Automatic Thermal Model Identification and Distributed Optimisation for Load Shifting in City Quarters

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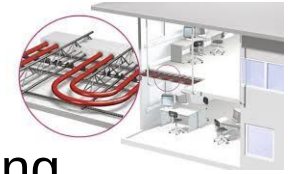
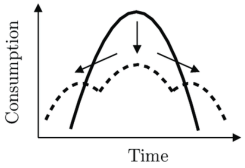
Introduction

- Modern buildings are often equipped with **t**hermally **a**ctivated **b**uilding **s**ystems (TABS) or floor heating systems



- Thermal inertia offers significant potential for load shifting

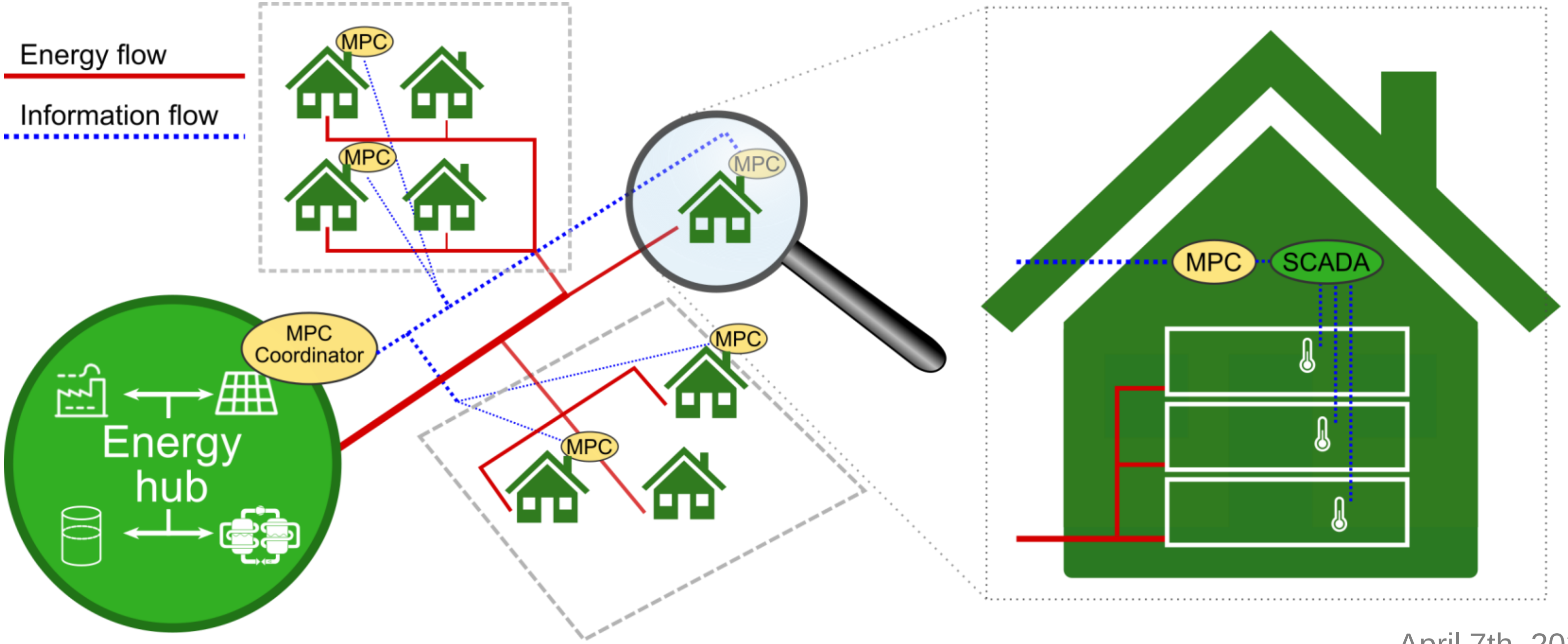
- Using **m**odel **p**redictive **c**ontrol (MPC) can leverage this potential e.g. for peak load reduction to best support an energy hub



- However, an MPC requires
  - models of all thermal zones within the building(s), and
  - a solver which can handle many zones at the same time

Introduction cont.

