5th International Conference on Smart Energy Systems
Copenhagen, 10-11 September 2019
#SESAAU2019

sim4dhs

an algorithm to simulate tree and meshed district heating networks dynamically

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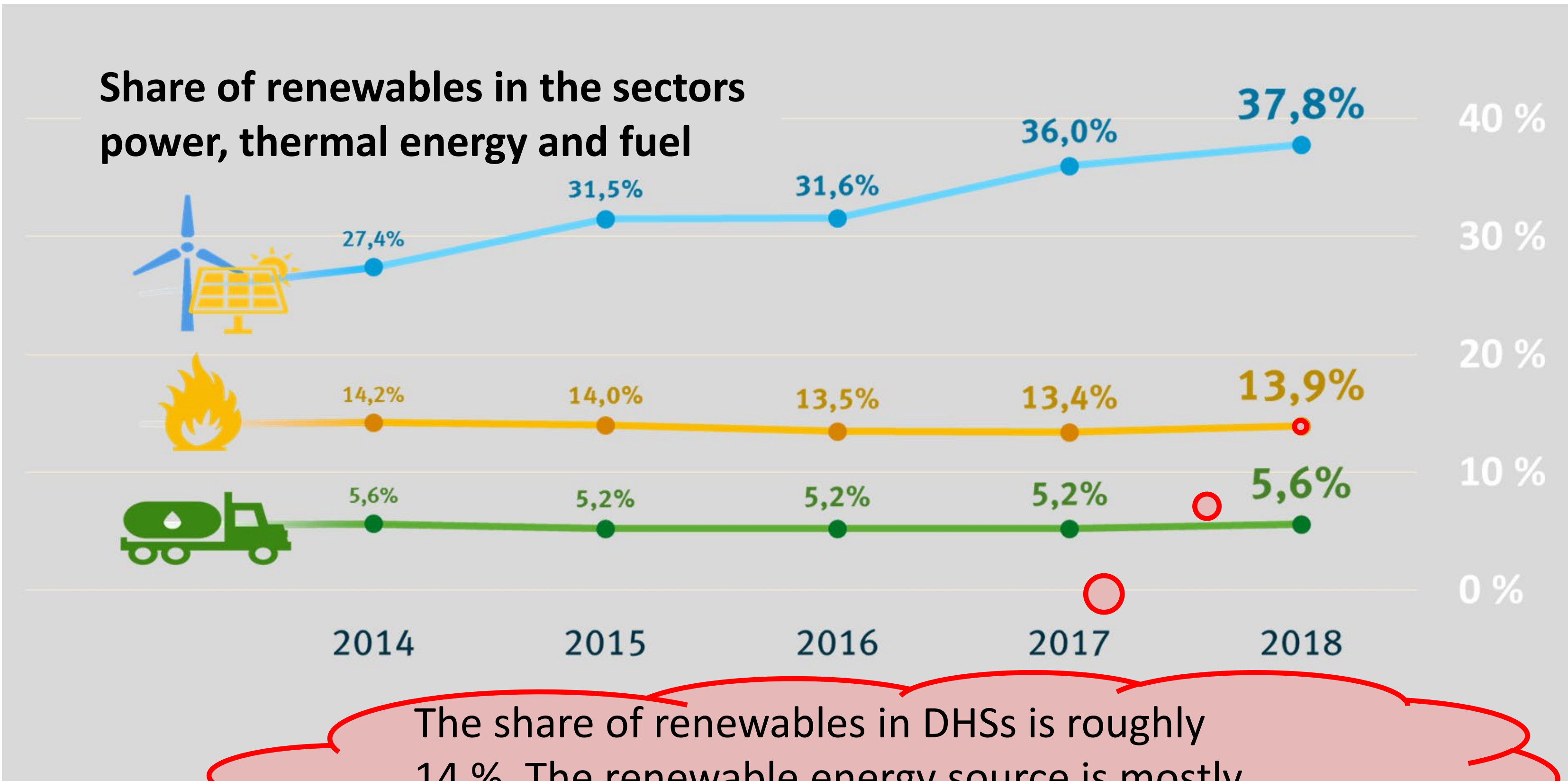
1. Introduction
2. Hydraulic Load factor
3. Methodology
4. Example networks
5. Outlook



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The share of renewables in DHSs is roughly 14 %. The renewable energy source is mostly the waste heat from waste incineration.

