Energy Efficient Construction

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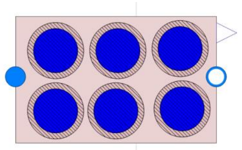
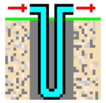
A comparison of borehole heat exchanger field models for energy system simulation

Xenia Kirschstein, Max Ohagen, Joscha Reber, Ingo Sass, Clemens Hübler





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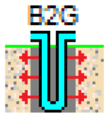

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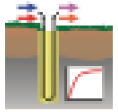

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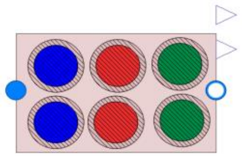

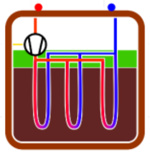

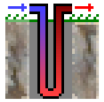

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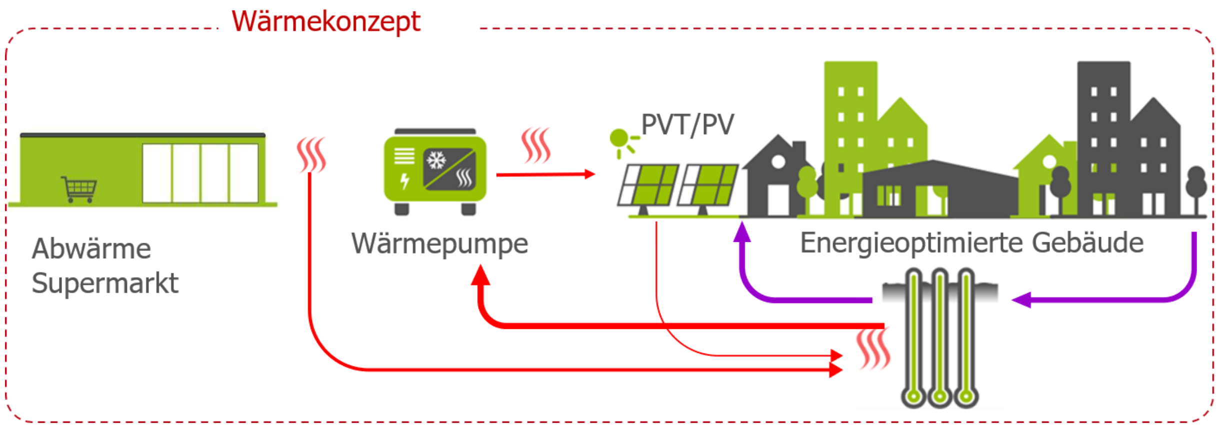
AGENDA

MULTI-SOURCE ENERGY SYSTEMS



- Heat pump operation times of a few minutes
- Central or decentral circulation pumps
- Often unbalanced heat extraction/injection

REQUIREMENTS FOR BHE FIELD MODELS

- high long-term accuracy
- high short-term accuracy
- irregular field geometries
- borehole resistance depending on flow velocity
- low computational effort

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TRNSYS

Modelica

Model	Short term	Long term	irregular	Calc. Time*	Rb = f(v)	limitations
DST + prepipe + eq. dist.	(+)	+	o	++	-	1 homogenous layer in BTES region
SBM + prepipe	(+)	+	+	-	o	(layering by Transsolar)
EWS + g-functions at outer boundary	(+)	+/o	(+)	(+)	(-)	Shank spacing, equidistant layers
B2G + g-functions	+	+	(+)	(+)	+	1 hom. layer, no 2U
Type 246 incl. g-function	?	(+)	(+)	-	?	?
HSRM (IBPSA)	+	+	(+)	(+)	+	Parallel, 1 hom. layer
MoBTES + eq. dist.	(+)	+	o	+	+	
'Hybrid' w/o FFT	+	+	+	o/?	+	
FEFLOW	+	+	+	--	+	

*Estimate – no quantitative comparison possible as most models not fully implemented available

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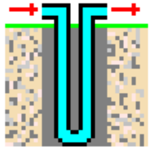
DST



