Smart System Integration of Waste Heat Recovery, Heat Pumps and PV to unlock the Energy Potential of Thermal Baths

11th International Conference on **Smart Energy Systems**

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Motivation: Thermal Baths in Austria

Very energy intensive
- Heating, often via gas boilers
- Cooling, often via chillers
- Electrical energy

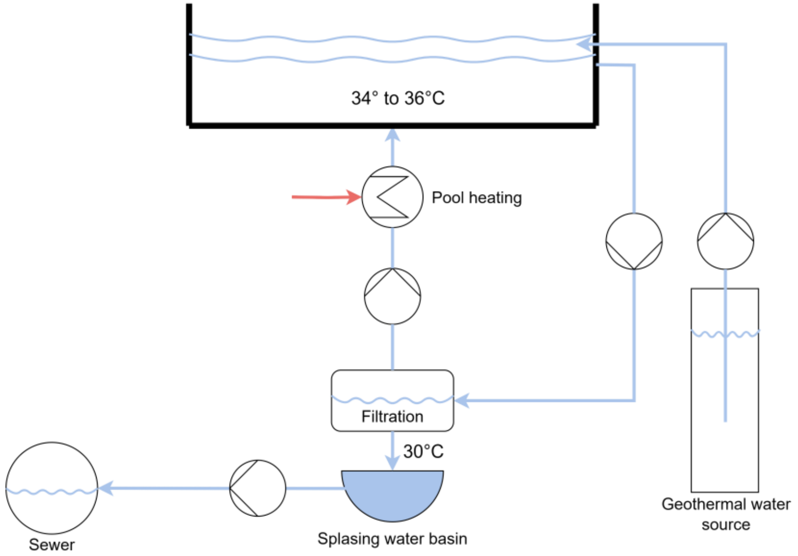
But: Cheap heat source available
- 32°C to 104°C
  (from a depth of 500 m to 3200 m)

Note
Huge potential for waste heat recovery


REDUCE Hotel Vital

Waste Heat Potential in Thermal Baths

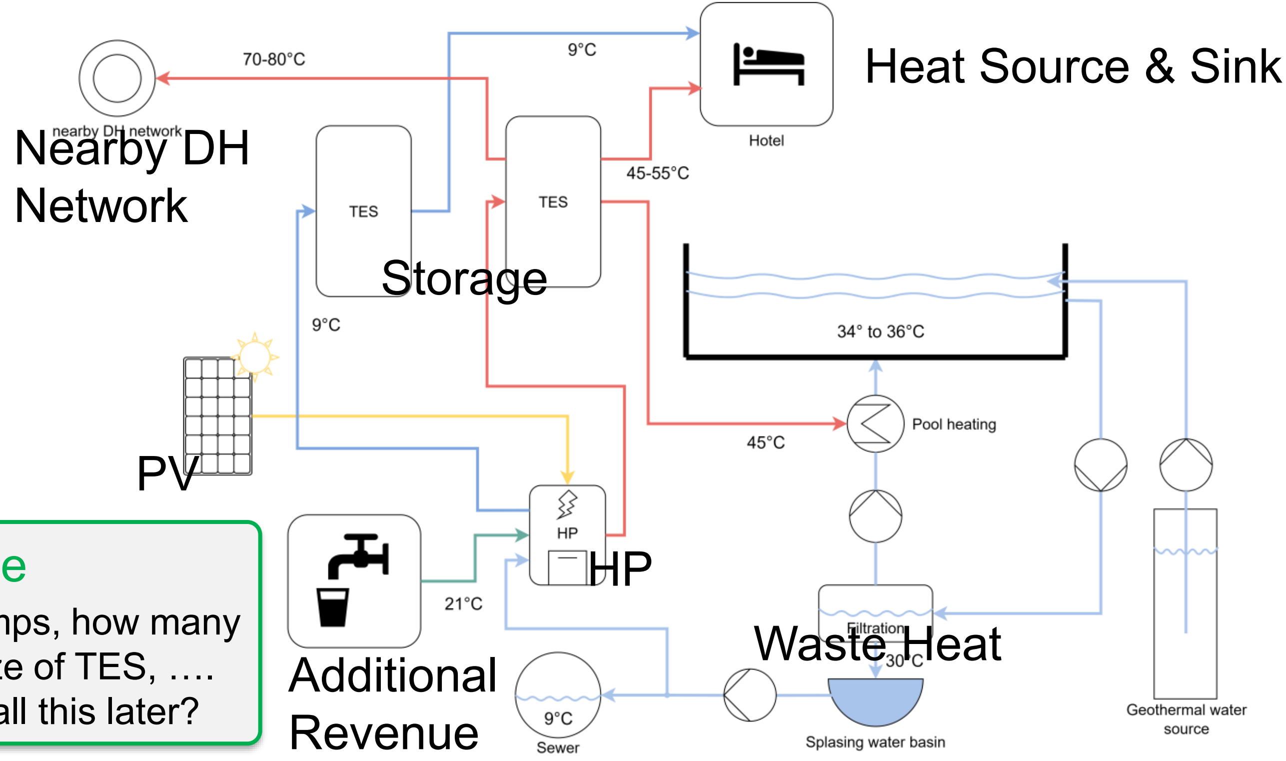
- **Splashing water** of pools is typically 30°
- Needs to cool down and degas (chlorine) before being dumped in the sewer