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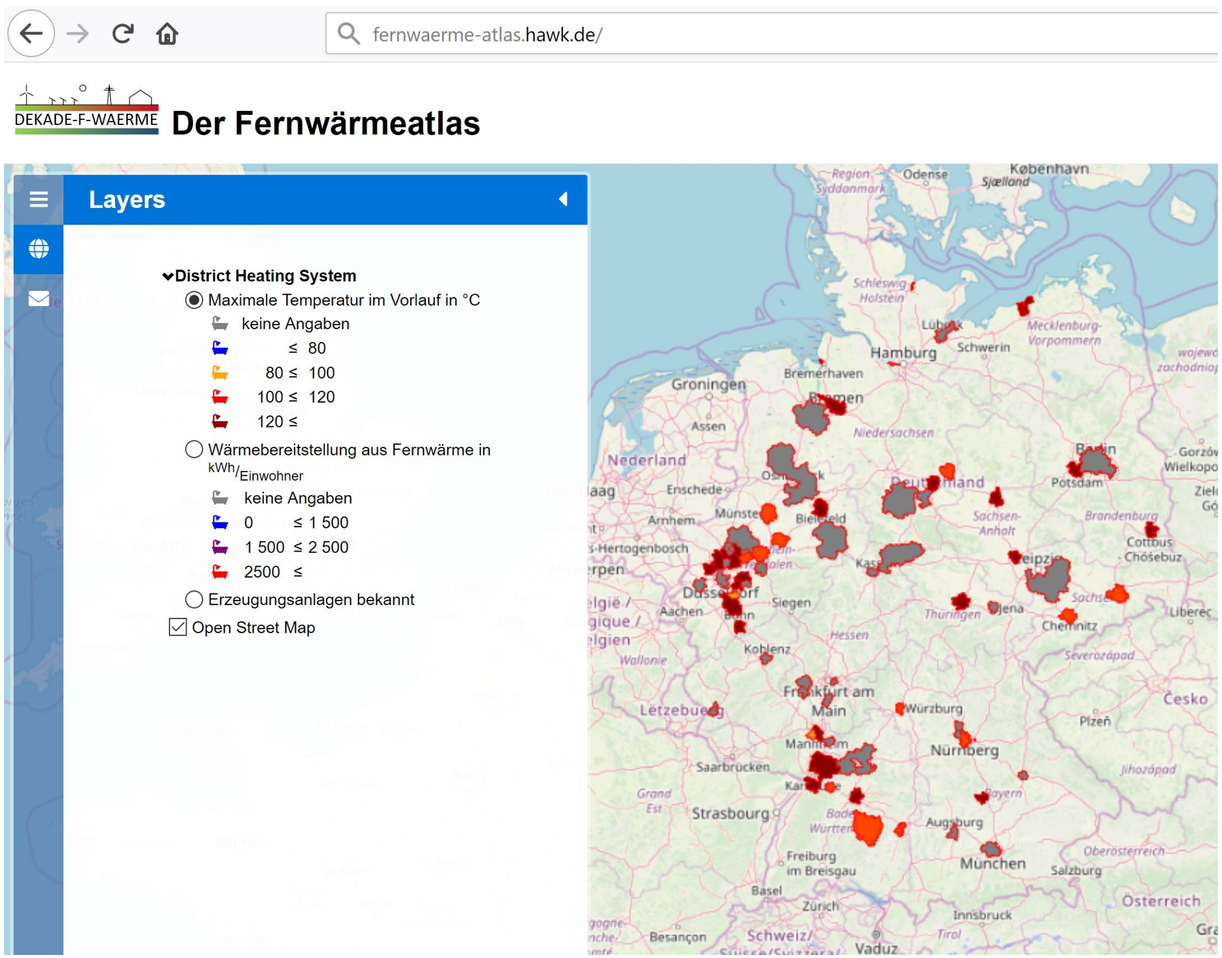

- Most of DHSs are operated with supply / return temperature @ >100 / >40 °C
- CHP mostly run by coal or gas.
- Heat demand decreased due to improved thermal insulation.
- High temperature levels make utilisation of waste heat difficult.
- High temperature levels make the integration of renewable energies economic infeasible.

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Targets:

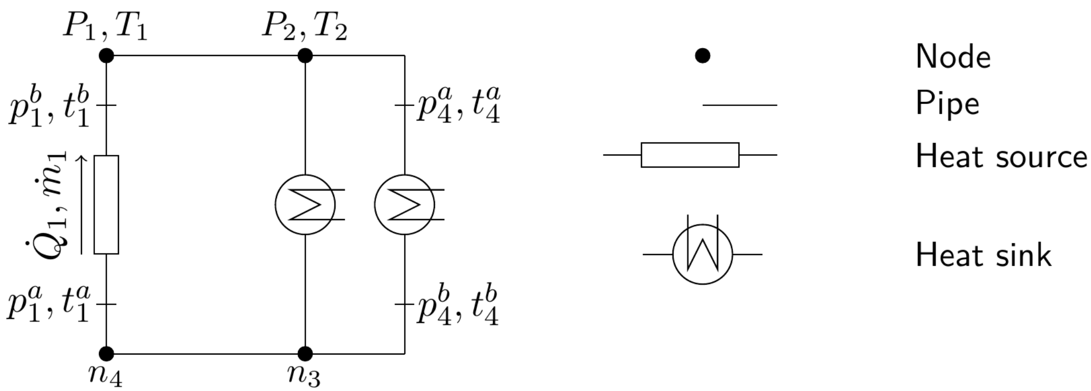
1. Examine thermo-hydraulic restrictions occurring while lowering DHSs operating temperatures.
2. Compare restrictions with restrictions of today's operational mode.
3. Quantify and qualify impact of thermo-hydraulic restrictions using hydraulic load factor

