



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

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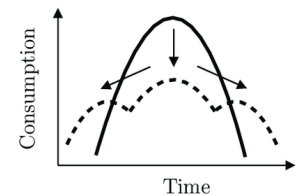
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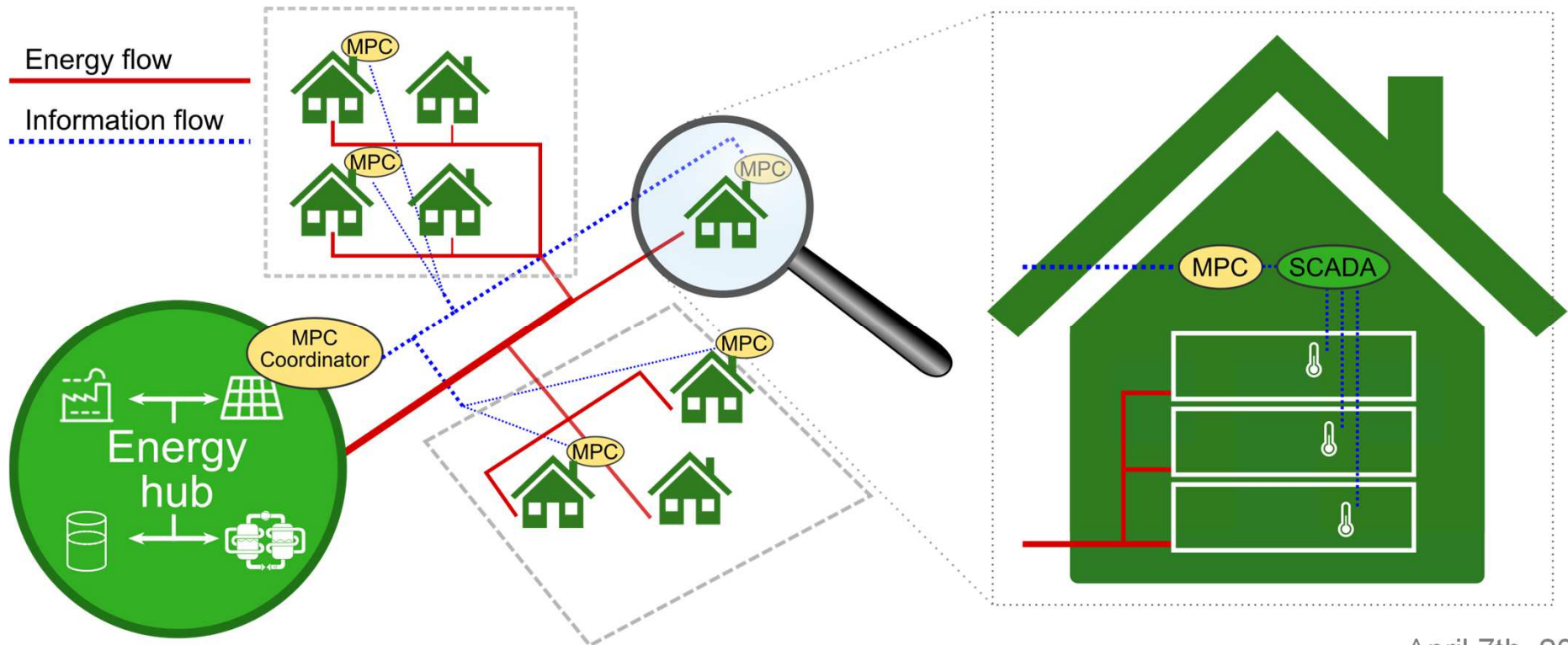
Introduction

- Modern buildings are often equipped with **thermally activated building systems (TABS)** or **floor heating systems**
- Thermal inertia offers significant potential for load shifting
- Using **model predictive control (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