- Every thermal zone is optimised on its own
- Central coordinator orchestrates load shifting



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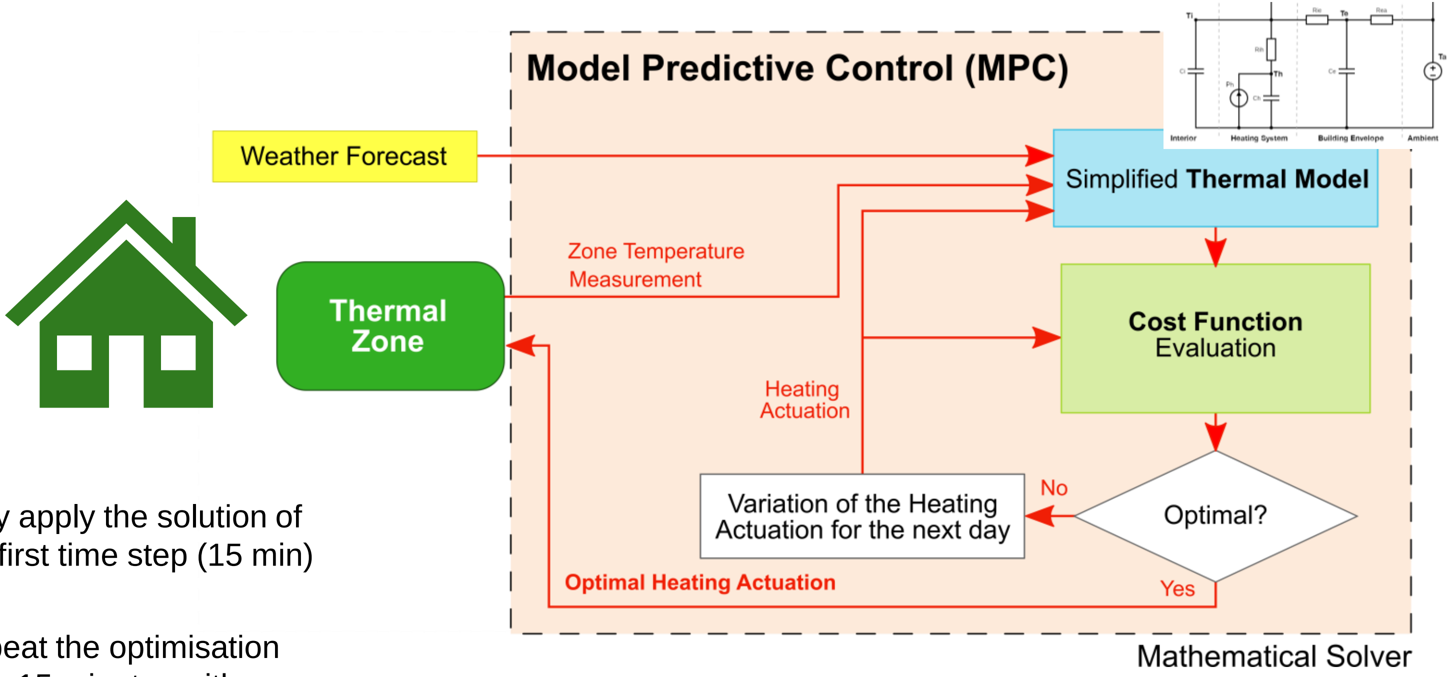
Model predictive control (MPC)



- Only apply the solution of the first time step (15 min)
- Repeat the optimisation after 15 minutes with new measurements and forecasts

Model predictive control (MPC) – Building Model

- We want to control the temperature of a single thermal zone:

Ambient temperature T_a →

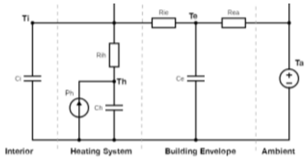
Solar irradiance I_g →

(Constant) influence β →

Feed temperature T_f →

Heating actuation u_h (control variable) →

→ Inner zone temperature T_i



→ RC-equivalent model

$$\frac{dT_\mathrm{i}}{dt} = \lambda_\mathrm{ei}(T_\mathrm{e} - T_\mathrm{i}) + \lambda_\mathrm{hi}(T_\mathrm{h} - T_\mathrm{i}) + \beta + \alpha_\mathrm{north} I_\mathrm{g,north} + \alpha_\mathrm{east} I_\mathrm{g,east} + \alpha_\mathrm{south} I_\mathrm{g,south} + \alpha_\mathrm{west} I_\mathrm{g,west}$$