- $$f_{hlf} = \frac{\dot{V}_{operation}}{\dot{V}_{max}} \qquad \text{(Equ. 1)}$$
- $$f_{HLF} = \frac{The\ sum\ of\ the\ length\ of\ pipes\ where\ f_{hlf} > 1}{Overall\ district\ heating\ network\ length} \qquad \text{(Equ. 2)}$$

Elaborate on actions to bridge thermo-hydraulic restrictions:

Measures help to bridge thermo-hydraulic restrictions, such as:

- Decentralised heat sources (heat boosters)	- Demand-side-management
- Centralised or decentralised heat storages	- Reduction of return temperature



Small example DHS with inscribed variables for pressure (P, p^a, p^b), temperature (T, t^a, t^b), heat-flow $(\dot{Q})$ and mass flow $(\dot{m})$; For clear view some variables are not inscribed.

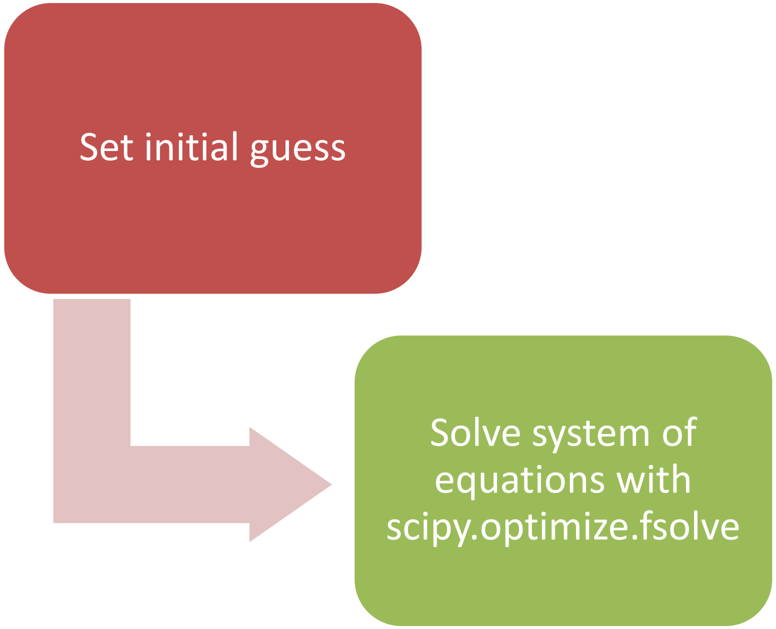
1st Kirchhoff's theorem

$$0 = \underline{I}_{(n-1,e)} \cdot \vec{\dot{m}}$$

$$0 = \begin{pmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,e} \\ a_{2,1} & \ddots & \cdots & \vdots \\ \vdots & \vdots & a_{i,j} & \vdots \\ a_{n-1,1} & \cdots & \cdots & a_{n-1,e} \end{pmatrix} \cdot \begin{pmatrix} \dot{m}_1 \\ \dot{m}_2 \\ \vdots \\ \dot{m}_e \end{pmatrix}$$