Idea

Utilize splashing water with heat pumps

An Integrated Energy System Utilizing Waste Heat and PV in Thermal Baths



! Challenge

Which heat pumps, how many heat pumps, size of TES, ….
How to control all this later?

Scenario Simulation and Control of Hybrid Energy Systems

Idea

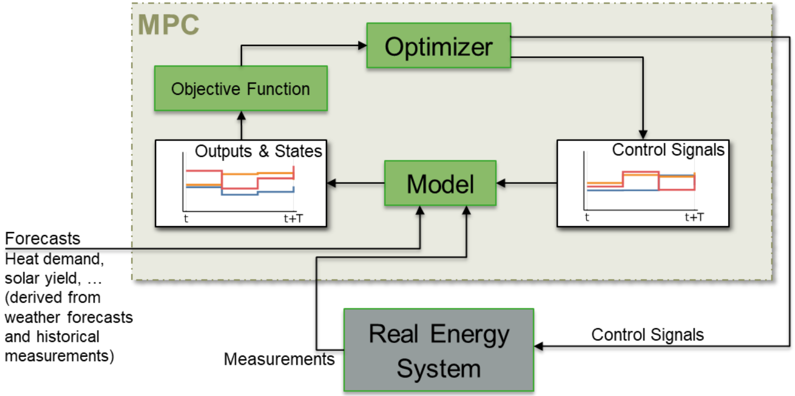
- Use holistic Model Predictive Control-based approach for control
- Perform scenario simulations and help design the system

Challenge

- Needs quite high model fidelity, especially thermal aspects
  - Temperature dependent COPs
  - Varying temperatures,…

! Solution

Multi-Temperature model for Model Predictive Control



! Note

Can be applied to many energy systems, e.g. DH networks[1] and buildings[2]

[1] Kaisermayer, V., et al. (2022). Smart control of interconnected district heating networks on the example of "100% Renewable District Heating Leibnitz." Smart Energy, 6. https://doi.org/10.1016/j.segy.2022.100069

[2] Kaisermayer, V., et al. (2024). Predictive building energy management with user feedback in the loop. *Smart Energy*, 100164. https://doi.org/10.1016/J.SEGY.2024.100164

