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Effect of control model mismatch on model predictive control performance of sensible energy storage in dwellings with a heat pump and local electricity production

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Outline

1. Introduction
2. Methods
3. Results
4. Conclusions

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1 – Outline

1. Introduction
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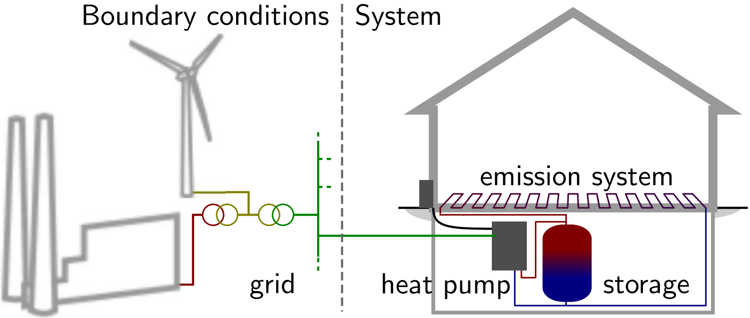
1 – System description

- Residential space heating with air coupled heatpump
- Electricity price variations correlated to wind power production
- Use of a stratified hot water storage tank as energy buffer
- Minimize space heating costs



1 – Storage tank non-linearity

Example with constant heatflow discharging, variable flow rate:

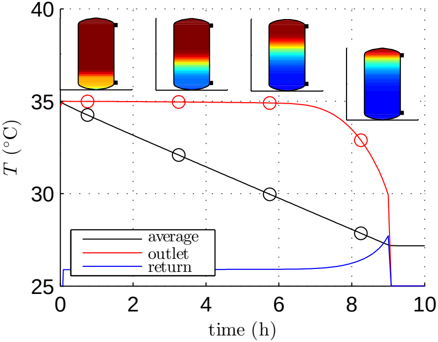
Described by:

$$C_{sto}\frac{\mathrm{d}T_{sto,avg}}{\mathrm{d}t} = \dot{Q}_{sh} - \dot{Q}_{em} \quad (1)$$

Constrained by:

$$\dot{Q}_{em} \leq (\varepsilon\dot{C})_{min}(T_{em,in} - T_{em}) \quad (2)$$

Linear only when $T_{em,in}$ is linearly dependant of $T_{sto,avg}$.



Linear description is invalid when a stratified storage is almost empty

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2 – OCP formulation

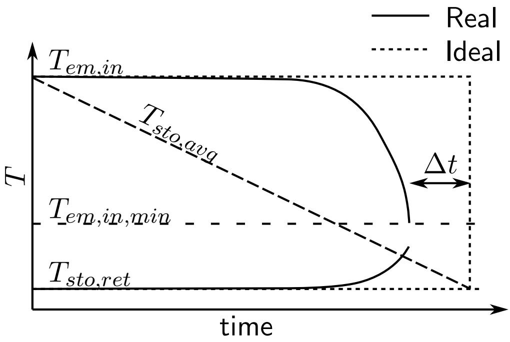
$$\min_{\dot{Q}_j^i} \quad \sum_i \dot{Q}^i_{sh,grid} p^i_{grid} + \dot{Q}^i_{sh,local} p^i_{local} + \cdots$$

s.t.

$$\begin{aligned} C_k \frac{T_k^{i+1} - T_k^i}{\Delta t} &= \mathsf{A}'_k \cdot \left(\dot{Q}^i_{sh,grid}, \dot{Q}^i_{sh,local}, \dot{Q}^i_{em}, T_k^{i+1/2}, \cdots \right)' \\ \dot{Q}^i_{sh,grid} + \dot{Q}^i_{sh,local} &<= \dot{Q}^i_{sh,max} \\ \dot{Q}^i_{em} &<= (\varepsilon \dot{C})_{min} (T^i_{em,in} - T^i_{em}) \end{aligned} \tag{3}$$

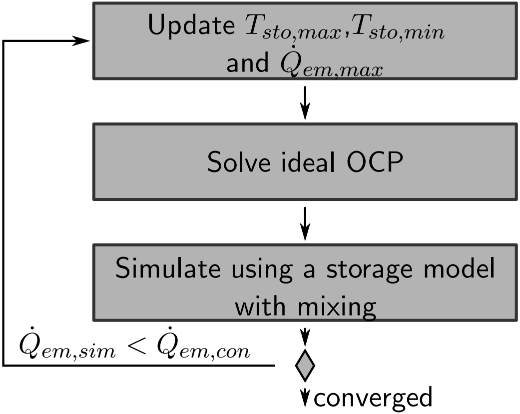
- State constraints discretized using direct collocation
- Soft constraints for operational and storage temperature
- Implemented directly in Matlab, solved by CPLEX

2 – Iterative linear optimal control



- Prediction for $T_{em,in}$ required, or
- Increase $T_{sto,avg,min}$ and reduce $\dot{Q}_{em,max}$ at times when storage is near empty
- Determine when storage is near empty using simulation