Constitutive relations

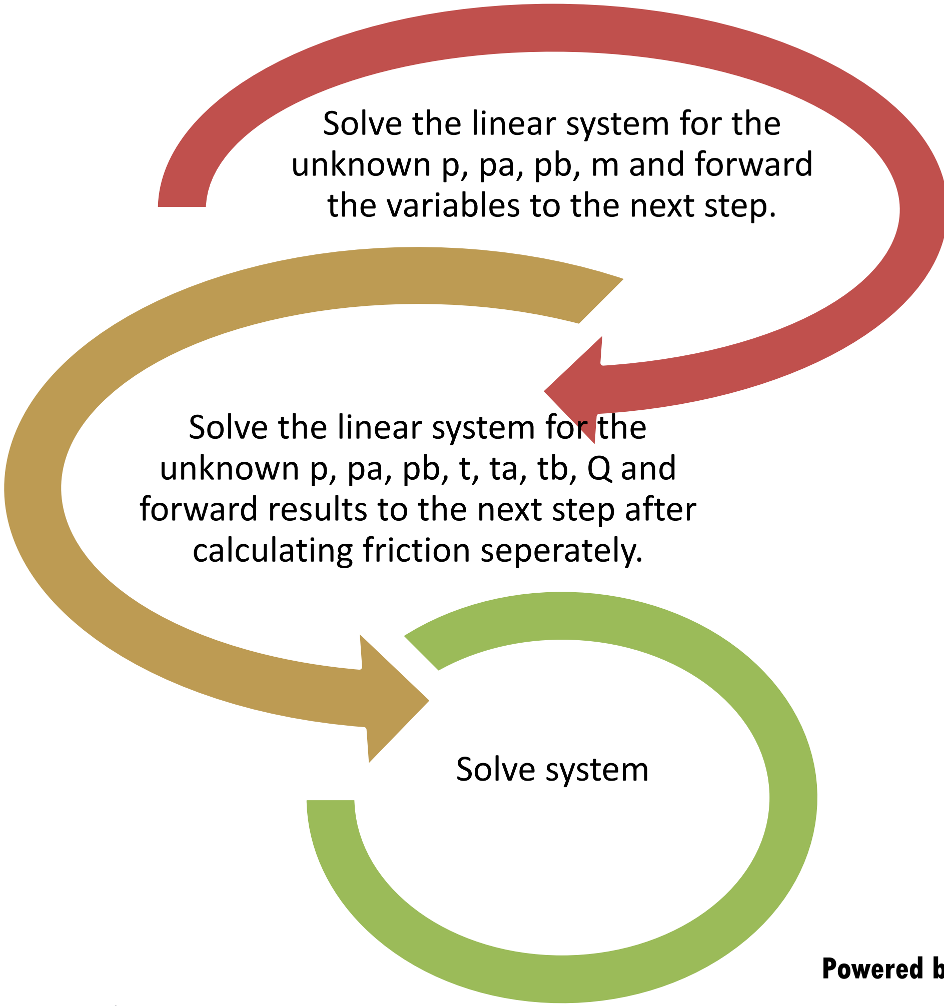
Edges	Dependencies	Equations
All edges	thermal	$0 = \dot{m}_i \cdot c_p \cdot \left(t_i^a - t_i^b\right) + \dot{Q}_i$
Straight pipe	thermal	$0 = (kA)_i \cdot \left(\bar{t}_i^{a,b} - t^{amb}\right) + \dot{Q}_i$
	hydraulic	$0 = \left(p_i^a - p_i^b\right) - \frac{8 \cdot \lambda_i \cdot l_i}{\rho \cdot \pi^2 \cdot d_i^5} \cdot \lvert\dot{m}_i\rvert \cdot \dot{m}_i + \varrho \cdot g \cdot \left(h_i^a - h_i^b\right)$
Heat source and heat sink	thermal	$0 = t_i^{b,set} - t_i^b$
Main heat source	hydraulic	$0 = p_1^{a,set} - p_1^a$
	hydraulic	$0 = p_1^{b,set} - p_1^b$
Additional heat source	thermal	$0 = \dot{Q}_i^{set} - \dot{Q}_i$
Heat sink	thermal	$0 = \dot{Q}_i^{set} - \dot{Q}_i$



- right solution
- long solving time (5 min. for a network with 250 consumers)

→ !! no sparsity of matrices possible !!

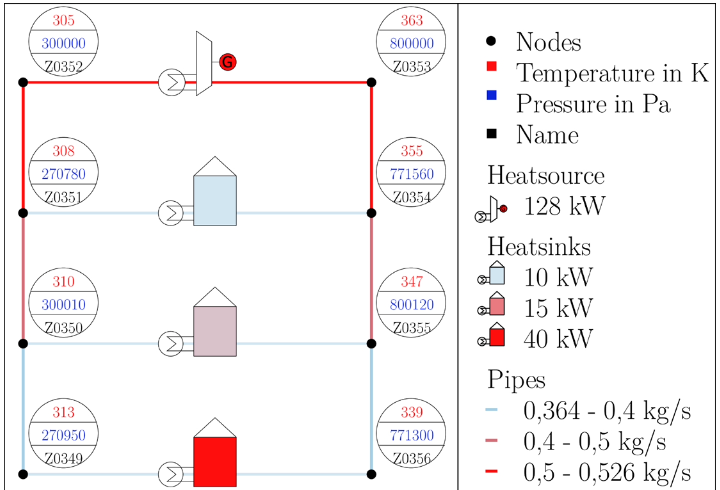
$$\begin{bmatrix} 1 & \cdots & 0 \\ & & 0 \\ \vdots & \ddots & 1 \\ & & -1 \\ & & 0 \\ 0 & \cdots & 0 \end{bmatrix}$$



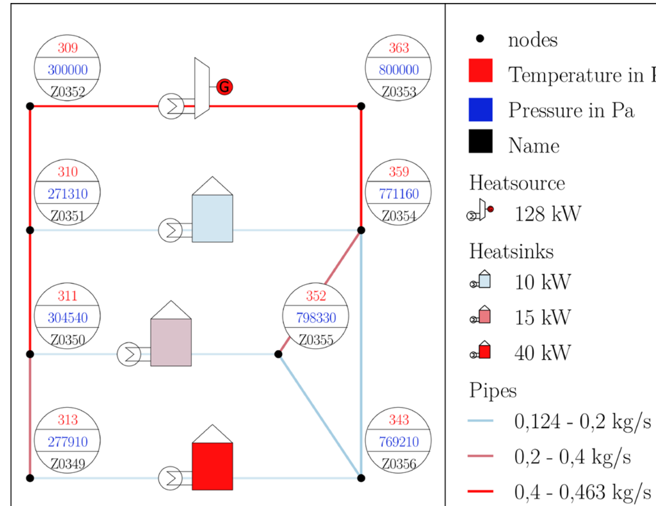
Using ipopt

- right results
- fast solving (from 5 min. down to 0.7 sec.)
- sparsity of matrices possible

