Karlsruher Institut für Technologie

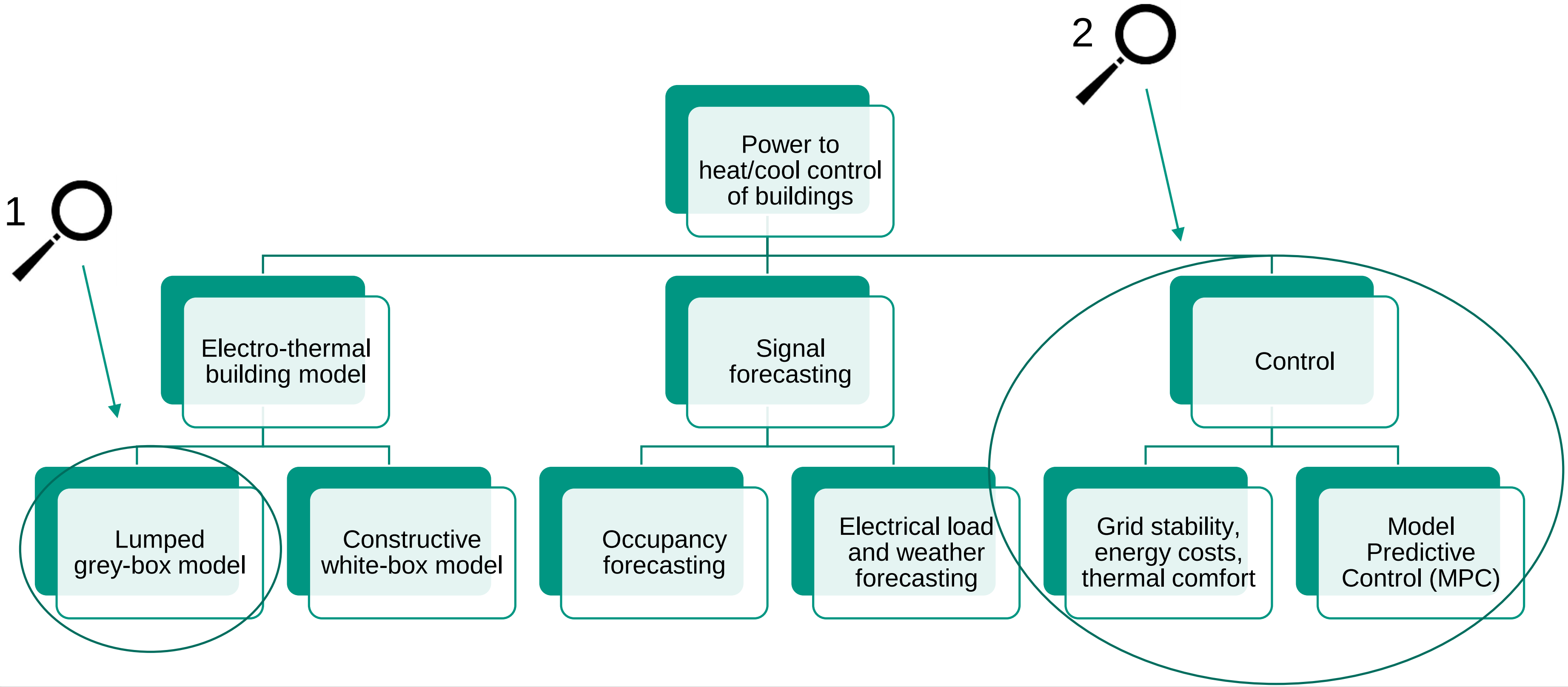
FlexKälte-Workshop: Flexibilisierung von Kälteversorgungssystemen

