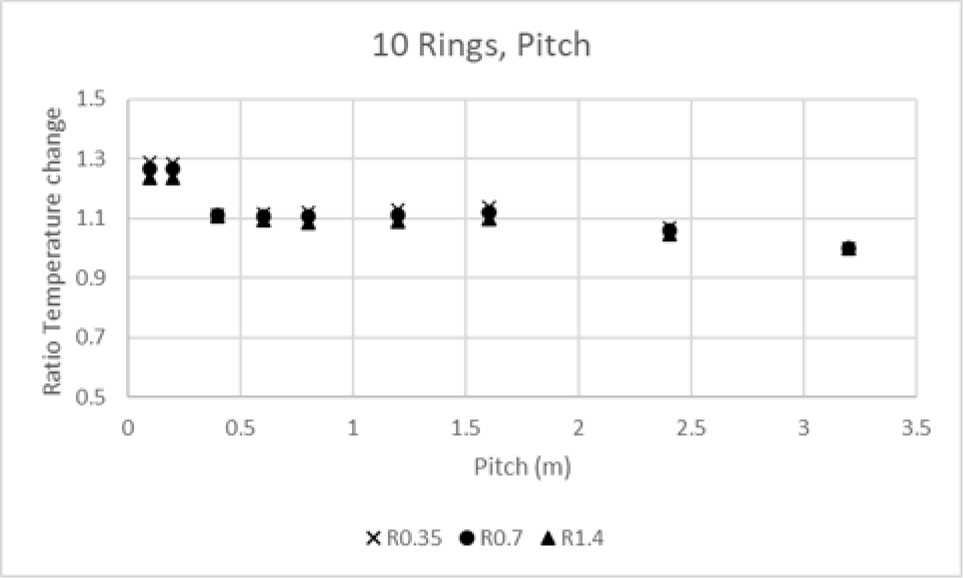






Performance analysis

Spiral GHEX, pitch



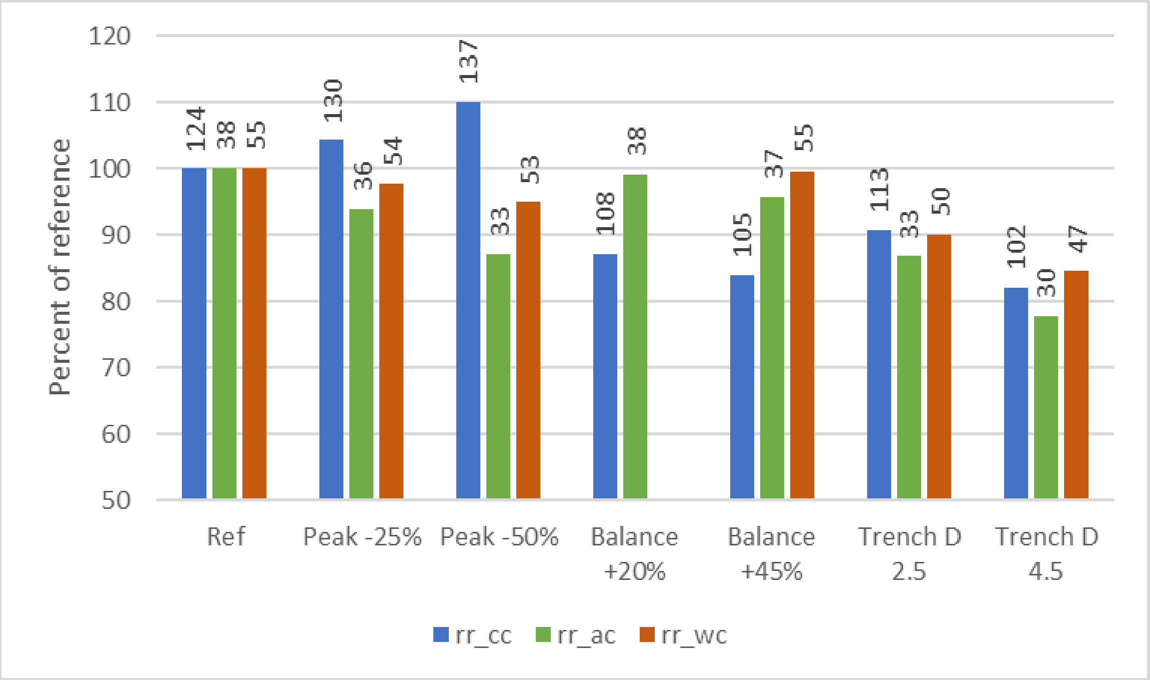
Performance analysis

Summary for shallow GHEX

- Soil thermal conductivity should be 1.5 W/mK or higher.
- Buried depth should exceed 1 meter.
- Minimum ring radius is 0.6 meters.
- Pitch for a slinky type heat exchanger is at least 60% of the ring radius.
- Pitch for an earth basket heat exchanger should be at least 0.3 m (but may depend as well on total number of rings that can be installed in a given depth interval.