→ Zone temperature

$$\frac{dT_\mathrm{e}}{dt} = \lambda_\mathrm{ie}(T_\mathrm{i} - T_\mathrm{e}) + \lambda_\mathrm{ae}(T_\mathrm{a} - T_\mathrm{e})$$

→ Mean envelope temperature

$$\frac{dT_\mathrm{h}}{dt} = \lambda_\mathrm{ih}(T_\mathrm{i} - T_\mathrm{h}) + \lambda_\mathrm{h}(T_\mathrm{f} - T_\mathrm{h})u_\mathrm{h}$$

→ TABS/floor temperature

11 model parameters

Model Identification

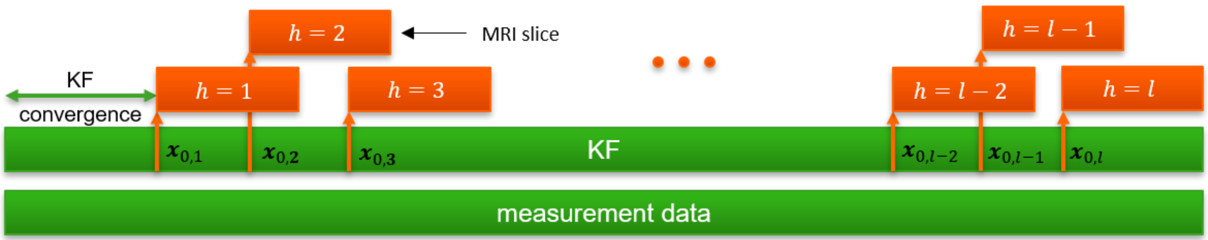
- Model parameters of the thermal zone model are unknown

- Existing solutions usually
  - require knowledge about the building construction,
  - are not optimised for the use within an MPC and
  - neglect the heating feed temperature and (constant) gains

- Hence, an identification method is proposed which
  - overcomes the mentioned problems of existing solutions, and
  - only requires measurement data of about one month where a conventional control heating system was used (e.g., PI controller)

Model Identification cont.

- **M**odel predictive **r**elevant **i**dentification (MRI) is used to optimise a multi-step-ahead prediction model
- Reduction of computational effort: measurement data is split into $h = 1 \ldots l$ slices of the same length as the MPC horizon
- Least square fit (zone temperature) for each slice is optimised
- Start values $x_{0,\mathrm{h}}$ are obtained from a Kalman Filter (KF)



Distributed Optimisation

- **Goal:** Leverage load shifting potential of every thermal zone to flatten the overall load profile
- **How:** Manipulate heating actuation while maintaining comfort

MPC cost function:

$$\min_{\substack{x_{j,k}, \alpha_{j,k}, u_{j,k}, \\ \dot{Q}_{\min}, \dot{Q}_{\max}, \\ \dot{Q}_{\text{total},k}}} \sum_{j=1}^{N} \left(c_{\text{ref}} \| T_{\text{i},j,k} - T_{\text{ref},j,k} \|_1 + c_{\text{comf}} \| T_{\text{i},j,k} - \alpha_{j,k} \|_1 \right) + c_{\text{flat}} (\dot{Q}_{\max} - \dot{Q}_{\min})$$

s.t.

$$\boldsymbol{x}_{j,k+1} = \boldsymbol{x}_{j,k} + T_s \boldsymbol{f}(\boldsymbol{x}_{j,k}, u_{j,k}, \boldsymbol{D}_k, \boldsymbol{\Theta}_j), \quad \boldsymbol{x}_{j,1} = \boldsymbol{x}_j^0 \;\; \forall k, j$$

$$T_{\text{i},j,\text{lb}} \leq \alpha_{j,k} \leq T_{\text{i},j,\text{ub}} \;\; \forall k, j$$

$$\dot{Q}_{\text{total},k} = \sum_{j=1}^{N} \dot{Q}_{j,\max} u_{j,k}, \qquad \dot{Q}_{\min} \leq \dot{Q}_{\text{total},k} \leq \dot{Q}_{\max} \;\; \forall k$$