Thema: **Modellierung von Kälteversorgungssystemen**

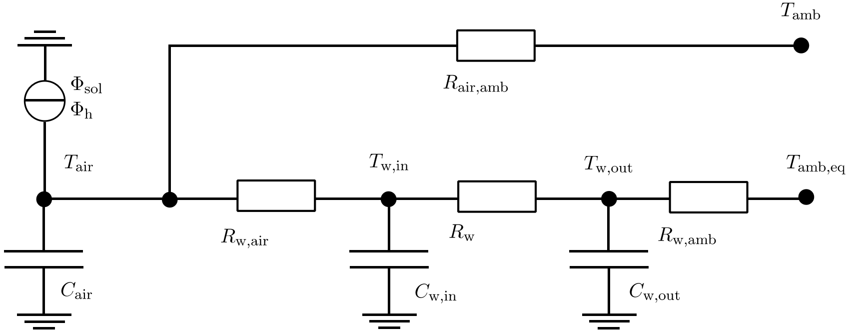
Autoren: **Moritz Frahm, Philipp Zwickel, Felix Langner**

Institut für Automation und angewandte Informatik

Introduction

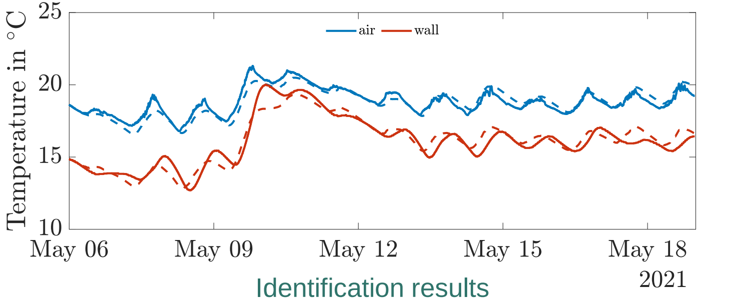


Lumped Electro-Thermal Building Model

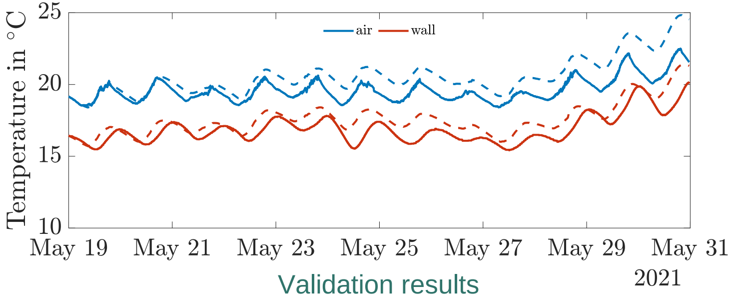


Electro-thermal building model, inspired by Harb et al. [1] and modified

Comparison of the measured temperature (solid line) with the simulated temperature (dashed line)



Identification results



Validation results

$$\frac{\mathrm{d}T_{\mathrm{air}}}{\mathrm{d}t} = \frac{1}{C_{\mathrm{air}}} \cdot \left(\frac{T_{\mathrm{w,in}} - T_{\mathrm{air}}}{R_{\mathrm{w,air}}} + \frac{T_{\mathrm{amb}} - T_{\mathrm{air}}}{R_{\mathrm{air,amb}}} + \Phi_{\mathrm{sol}} + \Phi_{\mathrm{h,air}} \right)$$

$$\frac{\mathrm{d}T_{\mathrm{w,in}}}{\mathrm{d}t} = \frac{1}{C_{\mathrm{w,in}}} \cdot \left(\frac{T_{\mathrm{air}} - T_{\mathrm{w,in}}}{R_{\mathrm{w,air}}} + \frac{T_{\mathrm{w,out}} - T_{\mathrm{w,in}}}{R_{\mathrm{w}}} + \Phi_{\mathrm{h,wall}} \right)$$

$$\frac{\mathrm{d}T_{\mathrm{w,out}}}{\mathrm{d}t} = \frac{1}{C_{\mathrm{w,out}}} \cdot \left(\frac{T_{\mathrm{w,in}} - T_{\mathrm{w,out}}}{R_{\mathrm{w}}} + \frac{T_{\mathrm{amb,eq}} - T_{\mathrm{w,out}}}{R_{\mathrm{w,amb}}} \right)$$