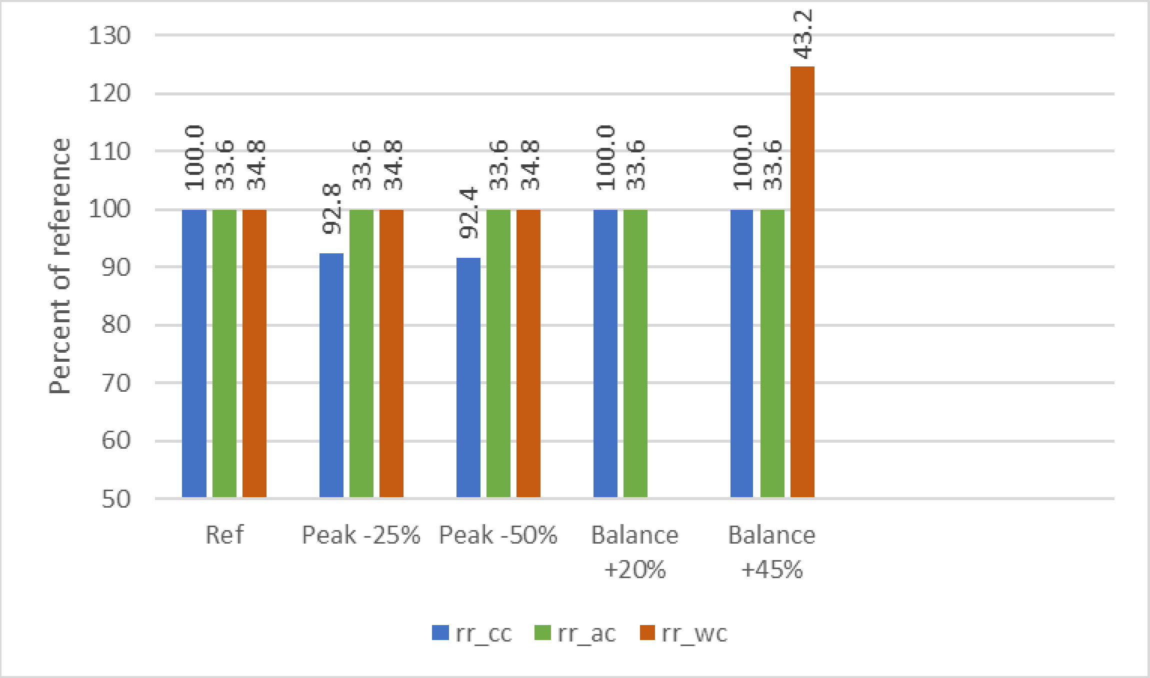
Performance analysis

System analysis, slinky retrofit residential



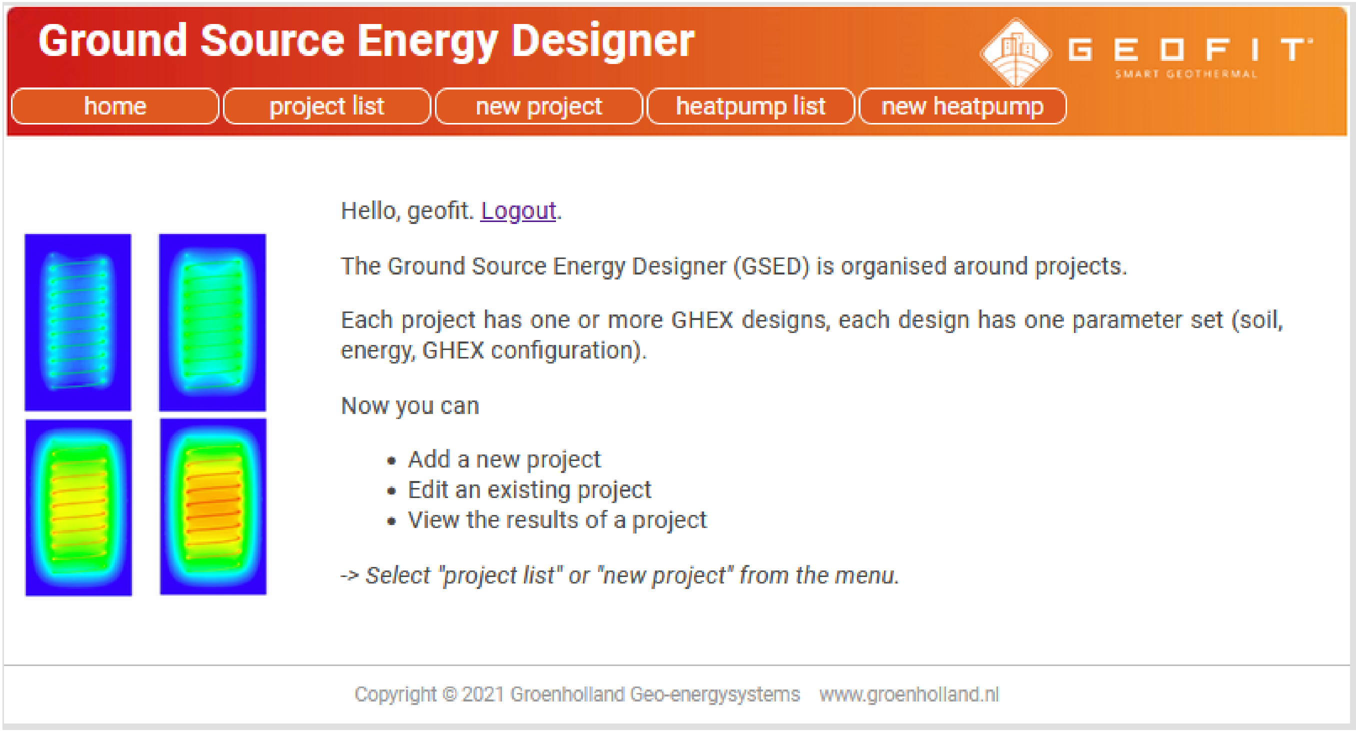
Performance analysis

System analysis, slinky retrofit residential



Engineering Tool

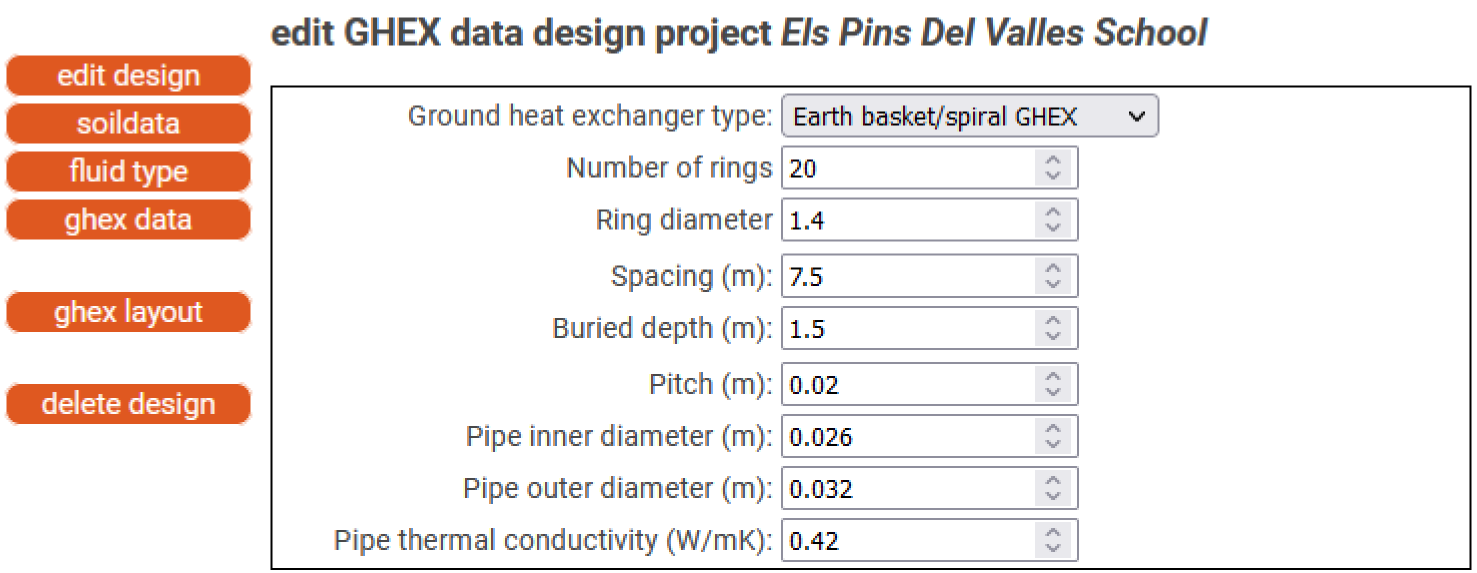
Engineering tool



Engineering tool

Organized around projects

- Every user has one or more projects, general user heat pump catalogue
- A project has one or more energy data profiles and one or more designs
- Each design has informaiton on soil, fluid and GHEX. Selection of Heat pump en energy profile



Easy to switch between different GHEX