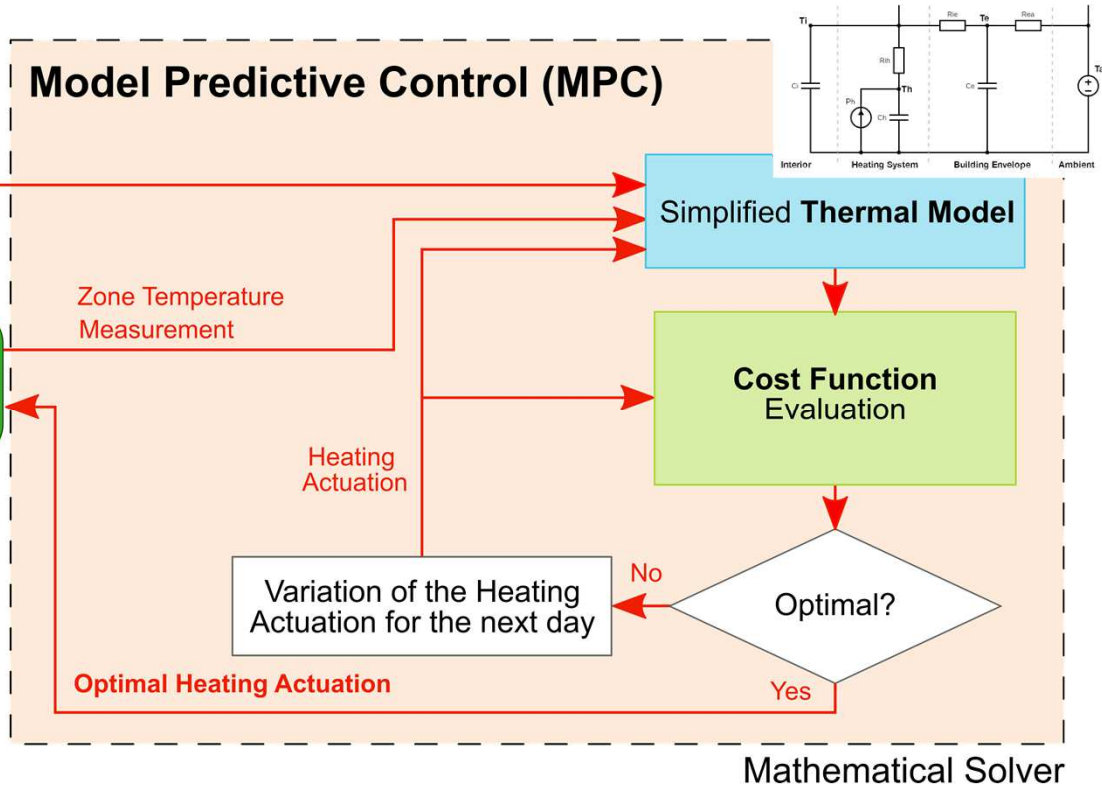
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Model predictive control (MPC)