Corresponding differential equations

$$\Phi_{\mathrm{h,air}} = (1 - f_{\mathrm{heat,rad}})\,\Phi_{\mathrm{h}}$$

$$\Phi_{\mathrm{h,wall}} = f_{\mathrm{heat,rad}}\Phi_{\mathrm{h}}$$

$$\Phi_{\mathrm{sol}} = f_{\mathrm{sol}}\phi_{\mathrm{global}}$$

$$T_{\mathrm{amb,eq}} = T_{\mathrm{amb}} + \phi_{\mathrm{global}}\frac{a_{\mathrm{f}}}{\alpha_{\mathrm{A}}}$$

Model inputs

Economic Model Predictive Control

Optimization of cost function $l(k,y,u)$

Time-discrete state-space representation of linear, time-invariant building model

$$\min_{u(\cdot|t)} \sum_{k=t}^{N-1} l\left(k, y(k|t), u(k|t)\right)$$

subject to $\forall k \in [0, N-1]$:

$$x(k+1|t) = A_{\mathrm{d}} x(k|t) + B_{\mathrm{d}} u(k|t) + B_{\mathrm{zd}} z(k|t)$$

$$y(k|t) = C_{\mathbf{d}} x(k|t)$$

$$x(0|t) = x(t),\ u(k|t) \in \mathcal{U},\ y(k|t) \in \mathcal{Y}$$

$$l(k,y,u) = \lambda(y-\tilde{y})^T(y-\tilde{y}) + (1-\lambda)p(k)^T u,$$

Model-predictive optimal-control algorithm, based on Zwickel et al. [2]