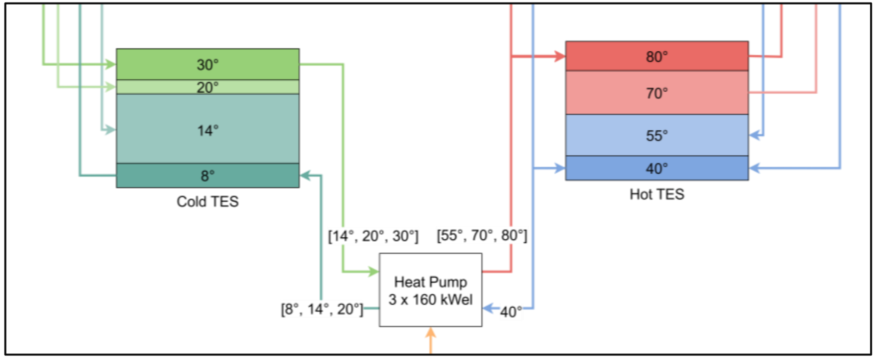
A Multi-Temperature Representation for Linear MPCs

Goal

- Stay within linear MPC (MILP) complexity
- Capture dependency on temperature
  - COP, Efficiency, …
- TES with stratification

Idea

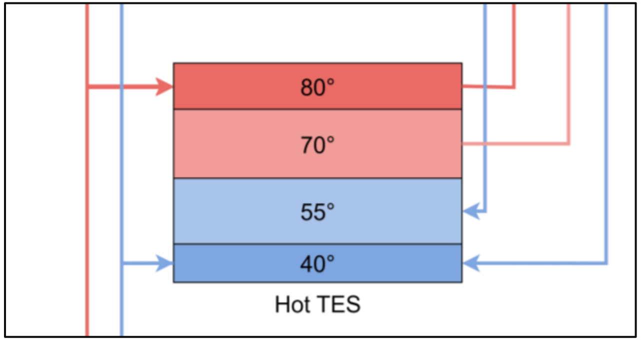
- Discretize fluid flow into **discrete temperatures**[3] → "Multi-Temperature"
- Model nonlinear relations with **convex combination**



[3] Muschick, D., et al. (2022). A multi-layer model of stratified thermal storage for MILP-based energy management systems. *Applied Energy*, *314*, 118890. https://doi.org/10.1016/j.apenergy.2022.118890

Example: Stratified Thermal Energy Storage (TES) and Heat Pump Model

- State is mass of water at different (constant) temperatures
- Allows us to model all major effects



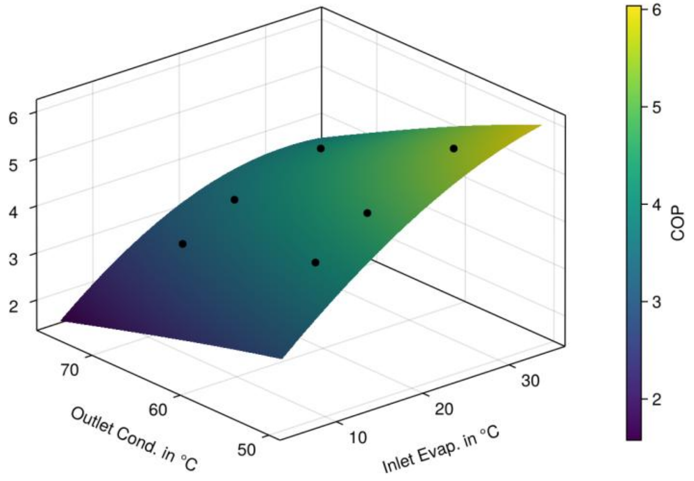
$$\dot{Q}_{\text{cond}} = \text{COP}(T_{\text{in,evap}}, T_{\text{out,cond}}) \cdot P_{\text{el}}$$
$$\dot{Q}_{\text{cond}} + \dot{Q}_{\text{evap}} + P_{\text{el}} = 0$$

- Constrain feasible operating points
$$(T_{\text{in,evap}}, T_{\text{out evap}}, T_{\text{in cond}}, T_{\text{out,cond}})$$