Type557a

By: Hellström 1989

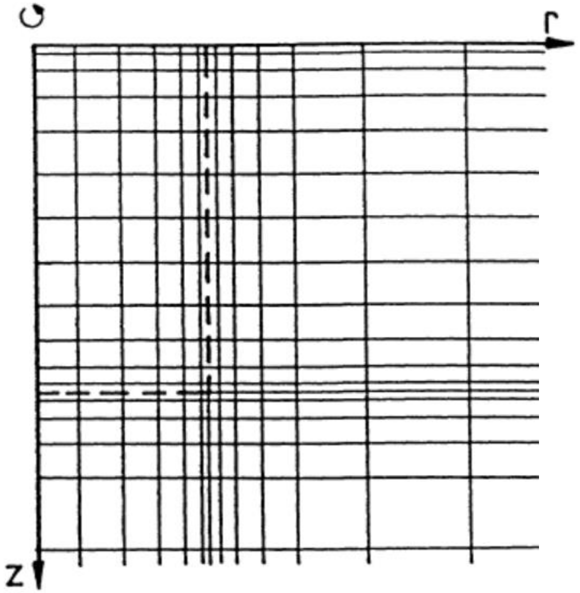
Availability: commercial (TESS library)

Connection schemes: Parallel, ringwise in series

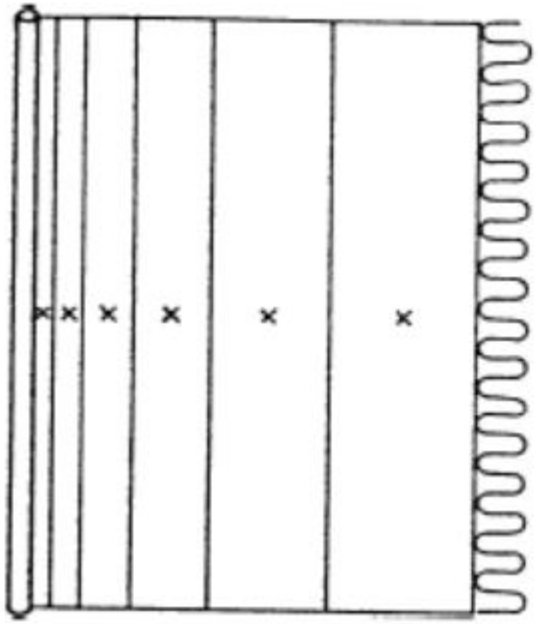
Modelling approach

Superposition of

- Global problem (FDM)
- Local problem (FDM)
- Steady flux (Analytical)



Source: Hellström 1989



Hellström, Göran**: Duct ground heat storage model.** Manual for computer code, 1989

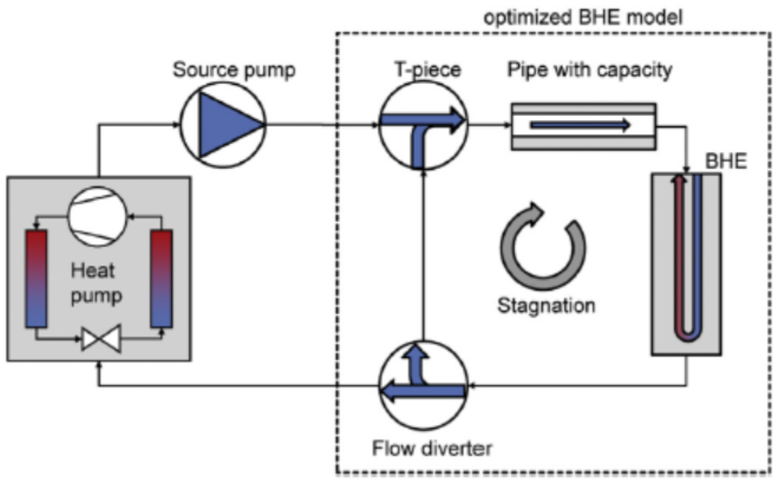
ADAPTION APPROACHES

Grout and fluid thermal capacity (DST + SBM)

- Pre-pipe approach (Pärisch et al. 2015)

Irregular field geometries (DST)

- Equivalent BHE distance (Park et al. 2018)



Source: Pärisch et al. 2015

Pärisch, Peter / Mercker, Oliver / Oberdorfer, Phillip / Bertram, Erik / Tepe, Rainer / Rockendorf, Gunter: **Short-term experiments with borehole heat exchangers and model validation in TRNSYS.** Renewable Energy, 2015
Park, Seung-Hoon / Jang, Yong-Sung / Kim, Eui-Jong: **Using duct storage (DST) model for irregular arrangements of borehole heat exchangers.** Energy, 2018

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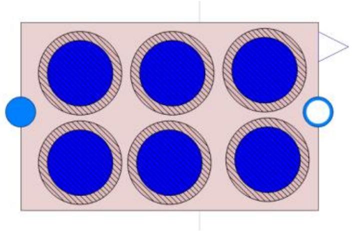
IBPSA MODEL