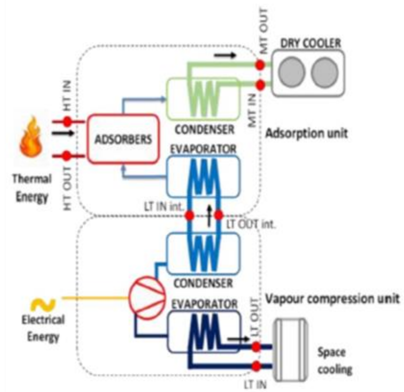
Engineering tool

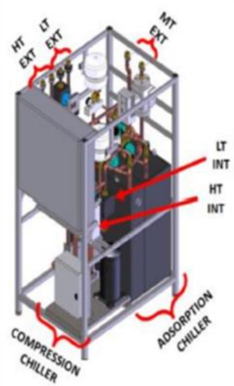
Highlights

- Direct (FLS) and G-function calculations possible
- Vertical, horizontal, slinky (ring) and spiral (earth basket) type GHEX
- Project organization: decoupled energy demand profile, heat pump data and GHEX type: easy to explore different solutions
- Different GHEX can have different energy demand profiles
- Temperature dependent fluid correlations
- Calculation of critical Reynolds and allows definition of transition zones
- Near surface seasonal temperature variations included