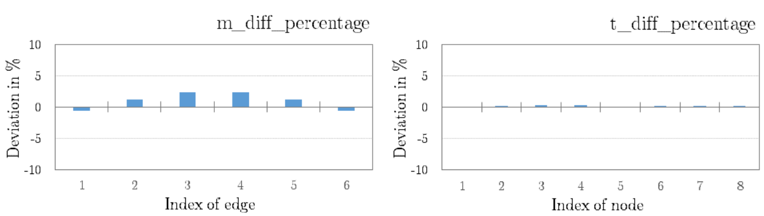
$$\begin{bmatrix} 2 & 5 \\ 3 & 7 \\ 9 & 2 \\ 8 & 5 \end{bmatrix}$$

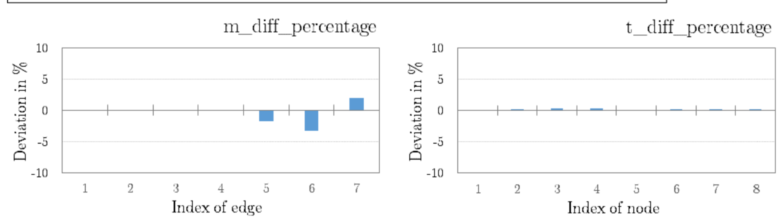


Start	End	Q	m	Tb	L	D	Ha	Hb	k	Fric	h
Z0349	Z0350	-5673	0.364	309.42	300	0.1	8	5	0.0001	0.035	2
Z0350	Z0351	-6220	0.469	307.1	300	0.15	5	8	0.0001	0.037	1.6
Z0351	Z0352	-5718	0.526	305.15	300	0.2	8	5	0.0001	0.039	1.2
Z0353	Z0354	-17627	0.526	355.15	300	0.2	5	8	0.0001	0.032	1.2
Z0354	Z0355	-15810	0.469	347.1	300	0.15	8	5	0.0001	0.031	1.6
Z0355	Z0356	-11692	0.364	339.42	300	0.1	5	8	0.0001	0.031	2



Start	End	Q	m	Tb	L	D	Ha	Hb	k	Re	Fric	h
Z0349	Z0350	-2912	0.319	310.97	300	0.05	8	5	0.0001	12157	0.03	2
Z0350	Z0351	-2236	0.411	310.16	300	0.05	5	8	0.0001	15299	0.028	1.6
Z0351	Z0352	-2594	0.463	309.16	300	0.08	8	5	0.0001	10556	0.031	1.2
Z0353	Z0354	-7249	0.463	359.41	300	0.08	5	8	0.0001	22821	0.026	1.2
Z0354	Z0355	-6749	0.216	351.96	360.6	0.05	8	5	0.0001	15993	0.028	1.6
Z0356	Z0355	-7192	-0.123	351.96	359.7	0.05	8	5	0.0001	8019	0.033	2
Z0354	Z0356	-10723	0.195	346.27	596.8	0.05	8	8	0.0001	13914	0.029	1.6