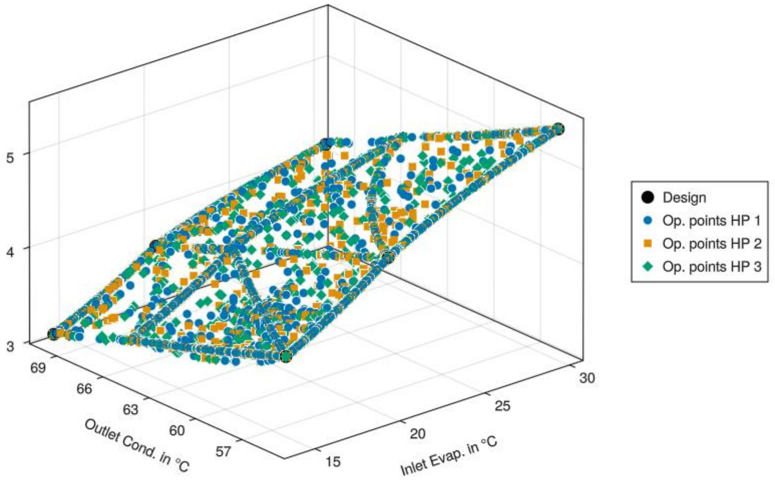
- Per operating point $\text{COP} = \text{const.}$
- Linear model per operating point
- Interpolation between operating points with convex combination

Example: Multi-Temp Heat Pump Model

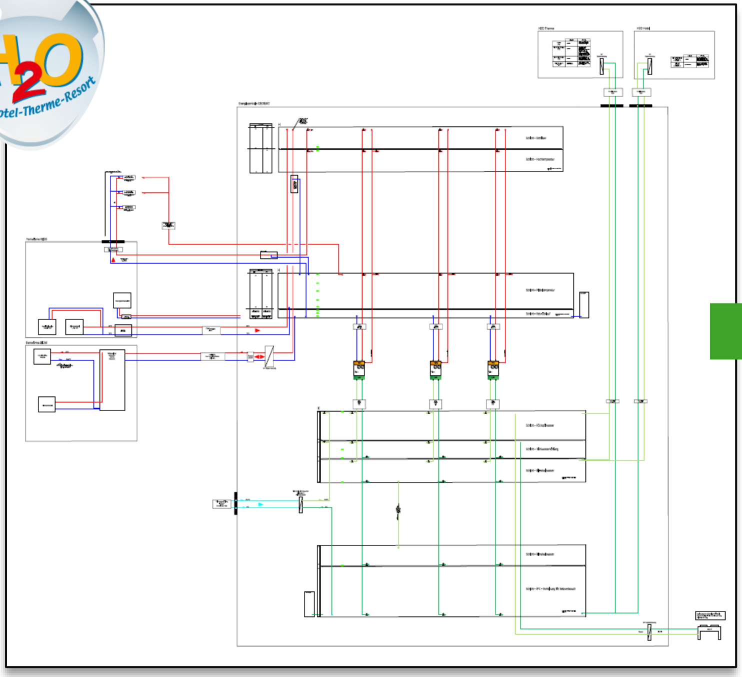
- COP map from datasheet
  6 design points