Thermal Zone

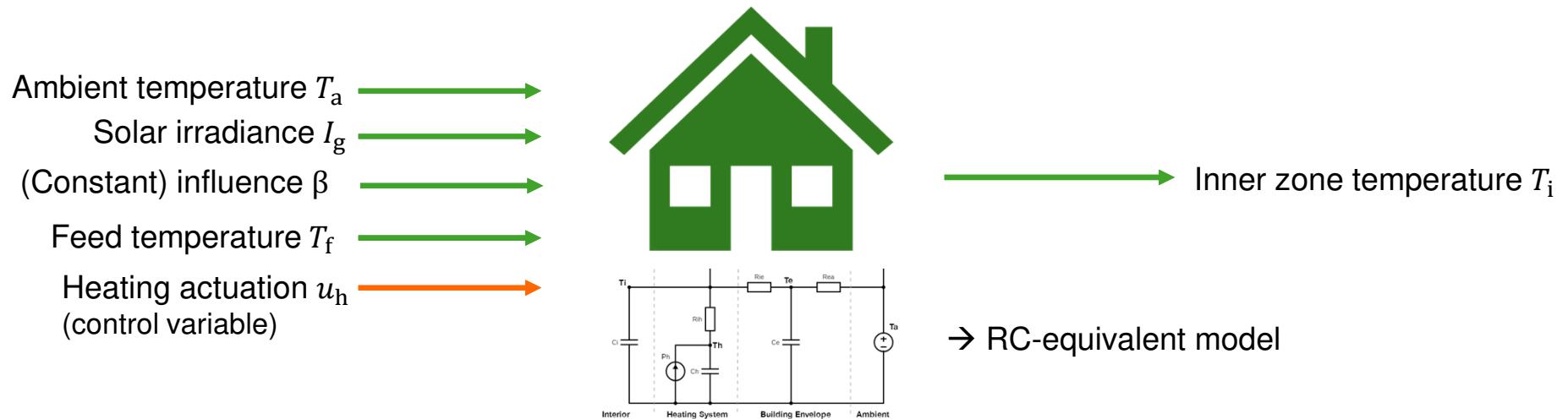
Weather Forecast



- 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:



$$\frac{dT_i}{dt} = \lambda_{ei}(T_e - T_i) + \lambda_{hi}(T_h - T_i) + \beta + \alpha_{north} I_{g,north} + \alpha_{east} I_{g,east} + \alpha_{south} I_{g,south} + \alpha_{west} I_{g,west} \rightarrow \text{Zone temperature}$$

$$\frac{dT_e}{dt} = \lambda_{ie}(T_i - T_e) + \lambda_{ae}(T_a - T_e) \rightarrow \text{Mean envelope temperature}$$

$$\frac{dT_h}{dt} = \lambda_{ih}(T_i - T_h) + \lambda_h(T_f - T_h)u_h \rightarrow \text{TABS/floor temperature}$$

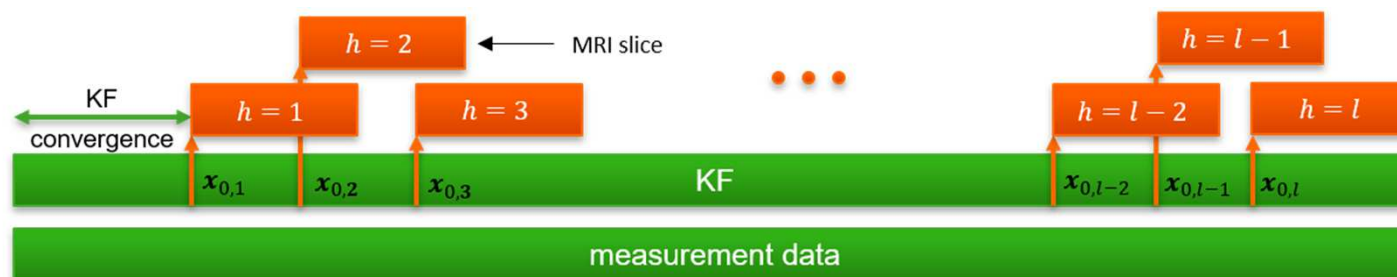
11 model parameters

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.

- **Model predictive relevant identification (MRI)** is used to optimise a multi-step-ahead prediction model
- Reduction of computational effort: measurement data is split into $h = 1 \dots l$ slices of the same length as the MPC horizon
- Least square fit (zone temperature) for each slice is optimised
- Start values $x_{0,h}$ 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:

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

$$\text{s.t. } \mathbf{x}_{i,k+1} = \mathbf{x}_{i,k} + T_s \mathbf{f}(\mathbf{x}_{j,k}, u_{j,k}, \mathbf{D}_k, \boldsymbol{\Theta}_j), \quad \mathbf{x}_{j,1} = \mathbf{x}_j^0 \quad \forall k, j$$