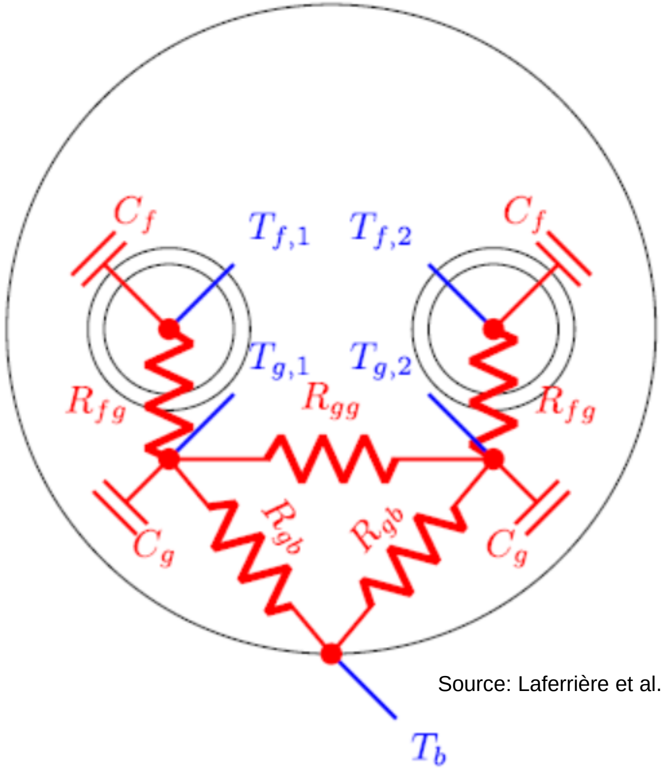
By: Laferrière et al. 2020 (extending Picard and Helsen 2014)

Availability: Free & OS (implementation in IBPSA library)

Connection schemes: Parallel

Modelling approach

- BHE: 5C5R-n TRCM (Bauer et al. 2011)
- Acceptable accuracy at $t > 2 \cdot Cg \cdot R_b$
- Ground: g-functions, $g_{FLS} + g_{CHS} - g_{ILS}$
- Superposition of FLS to account for temperature distribution along BHE



Source: Laferrière et al. 2020

Laferrière, Alex / Cimmino, Massimo / Picard, Damien / Helsen, Lieve: **Development and validation of a full-time-scale semi-analytical model for the short- and long-term simulation of vertical geothermal bore fields.** Geothermics, 2020

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SUMMARY OF APPROACHES

BHE

- Numerical approaches
  - TRM
  - TRCM
    - Bauer2011: 5C5R-n (1U)
    - B2G: 5C6R-n (1U)
    - Pasquier2012: 20C20R-n (1U)
  - Transient multipole expansion: No discretisation
- Analytical approaches
  - Equivalent pipe
  - Multipole → steady state (Claesson2019)

Coupling

- Local heat flows along BHE
  - Heat source term between brine and local solution (close BHEs) + Steady-flux-solution for redistribution of heat close to BHE
- Borehole wall temperature
  - Uniform
  - Segment-wise
- Average brine temperature → FDM in close BHE area

Global

- Rectangular 2D axi-symmetrical mesh
- Superposition of 2D axi-symmetrical numerical solutions
- Numerically derived g-function
  - uniform wall temperature
- Analytically derived g-functions
  - Integral solved numerically
- Analytical response factors / temperature penalization for thermal interaction

CASE 1

Darmstadt Ludwigshöhviertel

- 127 m BHE (2U)
- Granodiorite

GRT (07.2023)

- $\dot{V}$ = 0.88 m^3/h (Re ≈ 5980)
- q = 8 kW
- Duration 72 h, resolution 1 min
- Heat transfer medium: water