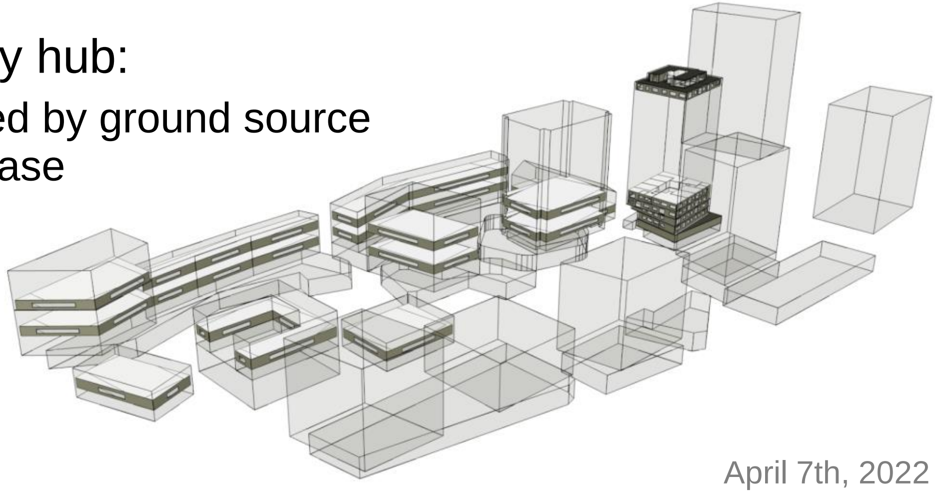
- **Problem:** Buildings consist of many zones

  → Central optimisation too complex and not scalable

- **Solution:** Distributed optimisation can split problem into many sub-problems which can be solved separately (e.g. using ADMM)

Preliminary case study

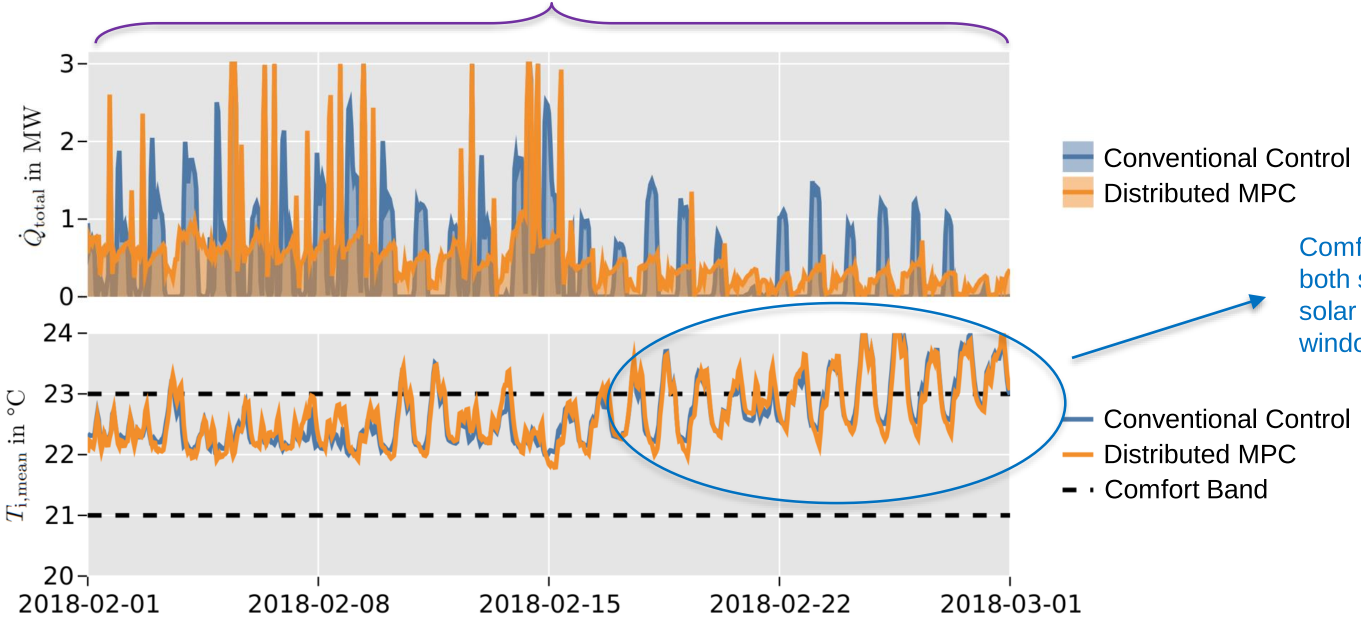
- Considered City Quarter: Quarter 1 of Graz Reininghaus
- Co-Simulation:
  - Building: EQUA IDA ICE model with 36 zones with floor heating (not TABS!)
  - MPC: Julia Programming Language
  - Timespan: February 2018
- Economic evaluation of energy hub:
  - Demand up to 1 MW_{th} covered by ground source heat pump with a fixed purchase tariff of 25 €/MW_{th}
  - Demand over 1 MW_{th} covered by district heating with a fixed purchase tariff of 62 €/MW_{th}