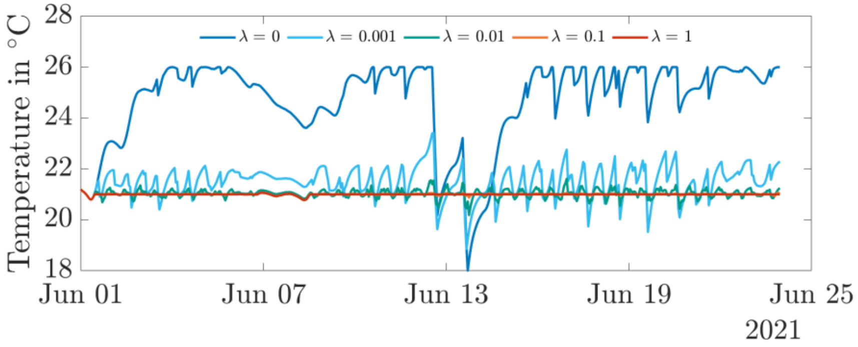
Temperature tracking $\tilde{y} = 21°C$

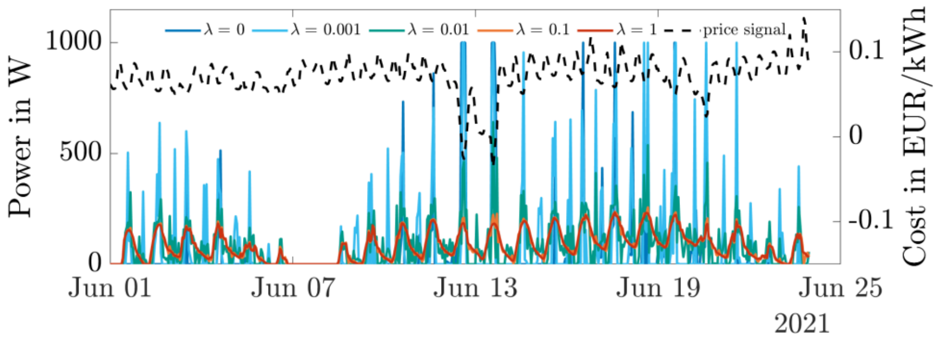
Boundaries

$u_{min} = 0\ kW$
$u_{max} = 1\ kW$

$y_{min} = 18°C$
$y_{max} = 26°C$

Energy cost





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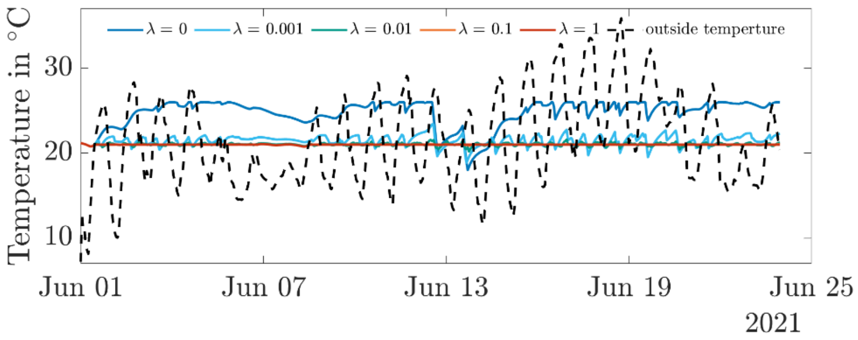

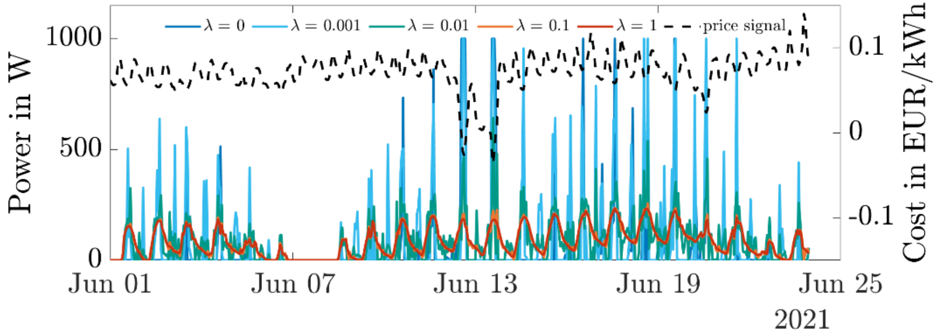

Discussion & Outlook

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- Easily applicable tools for modeling and control
  - application on various buildings
  - sufficient accuracy of model for control (closed loop)

- Direct consideration of measure-able and predict-able signals
  - weather
  - energy price
  - occupancy

- Limitations
  - simulation-based results
  - linear-time-invariant model
  - simplified solar signal

- Future work
  - real-world application
  - release of open-source toolbox
  - model and control complexity

Sources, Tools and Practical Application

- Literature sources

  - [1] Hassan Harb, Neven Boyanov, Luis Hernandez, Rita Streblow, and Dirk Müller. 2016. Development and validation of grey-box models for forecasting the thermal response of occupied buildings. Energy and Buildings 117 (2016), 199–207. https://doi.org/10.1016/j.enbuild.2016.02.021
  - [2] Philipp Zwickel, Alexander Engelmann, Lutz Gröll, Veit Hagenmeyer, Dominique Sauer, and Timm Faulwasser. 2019. A Comparison of Economic MPC Formulations for Thermal Building Control. In 2019 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe). IEEE, 1–5. https://doi.org/10.1109/ISGTEurope.2019.8905593
  - [3] Joel A E Andersson, Joris Gillis, Greg Horn, James B Rawlings, and Moritz Diehl. 2019. CasADi – A software framework for nonlinear optimization and optimal control. Mathematical Programming Computation 11, 1 (2019), 1–36. https://doi.org/10.1007/s12532-018-0139-4

- Tools
  - Matlab System Identification toolbox: https://de.mathworks.com/help/ident/index.html
  - Matlab Symbolic Math toolbox: https://de.mathworks.com/products/symbolic.html
  - CasADi efficient optimal control software: https://web.casadi.org/
- Practical Application
  - We are planning the release of the toolbox & paper ☺ https://github.com/Building-Measurement-to-Control-Toolbox