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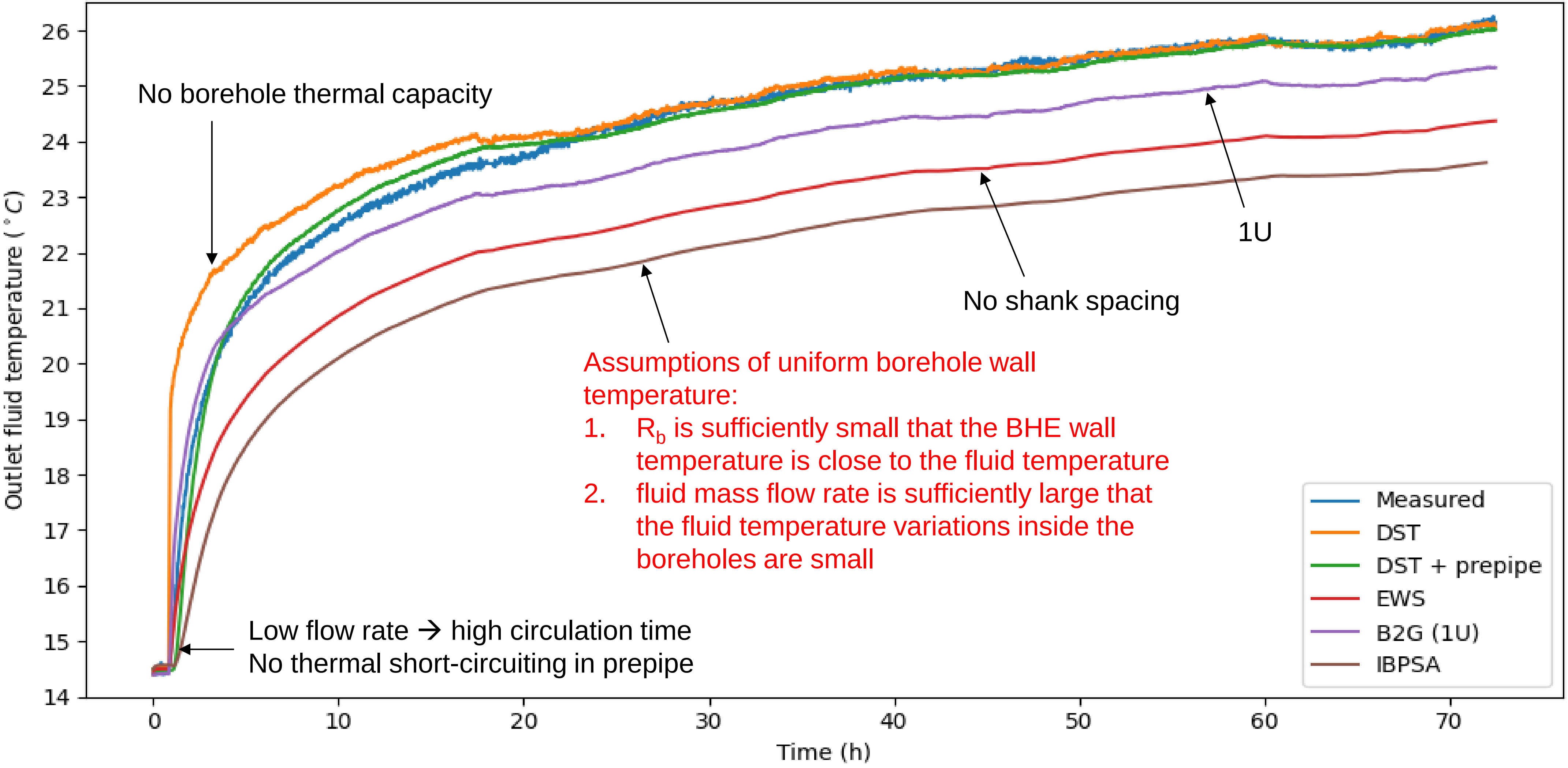
Parameter	Assumed value	Source
λ_{ground} (W/m/K)	3.2	lab*
$c_{p,ground}$ (kJ/kg/K)	0.861	lab* (from TD)
ρ_{ground} (kg/m3)	2700	lab*
λ_{grout} (W/m/K)	2.1	lab**
$c_{p,grout}$ (kJ/kg/K)	1.96	lab**
ρ_{grout} (kg/m3)	1590	lab**
shank spacing*** (m)	0.053	fitted
λ_{pipe} (W/m/K)	0.4	
T_{init} (ºC)	14.4	GRT

* From nearby rock samples, kindly provided by Lukas Seib; TD: Thermal diffusivity
** Kindly provided by Markus Schedel
*** here: centre of supply pipe to centre of return pipe



Outlet fluid temperature (°C)
Time (h)
No borehole thermal capacity
1U
No shank spacing
Assumptions of uniform borehole wall temperature:
1. R_b is sufficiently small that the BHE wall temperature is close to the fluid temperature
2. fluid mass flow rate is sufficiently large that the fluid temperature variations inside the boreholes are small
Low flow rate → high circulation time
No thermal short-circuiting in prepipe
Measured
DST
DST + prepipe
EWS
B2G (1U)
IBPSA

CASE 2

Darmstadt Postsiedlung

- Measured operational data 07.2023 – 08.2024, 5 min
- 23*120 m BHEs (2U)
- Sediment: sand, clay, silt
- Groundwater level approx. 27 m below ground level
- Heat transfer medium: 28 % monoethylene glycol

