LUNDS UNIVERSITET

Improving Robustness

in District Heating Systems

Felix Agner | September 4, 2021

Acknowledgements

Authors:

- Felix Agner (Dep. of Automatic Control, Lund University)
- Pauline Kergus (Dep. of Automatic Control, Lund University)
- Anders Rantzer (Dep. of Automatic Control, Lund University)
- Richard Pates (Dep. of Automatic Control, Lund University)

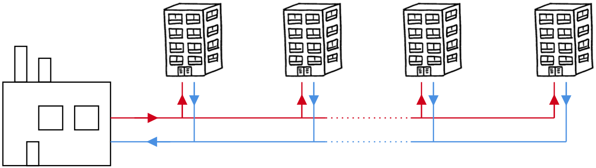
Contact: *felix.agner@control.lth.se*

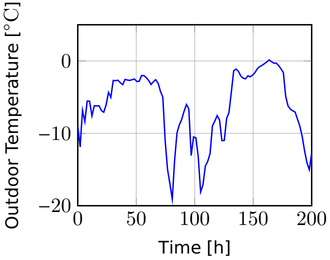
This work is funded by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program under grant agreement No 834142 (ScalableControl).

European Research Council

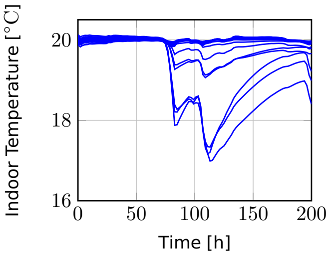
Established by the European Commission

Problem Formulation





(a) Outdoor Temperature



(b) Indoor Temperatures

Problem Formulation

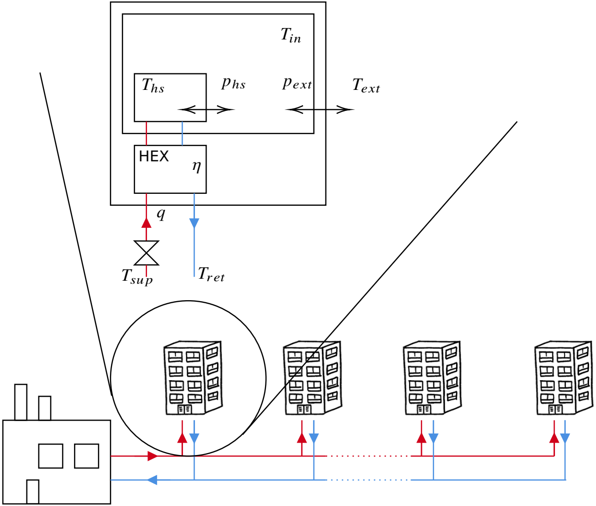
Objectives:

- Reduce worst case deviations in low outdoor temperatures
- Maintain distributed controller tuning

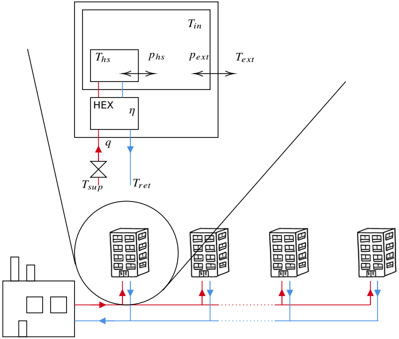
Contributions:

- Proposal of a load coordination technique
- A model of the set of feasible network flows
- Matlab simulated comparison between control structures

Building Models

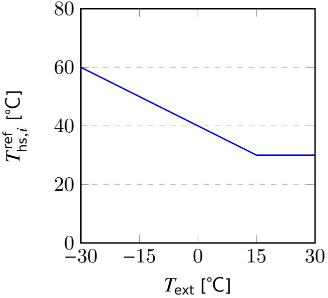


Traditional Control

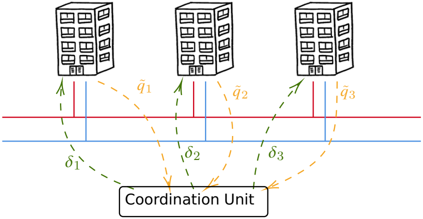


$$T_{hs}^{ref} = a_0 + a_1 T_{ext}$$

$$\tilde{q} = k(T_{hs}^{ref} - T_{hs})$$



Load Coordination



$\underset{\delta}{\text{minimize}}$	$\max_i \lvert \gamma_i \delta_i \rvert$	Min. max deviation
subject to	$\tilde{\mathbf{q}} - \delta = \mathbf{q}$	Actual flows modified by δ
	$\mathbf{q} \in \mathcal{Q}$	Actual flows should be feasible

---

$\gamma_i = \frac{1}{k_i(1-a_{1,i})}$, chosen to give equal temperature deviations

Optimal Control

$$\underset{\mathbf{q}(t)}{\text{minimize}} \quad \sum_{t=1}^{T} \max_i |e_i(t)| \tag{1}$$

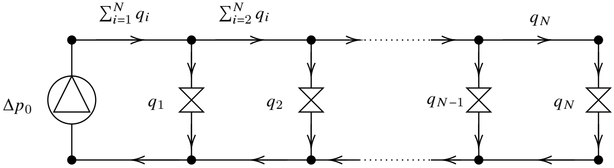
$$\text{subject to} \quad \mathbf{e}(t) = \mathbf{T}_c - \mathbf{T}(t) \tag{2}$$

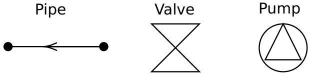
$$\mathbf{T}(t+1) = A\mathbf{T}(t) + B_1\mathbf{q}(t) + B_2 T_{\text{ext}}(t) \tag{3}$$

$$\mathbf{q}(t) \in \mathcal{Q} \tag{4}$$

Optimization over whole period and perfect system model is not feasible in practice.