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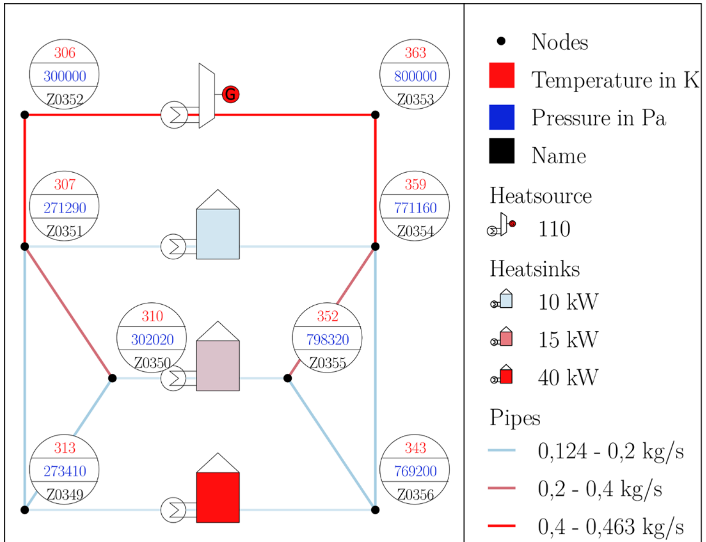
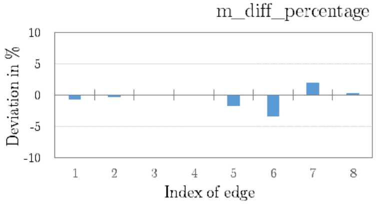
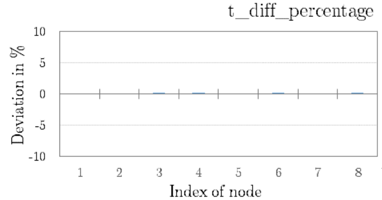
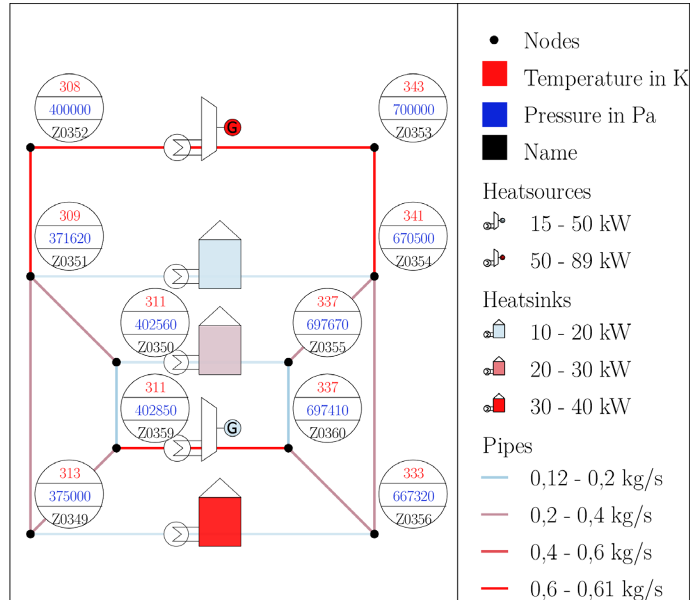


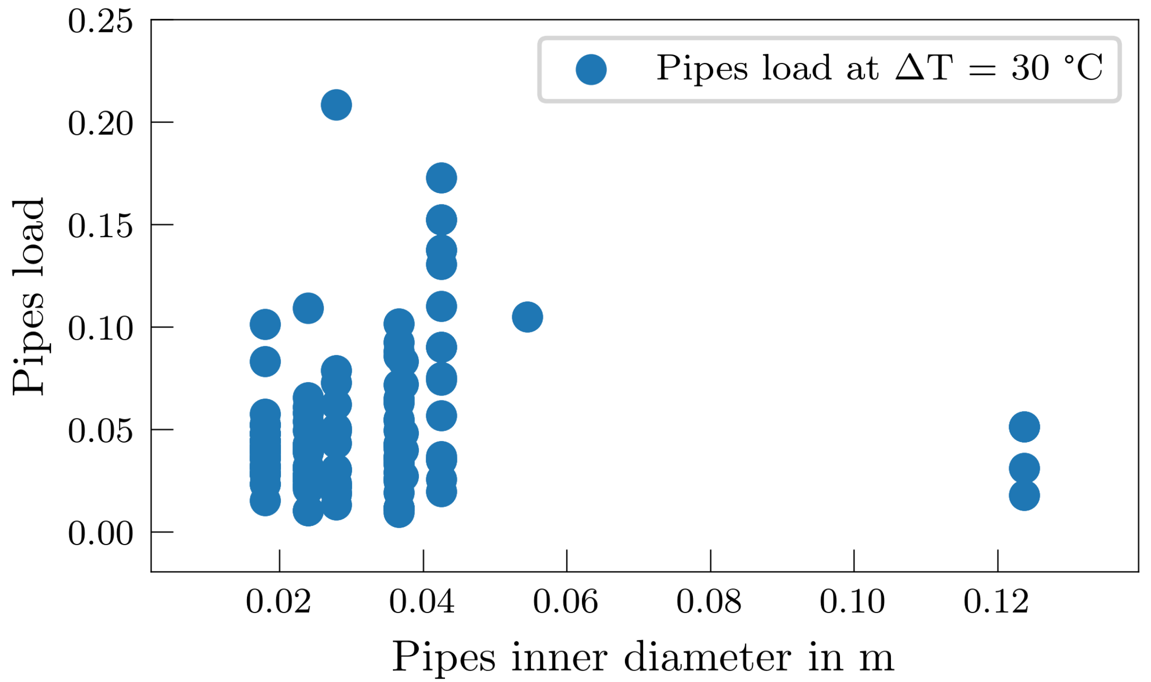
Start	End	Q	m	Tb	L	D	Ha	Hb	k	Re	Fric	h
Z0349	Z0350	-3258	0.124	306.89	360.6	0.05	8	5	0.0001	4552	0.039	2
Z0350	Z0351	-2450	0.217	306.85	360.6	0.05	5	8	0.0001	7648	0.034	1.6
Z0351	Z0352	-2323	0.463	306.23	300	0.08	8	5	0.0001	9944	0.032	1.2
Z0353	Z0354	-7249	0.463	359.41	300	0.08	5	8	0.0001	22839	0.026	1.2
Z0354	Z0355	-6750	0.217	351.98	360.6	0.05	8	5	0.0001	16026	0.028	1.6
Z0355	Z0356	-7212	0.125	338.15	360.6	0.05	5	8	0.0001	8051	0.033	2
Z0354	Z0356	-10775	0.195	346.2	600	0.05	8	8	0.0001	13904	0.029	1.6
Z0349	Z0351	-5387	0.195	306.56	600	0.05	8	8	0.0001	7122	0.034	2