Case study results

- Two scenarios:
  - without the distributed MPC, i.e., with conventional PI zone controllers
  - with the proposed distributed MPC

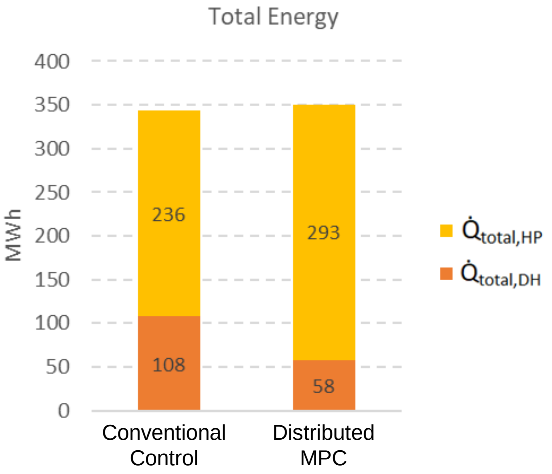
Sharp peaks (present in both scenarios, orange overlays blue) are un-controllable demands from commercial zones

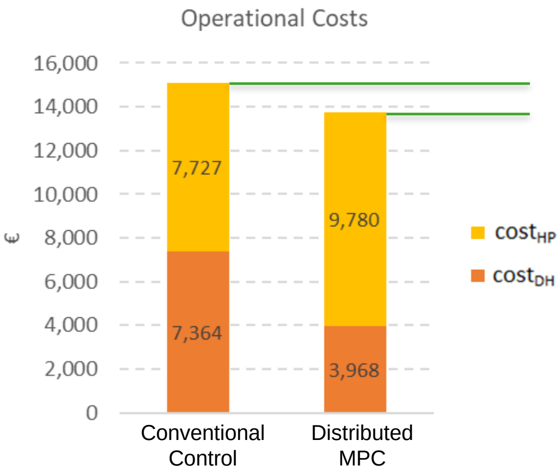


Comfort Band violated for both scenarios due to high solar irradiances through windows

Case study results cont.

- Total energy demand is approx. the same for both scenarios
- <u>Operational costs reduced by 9%</u> when using the distributed MPC (higher share of heat from heat pump)





9% cost savings

Summary and Outlook

- **Summary:**
  - Distributed MPC reduced operational costs by 9%
  - Same comfort with floor heating system in both scenarios
    → MPC is expected to improve comfort for TABS
  - Fully automatic identification of required MPC models
  - Computational effort can be distributed, i.e., is scalable

- **Outlook:**
  - Further simulation studies considering longer time periods
  - Inclusion of cooling via TABS and floor heating system

- **Final Workshop:**
  - Fr. **16th of September, 2022** 9:00 – 11:00 AM
  - TU Graz FSI, Inffeldgasse 11, 8010 Graz
  - best-research.eu/content/de/kompetenzbereiche/alle_projekte/view/637

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