Ground Source Heat Pumps

Novel technologies





Radiant heating and cooling

Thermally active slabs

Manifold stations

Geothermal energy stations

Controls

Images from partner Uponor, Fahrenheit, CNR, Ochsner

Refrigerants & Regulations

- **Montreal Protocol:** ODS like chlorofluorocarbons (CFCs) & hydrochlorofluorocarbons (HCFCs) banned / to be phased out in production on a global scale.

- **Kyoto protocol:** Hydrofluorocarbons (HFCs) to be phased out (in production & consumption) in most developed countries due to high Global Warming Potential (GWP)

- **F-Gas regulation*** phase down HFCs in various steps. By 2030, average permissible GWP significantly below 500.

*EU regulation No 517/2014

Classification of refrigerants

Flammability					
higher	A3	R290, R1270, R601, R600, R600a, E170	B3	
lower	A2	R142b, R152a, R365mfc, SES36, R1234ze(Z)	B2	
lower	A2L	R1234ze(E), R1234yf	B2L	R717
no flame propagation	A1	R113, R114, R124, R134a, R236fa,R227ea, R1336mzz(Z), R1336mzz(E), R1233zd(E), R1224yd(Z), R718, R744	B1	R123, R21, R245ca, R245fa
	Toxicity: lower		Toxicity: higher	

Toxicity

A: no/low

B: high toxicity

Flammability

1: no flame propagation

2: lower flammability

3. Higher flammability

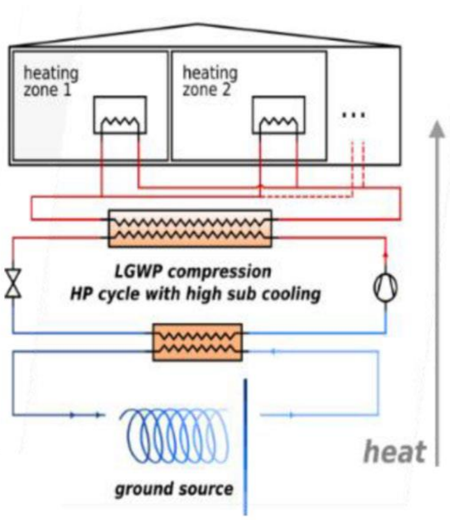
Source: C. Arpagaus, F. Bless, M. Uhlmann, J. Schiffmann, S.S. Bertsch,
High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials, Energy 152 (2018) 985–1010

Electrically driven heat pump

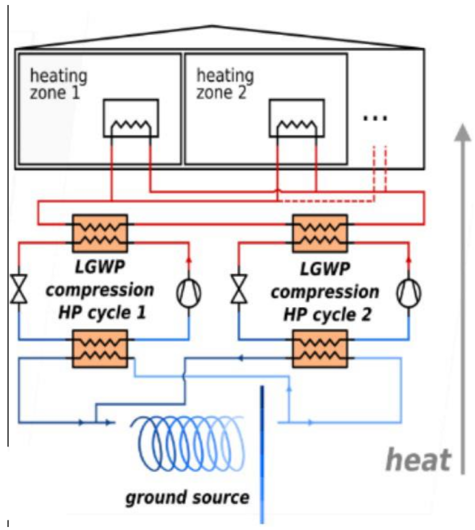
General parameters:

- Design: Standing cabinet with small ground area (approx. $1m^2$)
- Compressor: Scroll
- Refrigerant: R513A
- Superheating: 5K
- Subcooling: 8K
- Sink: dT = 10K (Water)
- Source: dT = 3K (Ethylene glycol)

Single stage



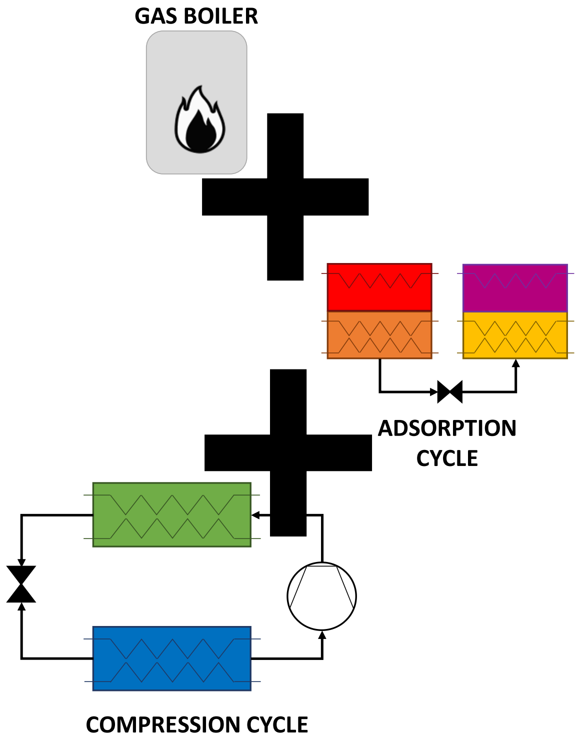
Twin-cycle



Thermally driven heat pump

For the thermally-driven heat pump, **three operating modes** are possible:

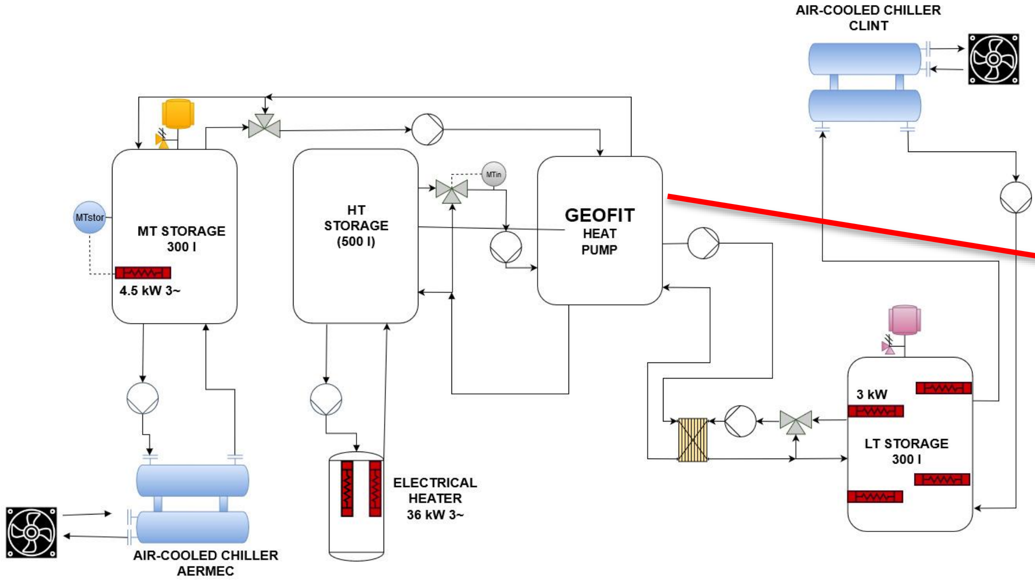
- Direct heating with sorption heat pump
- Indirect heating of sorption heat pump with gas boiler as back-up and
- Cooling with compression cycle.



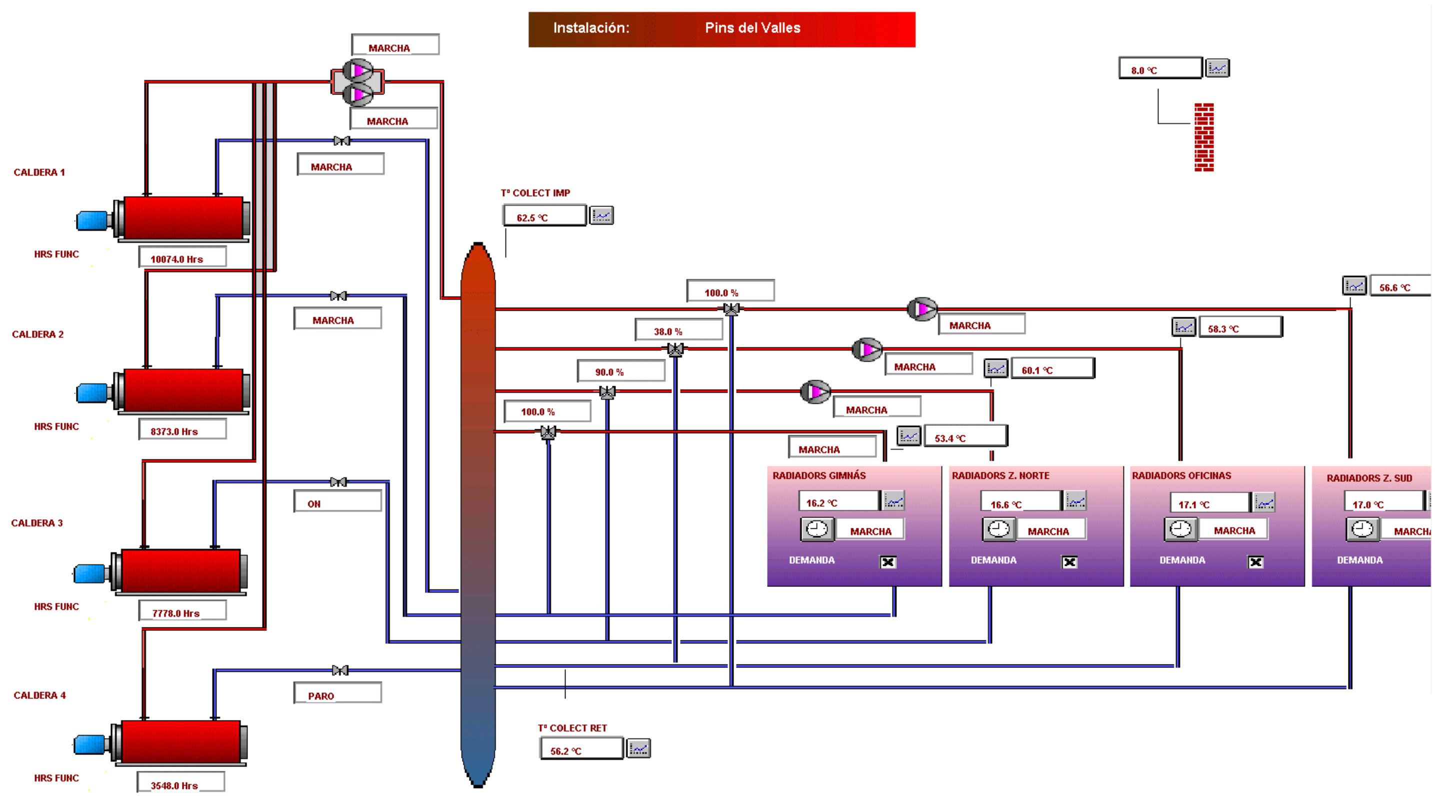
Lab tests: Electrically driven heat pump@AIT lab