- Achieved COPs in MPC



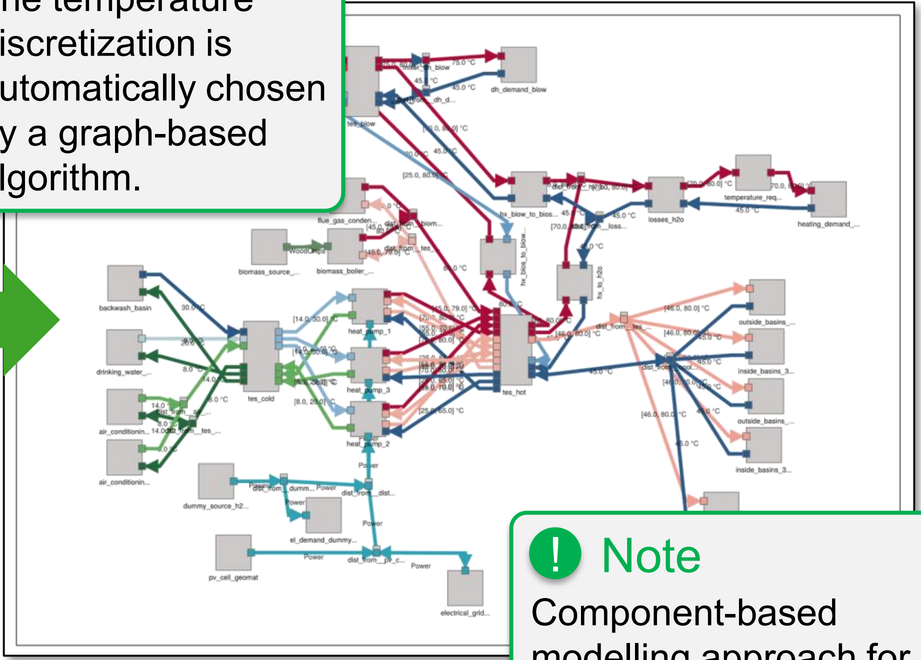
Scenario analysis: System Structure



P&ID Schema

Note

The temperature discretization is automatically chosen by a graph-based algorithm.



MPC Model

Note

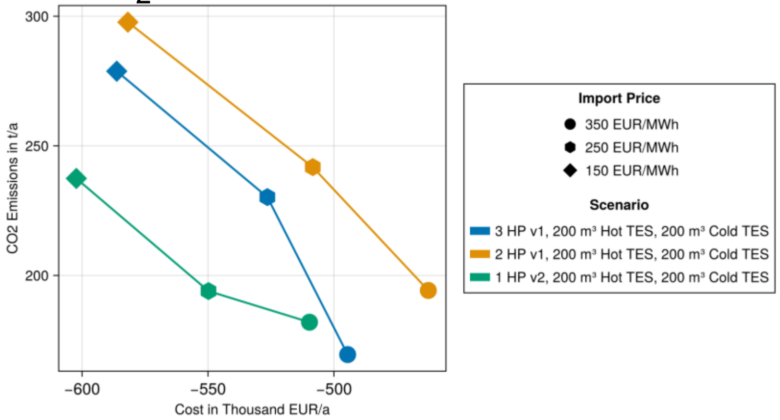
Component-based modelling approach for the MPC makes fast alterations possible

Scenario analysis: Results

Scenarios

- Which heat pump, How many heat pumps?
- Influence of el. import price?
- Size of TES?

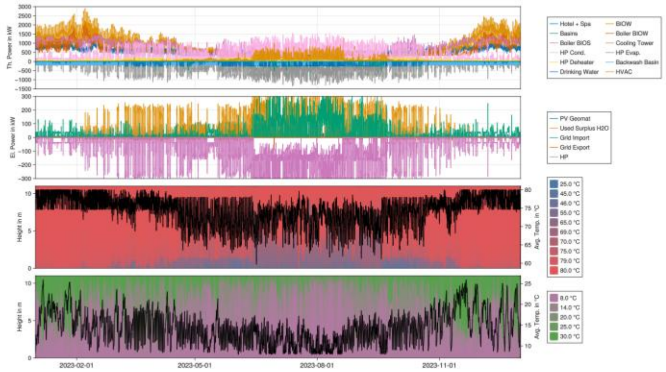
Influence of El. Import Price on CO_2-emissions and OPEX



Results

- Using two or three smaller heat pumps allows for better modulation
- A larger ammonia heat pump would achieve a higher COP, but it offers limited modulation and is too expensive
- Boiler in nearby DH network can be turned of from May until September

Detailed Yearly Simulations



Summary & Outlook

- Waste heat integration using HPs results in a complicated multi-energy system and required at different temperatures
- A holistic Model Predictive Controller was developed based on the **“multi-temperature” modelling approach** to perform
  - Scenario simulation/analysis for system planning (no low-level controllers need to be developed and tuned)
  - Real-time control for operation
- **Scenario analysis** was performed to help with specific design choices
- **Next step:** Build the system (2026) and deploy the controller

! See our other talks

Bernd Riederer: Smart control of hydrogen-based multi-energy systems
Astrid Leitner: Real-World Implementation of Residential Energy Management Systems: Balancing Thermal and Electrical Energy

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