Karlsruher Institut für Technologie

20.11.2020

Energie und Umwelt – Meine Idee für morgen

Model Predictive Control Strategies for Power to Heat of Buildings

Institut für Automation und angewandte Informatik

ENERGY LAB 2.0

Motivation

- **EU Green Deal**
  - first climate neutral continent by 2050
  - target: net-zero greenhouse gas emissions (GHE)
  - more than 75% of GHE result from energy production and use
  - building sector: 40% of consumed energy

- **Demand for research in energy and buildings**
  - buildings' energy demand: mostly heat
  - energy-efficient heat generation: heat pump
  - possibility for intelligent sector coupling (Power to Heat "*P2H*") and control strategies

- **Heat pumps can benefit the power grid**
  - stabilize the power grid frequency by following a power demand signal (match electricity generation)
  - importance for grid stabilization: ongoing integration of volatile, renewable energy sources (wind, solar)
  - service quality depends on heat pump's available capacity to store energy

- **Utilize buildings as thermal energy storage**
  - cost-efficient alternative to typical storages like water tanks or batteries
  - identification of this usually unused capacity: dynamic thermal building model

Model

- **Lumped Capacitance Model**

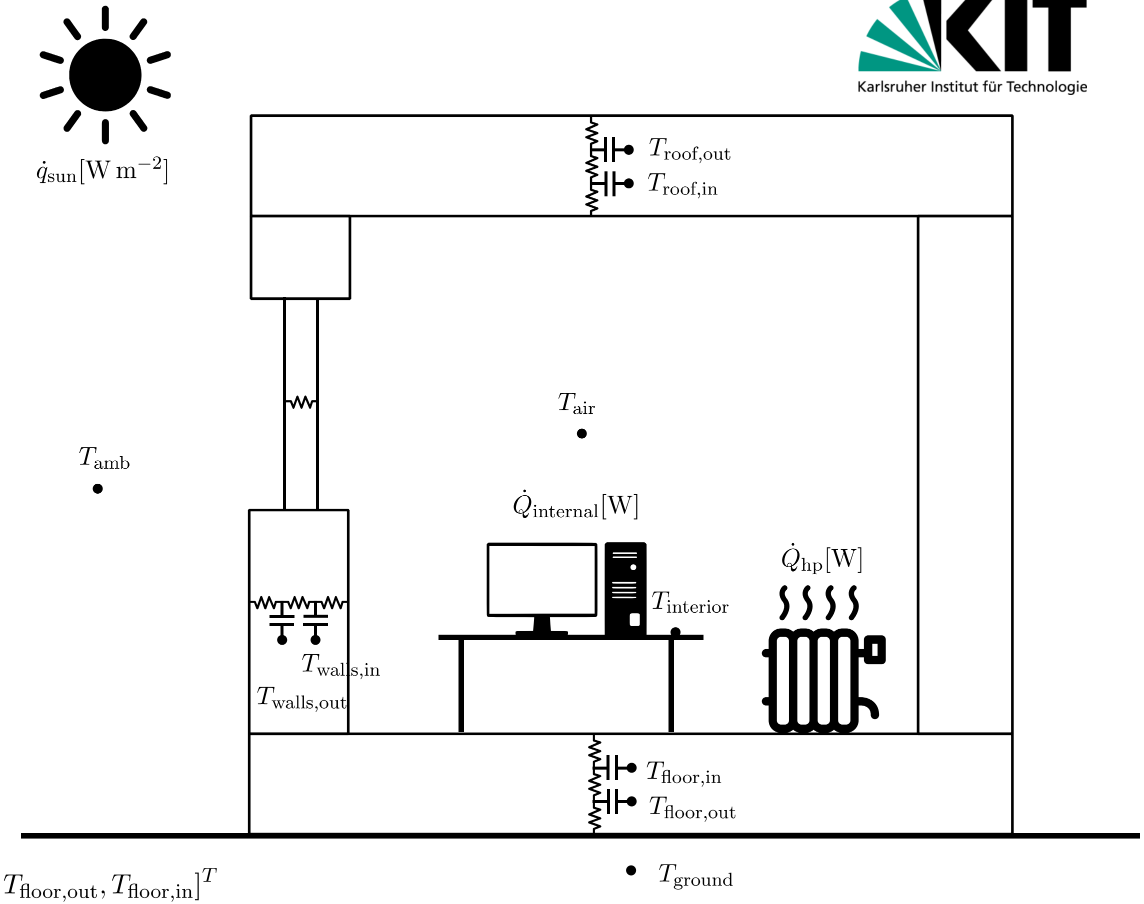
$$C_i \frac{dT_i}{dt} = \sum_j \dot{Q}_{i,j} + \sum_k \dot{Q}_{i,k}$$