Lab tests: Thermally driven heat pump@CNR-ITAE lab

Testing rig @ CNR ITAE



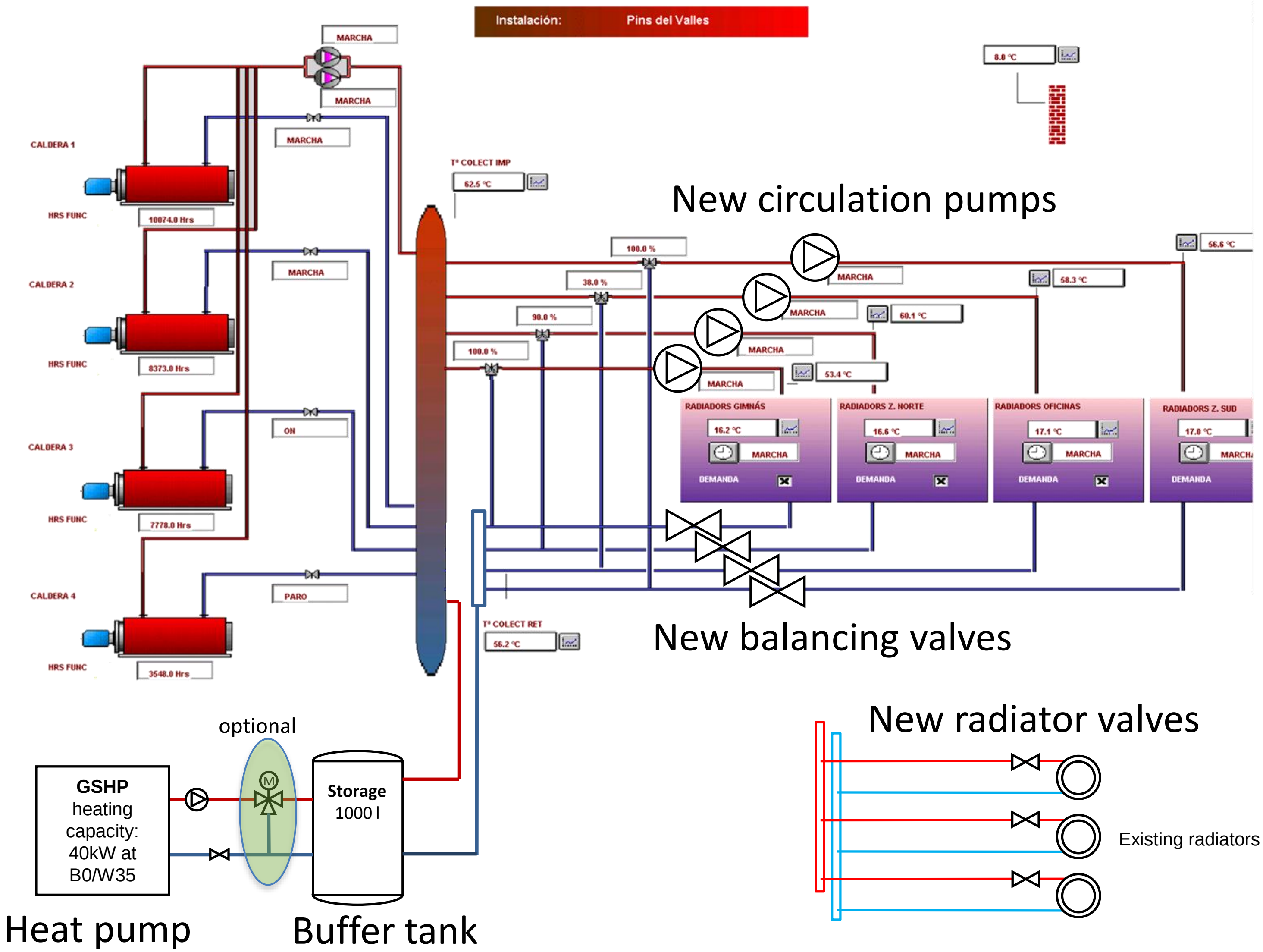
Integration example: St. Cugat Current system