Start	End	Q	m	Tb	L	D	Ha	Hb	k	Re	Fric	h
Z0350	Z0351	-2026	0.267	309.05	282.9	0.05	5	8	0.0001	9708	0.033	1.6
Z0351	Z0352	-2479	0.607	308.05	300	0.08	8	5	0.0001	13460	0.03	1.2
Z0353	Z0354	-5511	0.607	340.95	300	0.08	5	8	0.0001	23490	0.027	1.2
Z0354	Z0355	-4121	0.266	337.25	282.9	0.05	8	5	0.0001	15819	0.031	1.6
Z0354	Z0356	-8414	0.255	332.95	600	0.05	8	8	0.0001	14690	0.031	1.6
Z0349	Z0351	-5528	0.254	309.05	600	0.05	8	8	0.0001	9487	0.033	2
Z0349	Z0359	-2193	0.229	310.85	282.9	0.05	8	5	0.0001	8712	0.034	1.6
Z0359	Z0350	-1754	0.118	310.55	200	0.05	5	5	0.0001	4385	0.04	2
Z0356	Z0360	-3805	-0.228	336.65	282.9	0.05	8	5	0.0001	12762	0.032	1.6
Z0360	Z0355	-3311	-0.117	337.25	200	0.05	5	5	0.0001	6780	0.036	2


Pipes load at ΔT = 30 °C
Pipes load
0.25
0.20
0.15
0.10
0.05
0.00
0.02
0.04
0.06
0.08
0.10
0.12
Pipes inner diameter in m

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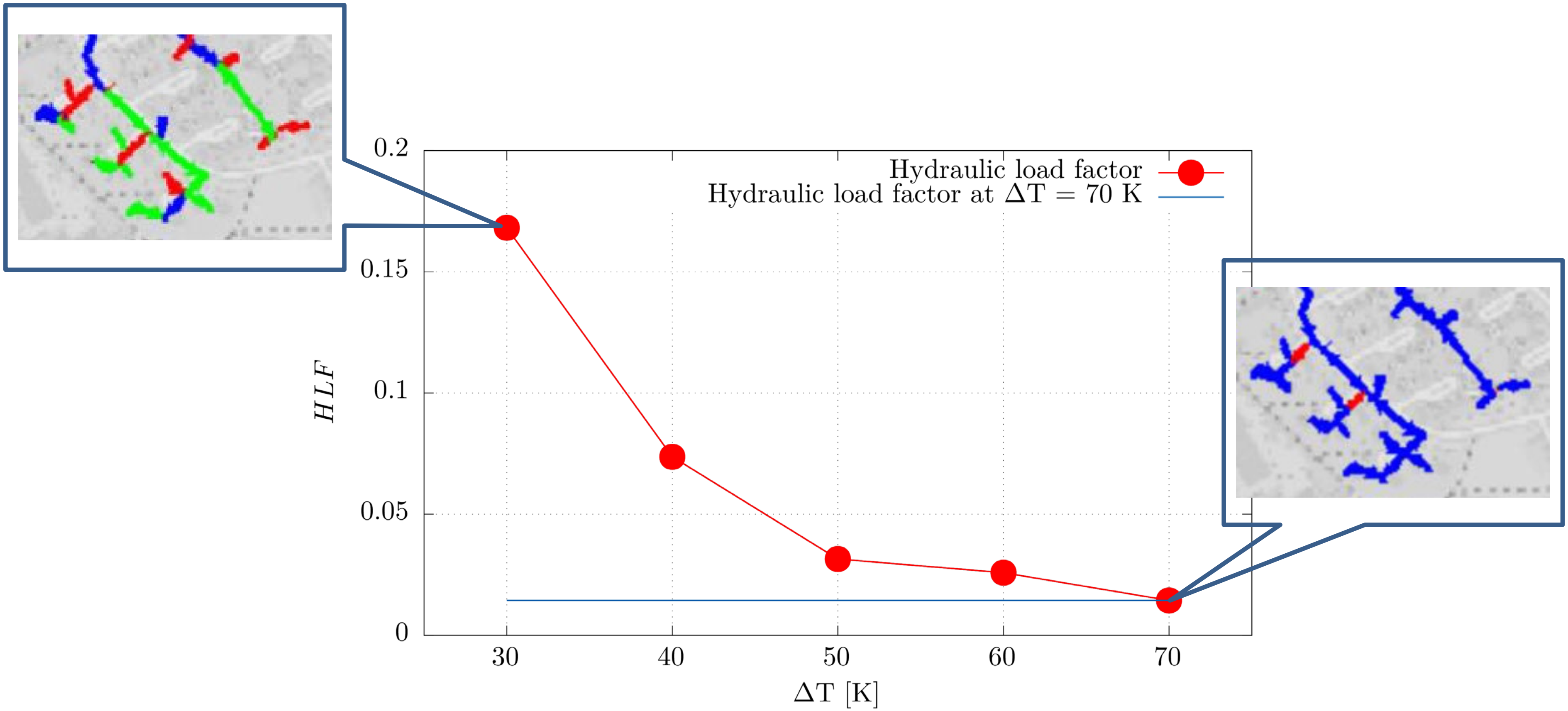