Source: Geo-En Energy Technologies GmbH

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Parameter	Assumed value	Source
λ_{ground} (W/m/K)	2	GRT
c_{ground} (kJ/m3/K)	2.4	Permit application
λ_{grout} (W/m/K)	2.1	Same grout as case I
$c_{p,grout}$ (kJ/kg/K)	1.96	
ρ_{grout} (kg/m3)	1590	
shank spacing (m)	0.074	Permit application
λ_{pipe} (W/m/K)	0.42	Permit application
T_{init} (ºC)	13.5	GRT

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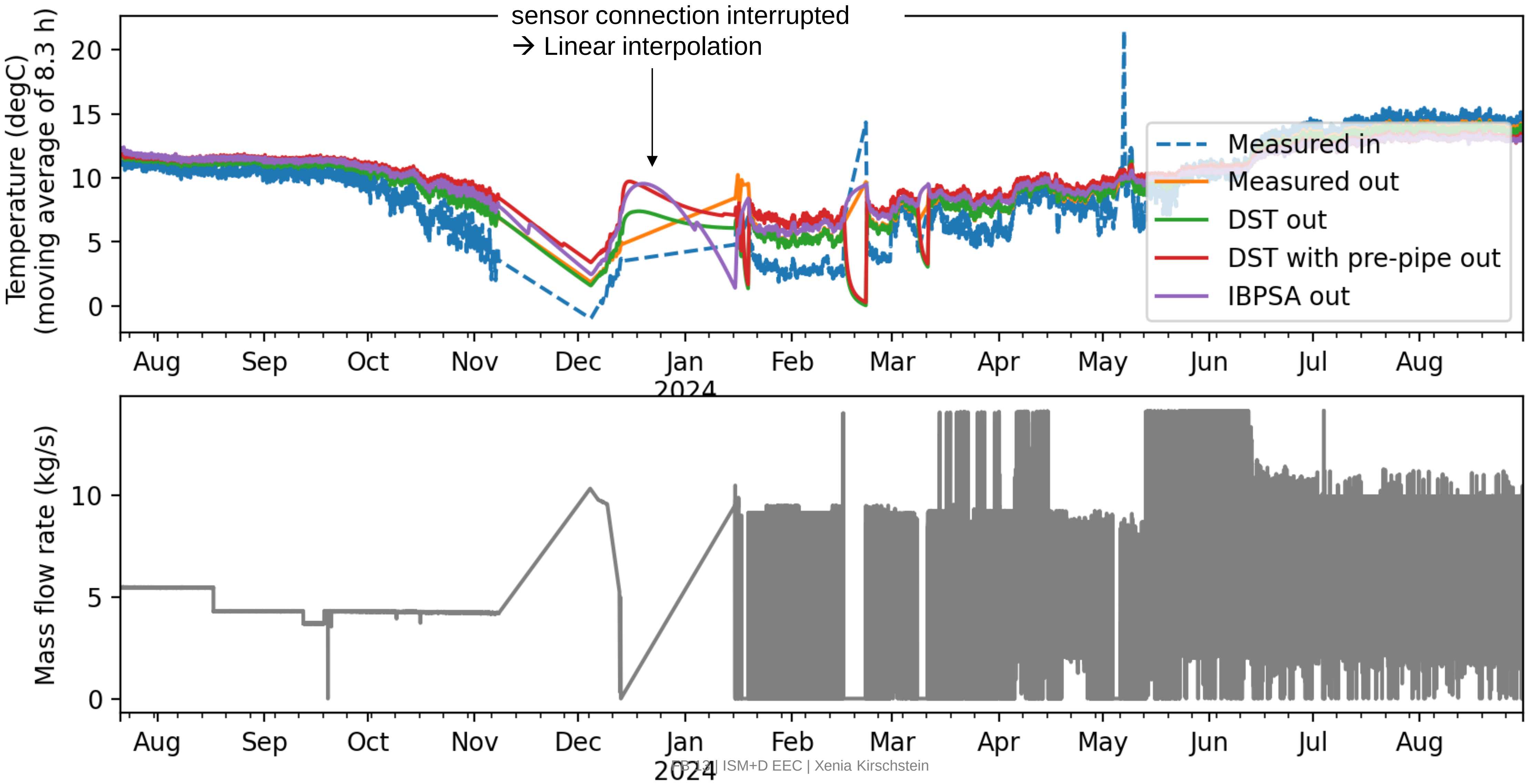