Integration example: St. Cugat current situation

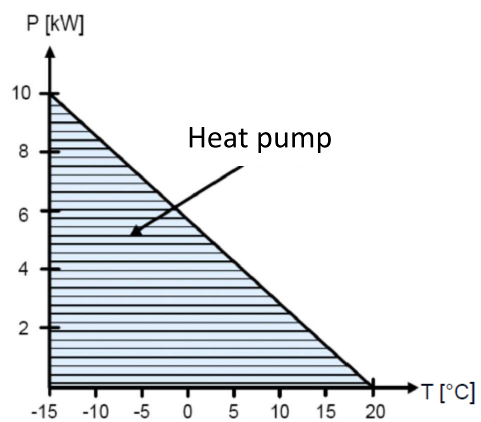
- Different types of radiators installed

Integration example: St.Cugat Geofit system



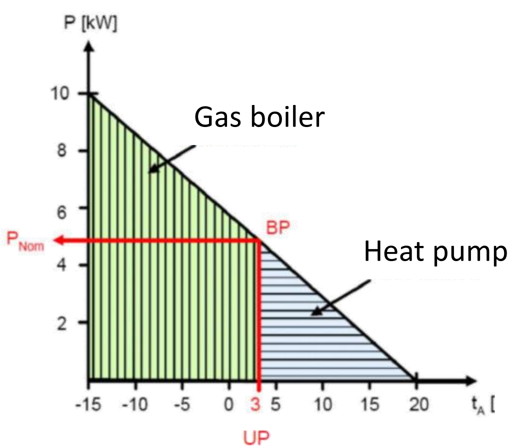
Integration example: St. Cugat operating strategies

Monovalent



- Heat pump only
- Design for 100% heat demand
- Feasible for small temperature lifts

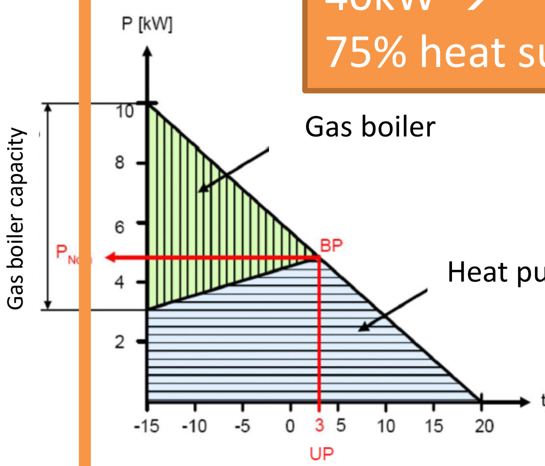
Bivalent alternativ



- Co-generation heat pump with gas boiler
- Heat pump covers heat demand partly
- Gas boiler only above BP