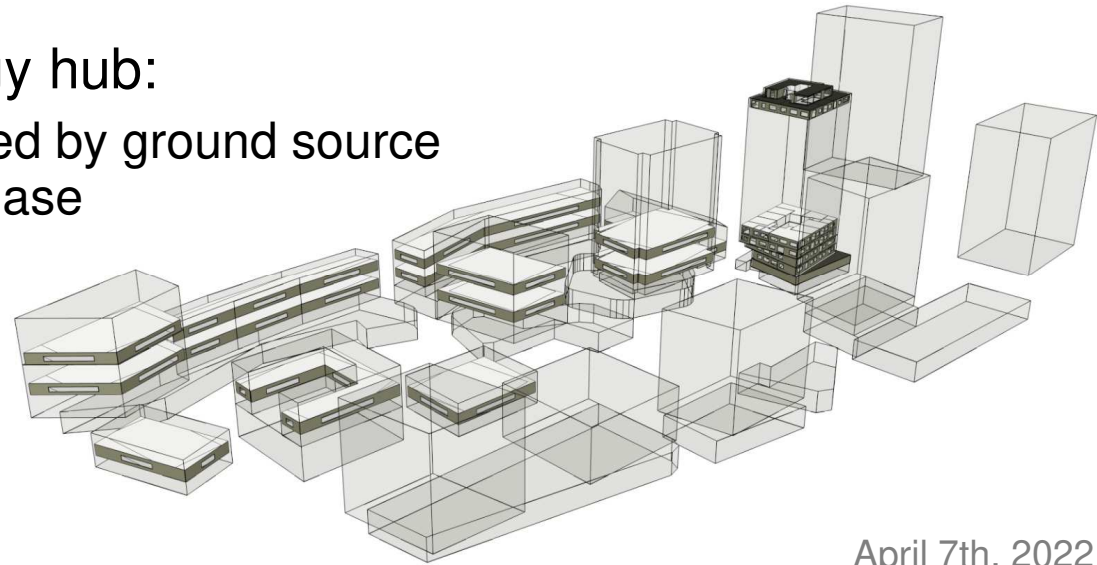
$$T_{i,j,\text{lb}} \leq \alpha_{j,k} \leq T_{i,j,\text{ub}} \quad \forall k, j$$