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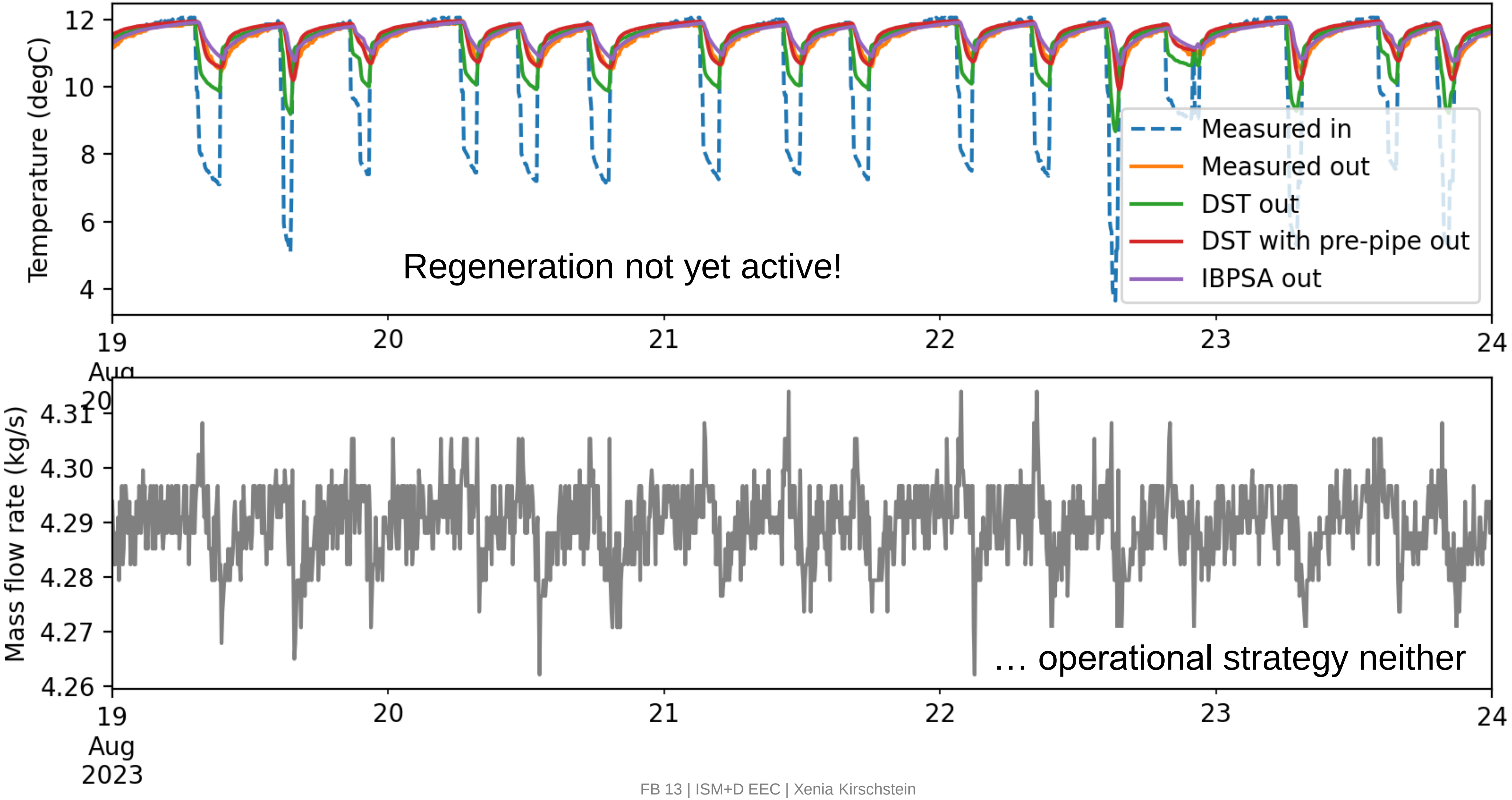