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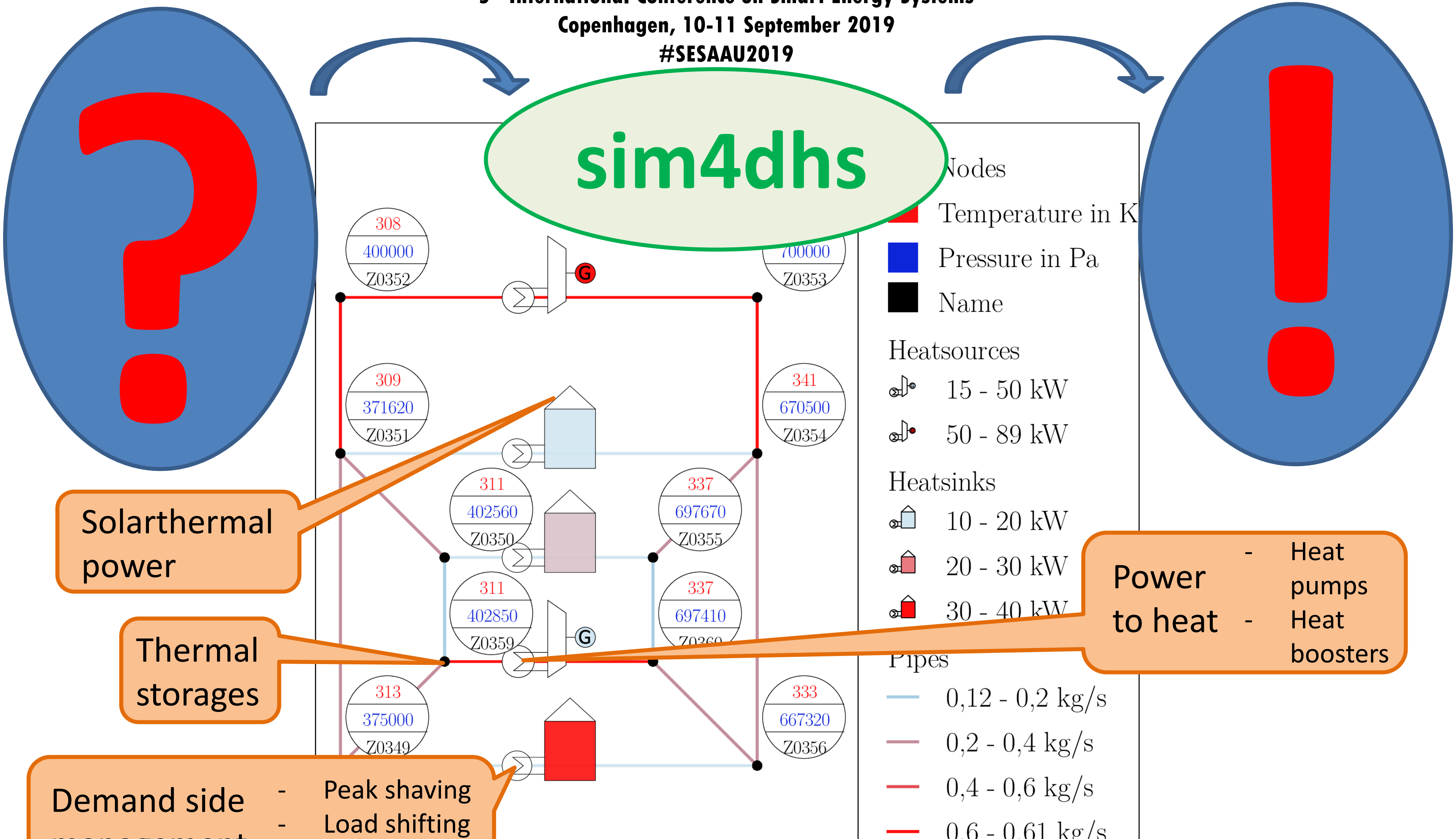

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Please feel free to ask any question!

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