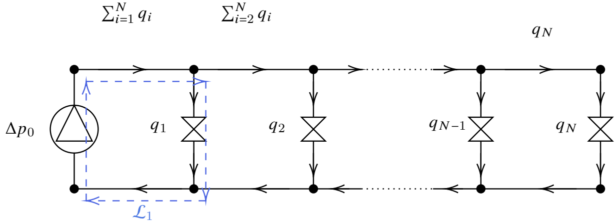
Network Structure





Component models: *Hydraulic performance optimization of meshed district heating network with multiple heat sources*, Wang, You, Zhang, Zheng, Zheng and Miao, in *Energy*, 2017.

Network Constraints

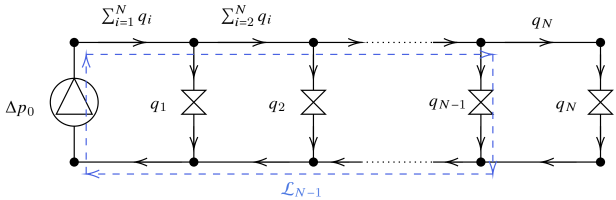


$$c_1(\sum_{i=1}^{N} q_i)^2 + c_2 + c_3 \geq a_1(\sum_{i=1}^{N} q_i)^2 + b_1^{\text{min}} q_1^2 \qquad (5)$$

---

c_i pump curve parameter, a_i and b_i resistance of pipe/valve

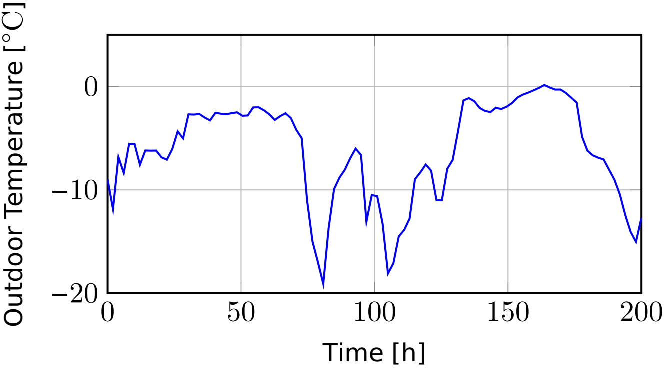
Network Constraints



$$\mathcal{Q} = \{\mathbf{q} \mid \mathbf{q} \geq 0,\ \mathbf{q}^T M_l \mathbf{q} - c_2 - c_3 \leq 0 \text{ for } l = 1 \dots N\} \quad (6)$$

$\mathcal{Q}$ is the intersection of N quadratic constraints

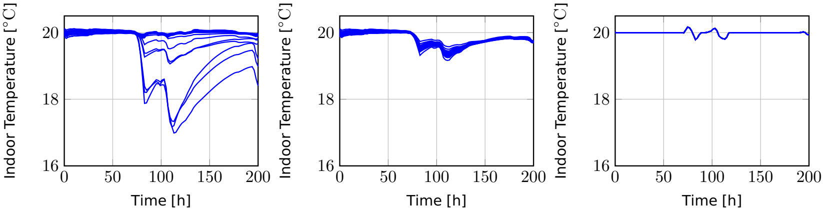
Simulation Setup



Notable: Temperature drops at 80, 110 and 200 h.

Simulation Results

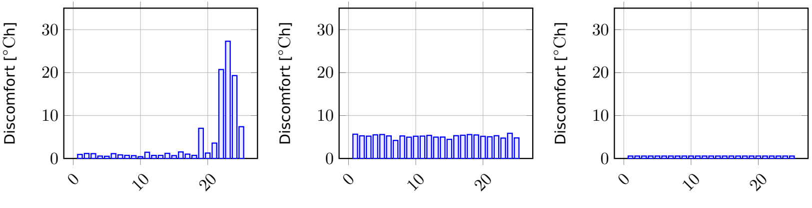
Indoor Temperatures



(a) Traditional (b) Load Coordination (c) Optimal

Simulation Results

Discomfort



(a) Traditional (b) Load Coordination (c) Optimal

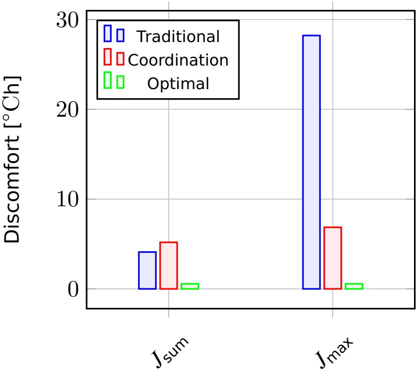
$$J_i = \sum_{t=1}^{T} |e_i(t)| t_s$$

$\mathbf{e}(t) = \mathbf{T}_c - \mathbf{T}(t)$, indoor temperature deviation

Simulation Results

$$J_{\text{sum}} = \sum_{t=1}^{T} \frac{1}{N} \sum_{i=1}^{N} |e_i(t)| t_s$$

$$J_{\text{max}} = \sum_{t=1}^{T} \max_{i} |e_i(t)| t_s$$



$\mathbf{e}(t) = \mathbf{T}_c - \mathbf{T}(t)$, indoor temperature deviation

Conclusions

- Introducing load coordination improves fairness
- IT infrastructure and a model of the distribution system required
- Even further performance possible to gain from predictive control

Outlooks:

- Data-driven model of network
- Include "charging" behavior
- Extend to more advanced local controllers, PI(D)

Thank you for your time!

Contact: *felix.agner@control.lth.se*