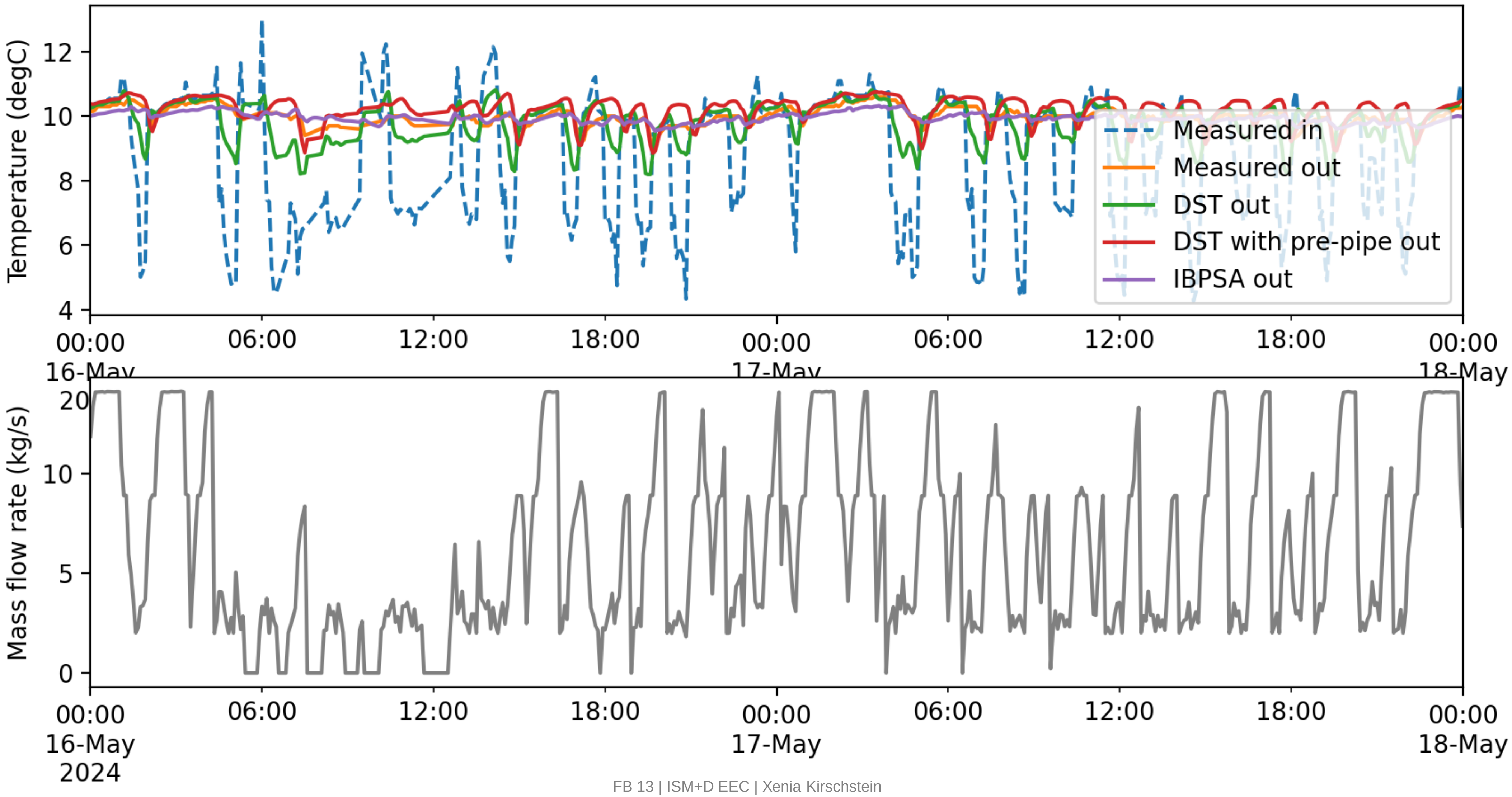
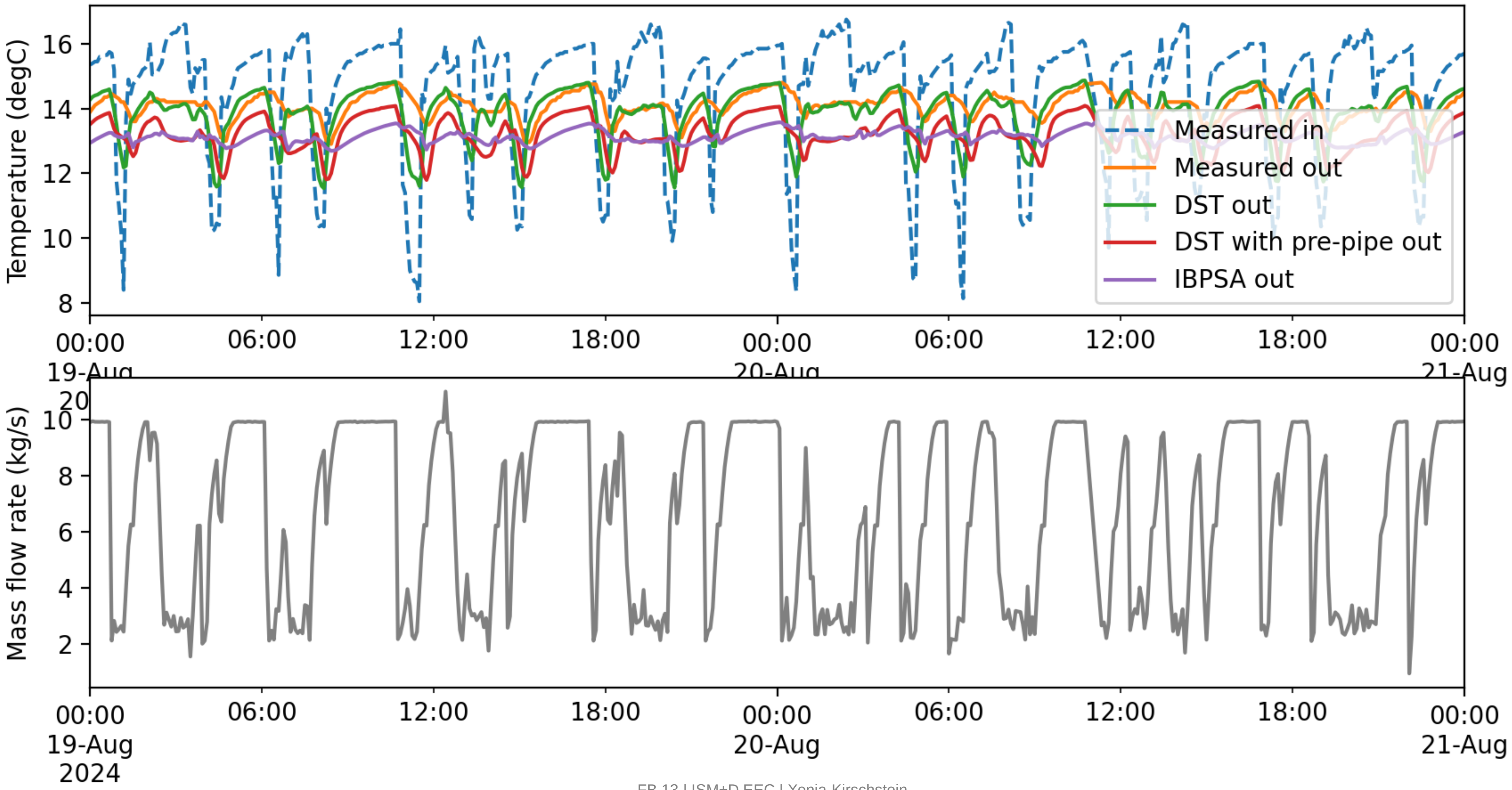