$$\dot{Q}_{i,k} = \frac{T_k - T_i}{R_{i,k}}$$

- **State-Space notation of LTI system**

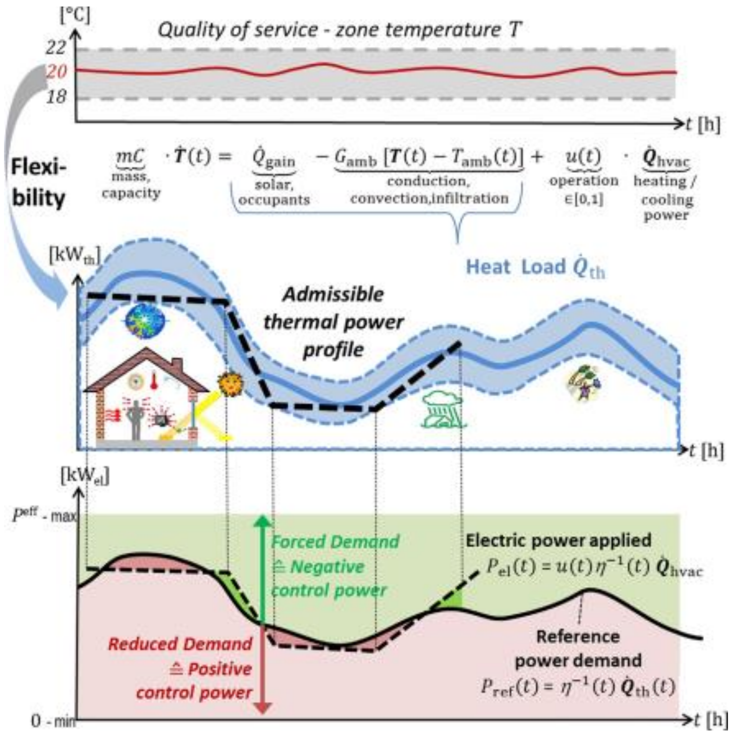
$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}_\mathrm{u} u(t) + \mathbf{B}_{\mathbf{z}_m} \mathbf{z}_\mathrm{m}(t)$$
$$y(t) = \mathbf{C}\mathbf{x}(t)$$
$$\mathbf{x}(0) = \mathbf{x_0}$$

$$u = \dot{Q}_\mathrm{hp}$$
$$\mathbf{z}_\mathrm{m} = [\dot{q}_\mathrm{sun}, \dot{Q}_\mathrm{internal}, T_\mathrm{amb}, T_\mathrm{ground}]^T$$
$$y = T_\mathrm{air}$$



$$\mathbf{x} = [T_\mathrm{air}, T_\mathrm{interior}, T_\mathrm{walls,out}, T_\mathrm{walls,in}, T_\mathrm{roof,out}, T_\mathrm{roof,in}, T_\mathrm{floor,out}, T_\mathrm{floor,in}]^T$$

Control



- **Model Predictive Control**
  - minimize the input u in a cost functional l
  - cost factors w_1, w_2, w_3, w_4 weigh up the various optimization goals:
    - follow reference temperature signal y_r
    - reduce energy consumption u
    - reduce energy costs (p : energy price function)
    - follow reference power signal u_r

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

$$\mathbf{x}(k+1|t) = \mathbf{A}\mathbf{x}(k|t) + \mathbf{B}_{\mathrm{u}} u(k|t) + \mathbf{B}_{\mathbf{z}_m} \mathbf{z}_{\mathrm{m}}(k|t)$$

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

$$l(k, y, u) = w_1 (y_{\mathrm{r}} - y)^T (y_{\mathrm{r}} - y) + w_2 u^T u + w_3 p(k)^T u + w_4 (u_{\mathrm{r}} - u)^T (u_{\mathrm{r}} - u)$$

Literature

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