2 – Iterative linear optimal control



Update $T_{sto,max}$,$T_{sto,min}$ and $\dot{Q}_{em,max}$

Solve ideal OCP

Simulate using a storage model with mixing

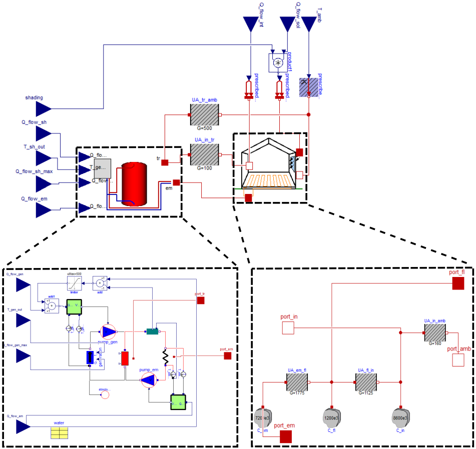
$\dot{Q}_{em,sim} < \dot{Q}_{em,con}$

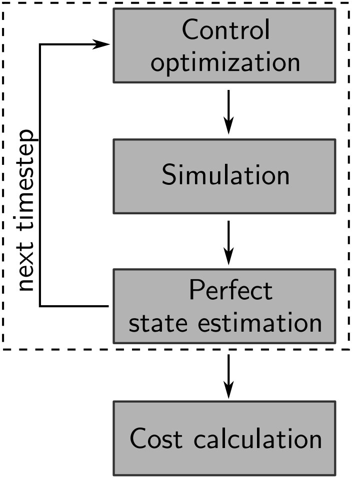
converged

In open-loop optimal control, the iterative linear program can result in around 10% decrease in total costs when required backup heating is included [1]

2 – MPC formulation

- Equal control and emulator model except for storage tank
- 3 day control horizon
- 1 hour control timestep





Control optimization

Simulation

Perfect state estimation

Cost calculation

next timestep

3 – Outline

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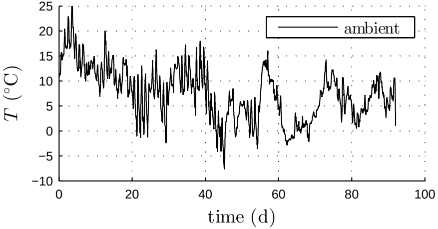
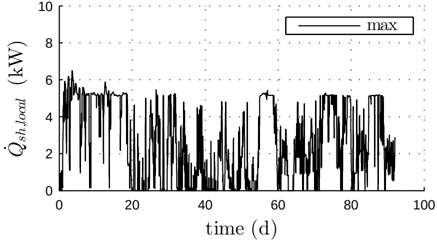
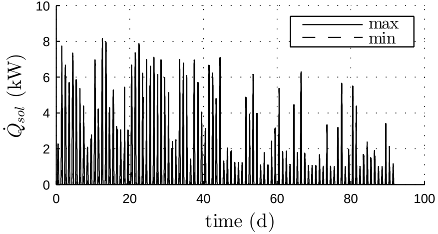
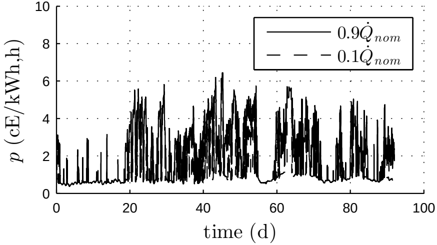
3 – Case



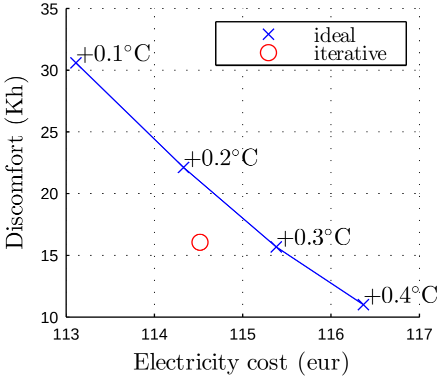






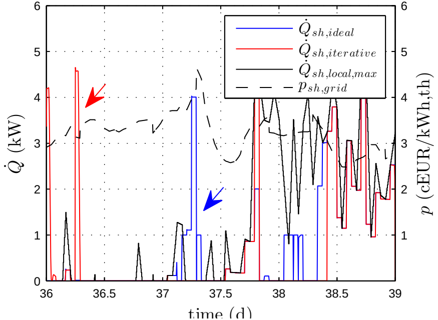
TMY October, November, December

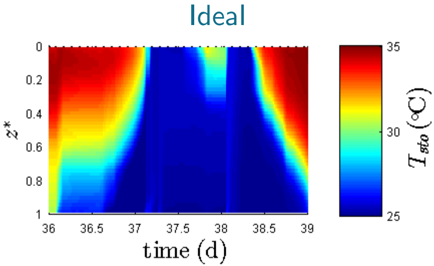
3 – Cost difference

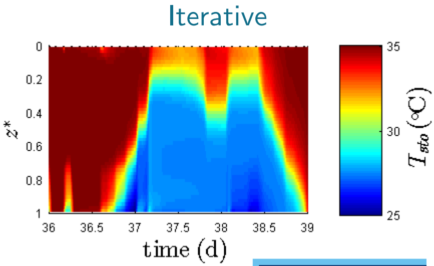


At equal discomfort, iterative solution performs only slightly better

3 – Comparison of control actions




Ideal


Iterative

Empty storage prediction

vs.

Higher average temperature

&

Perfect state estimation

3 – Discussion

- Building functions as a damper?
- How does the storage state estimation quality affect the *ideal model* performance?
  → Try less accurate estimation technique
- In the *ideal model* a different $T_{sto,min}$ estimation method will give different results.
  → Sensitivity analysis
- *Ideal model* requires tuning to achieve sufficient thermal comfort.
  → Can be made adaptive
- Similar results with different energy price scheme?
  → Try different formulations

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The use of ideal stratified storage optimal control formulations in *closed loop* model predictive control does not result in large estimation errors for energy costs

The iterative linear program results in a slightly lower energy cost and requires *less tuning* and thus is recomended for use in real-world MPC

Questions?

[1] Brecht Baeten, Rogiers Frederik, Dieter Patteeuw, and Lieve Helsen.
Comparison of optimal control formulations for stratified sensible thermal energy storage in space heating applications.
In *IEA-ECES-Greenstock*, 2015.