Bivalent parallel

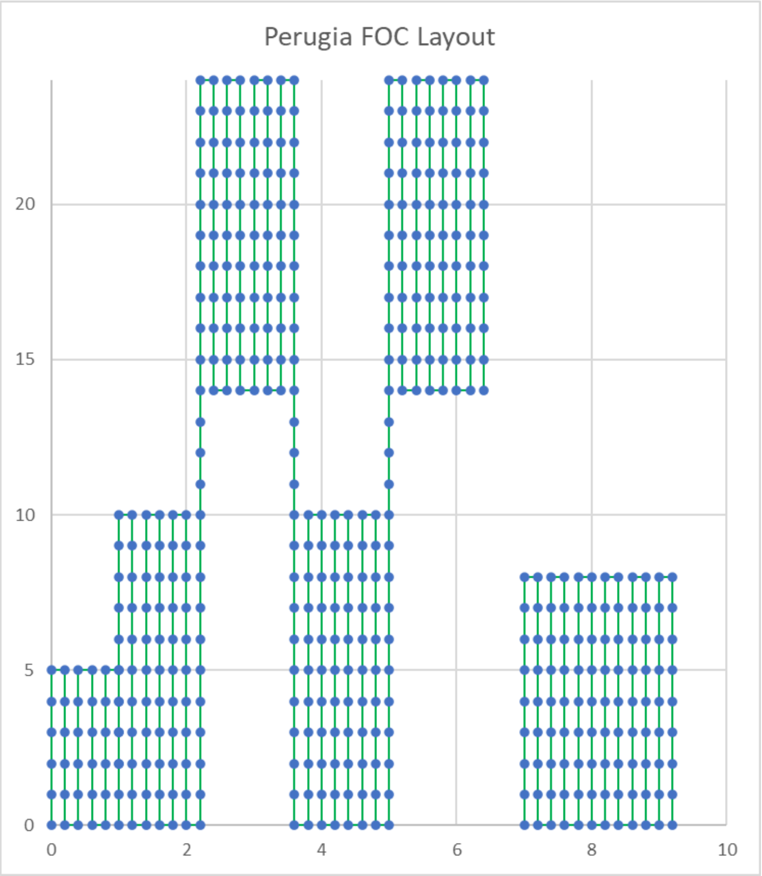
40kW →
75% heat supply



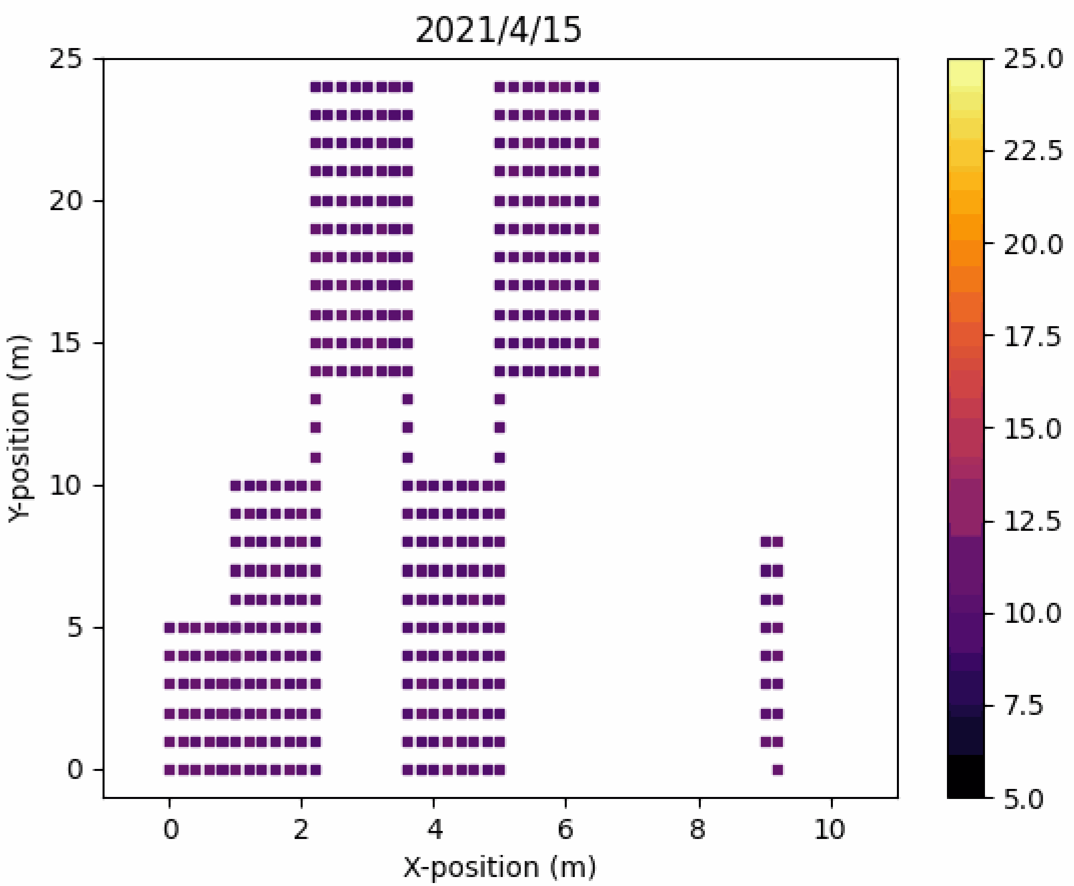
- Co-generation heat pump with gas boiler
- Heat pump covers most of heat demand
- Base load with heat pump

Field Tests

Perugia (IT) – slinky installation



Perugia (IT) – slinky animation



Bordeaux (FR) – spiral installation

Summary

Summary

GEOFIT

- Developed an integrated framework for the design of different types of ground heat exchangers
- Validation of the new calculation methods based on laboratory experiments, CFD modelling and field-tests
- Toolkit developed for the design of different types of ground heat exchangers
- Design manual for ground heat exchanger design
- Performance analysis of different GHEX and usage types
- Cost efficient heat pump systems tailored for retrofit use-case

Geofit WP3 Publications

EUROPEAN GEOTHERMAL CONGRESS 2022

Publications:

Dorr, C.J., 2020. CFD Analysis of Ground Source Heat Exchangers. MSc Thesis, Montan University Leoben, Austria.

Fernandez, S. 2021. Simulation of the interaction among underground heat exchangers. Master Thesis, University Rovira i Virgili, Tarragona, Spain.

Kling et al, 2022. Design Framework and Laboratory Experiments for Helix and Slinky Type Ground Source Heat Exchangers for Retrofitting Projects. Processes Special Issue: Advances in Integrated Geothermal Energy Systems.

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Thank You

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