Temperature (degC)
12
10
8
6
4
Measured in
Measured out
DST out
DST with pre-pipe out
IBPSA out
00:00 16-May
06:00
12:00
18:00
00:00 17-May
06:00
12:00
18:00
00:00 18-May
Mass flow rate (kg/s)
20
10
5
0
00:00 16-May 2024
06:00
12:00
18:00
00:00 17-May
06:00
12:00
18:00
00:00 18-May


Temperature (degC)
16
14
12
10
8
Measured in
Measured out
DST out
DST with pre-pipe out
IBPSA out
00:00
19-Aug
2024
06:00
12:00
18:00
00:00
20-Aug
06:00
12:00
18:00
00:00
21-Aug
Mass flow rate (kg/s)
10
8
6
4
2

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OUTLET TEMP. DEVIATION

	R^2 (-)	RMSE (K)	MAE (K)	ΔQ_{out} (MWh)	ΔQ_{out} (%)	ΔQ_{in} (MWh)	ΔQ_{in} (%)
DST	0.71	1.38	0.69	33.5	19	14.6	21
DST with pre-pipe	0.71	1.39	0.82	-41.6	23	-19	27
IBPSA	0.93	0.7	0.53	-24.6	14	-35.8	51

- without 8.11.23 – 15.01.24
- measured temperature difference is used to calculate the inlet temperature → error accumulates
- measurement uncertainty 0.4 K per temperature sensor, 0.5 % volume flow sensor

CONCLUSION

- Constant mass flow rate → better fit
- **DST + pre-pipe** model for BTES-like geometries and steady operation → Case I (GRT)
- **IBPSA** model for irregular geometries and dynamic operation → Case II (Postsiedlung)
- Influence of connection pipes should be measured
- The results are very sensitive → **measured data for calibration** is crucial!

THANK YOU!

Contact:

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