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

- **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}

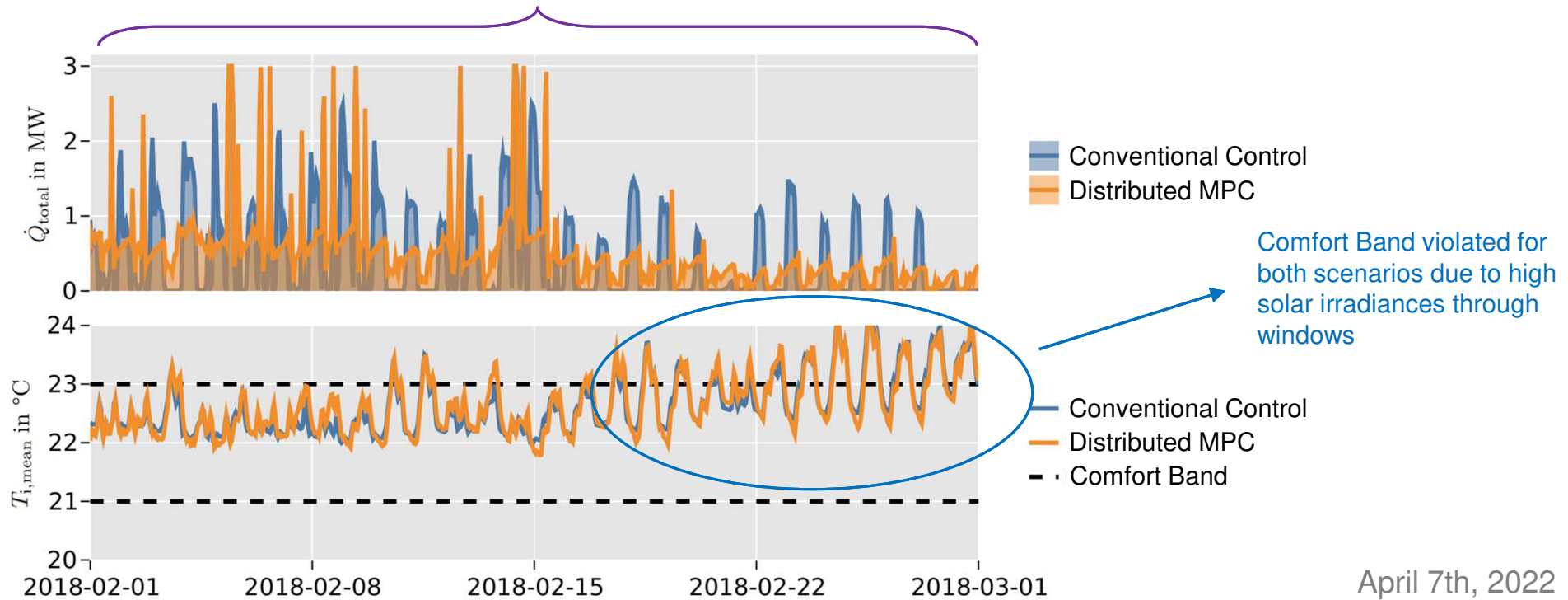


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Case study results

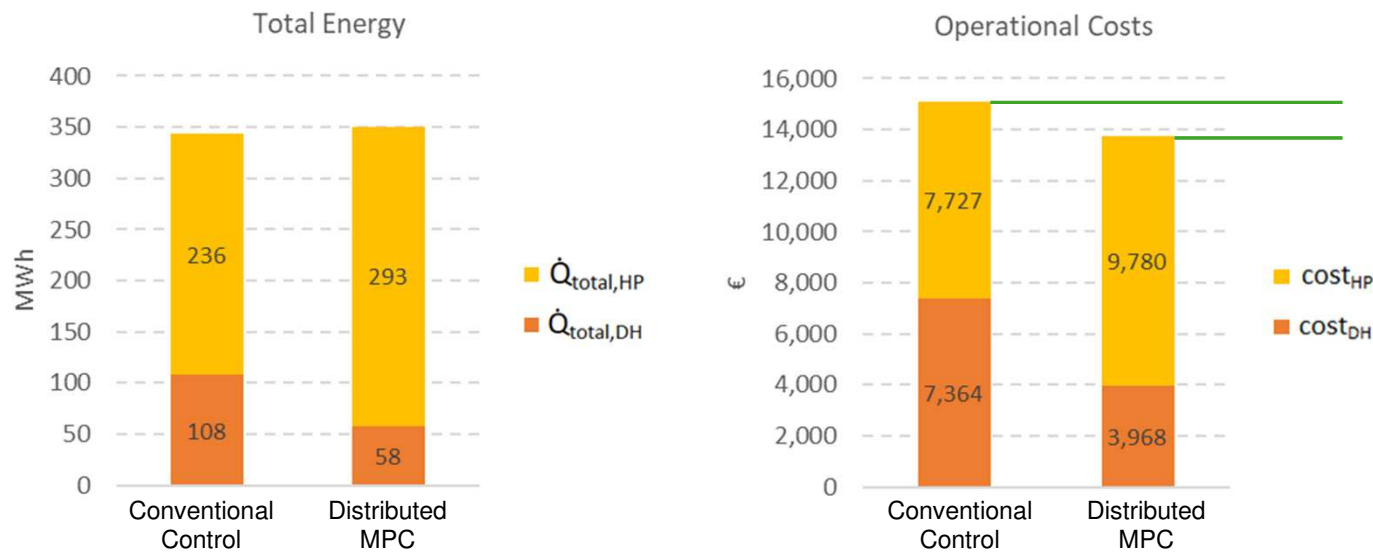
- Two scenarios:
 - without the distributed MPC, i.e., with conventional PI zone controllers
 - with the proposed distributed MPC

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



Case study results cont.

- Total energy demand is approx. the same for both scenarios
- Operational costs reduced by 9% 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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