Model-Based Control of Absorption Heat Pumping Devices –

General Approach and Exemplary Application to Solar Cooling Systems

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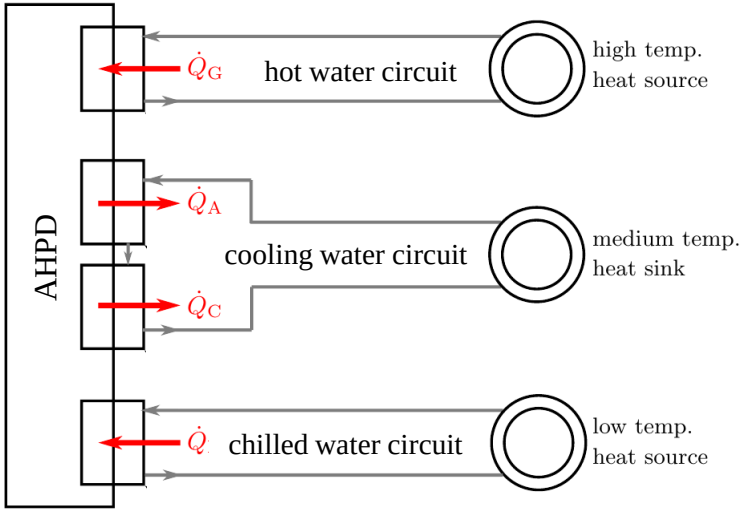
Absorption heat pumping devices (AHPDs) –

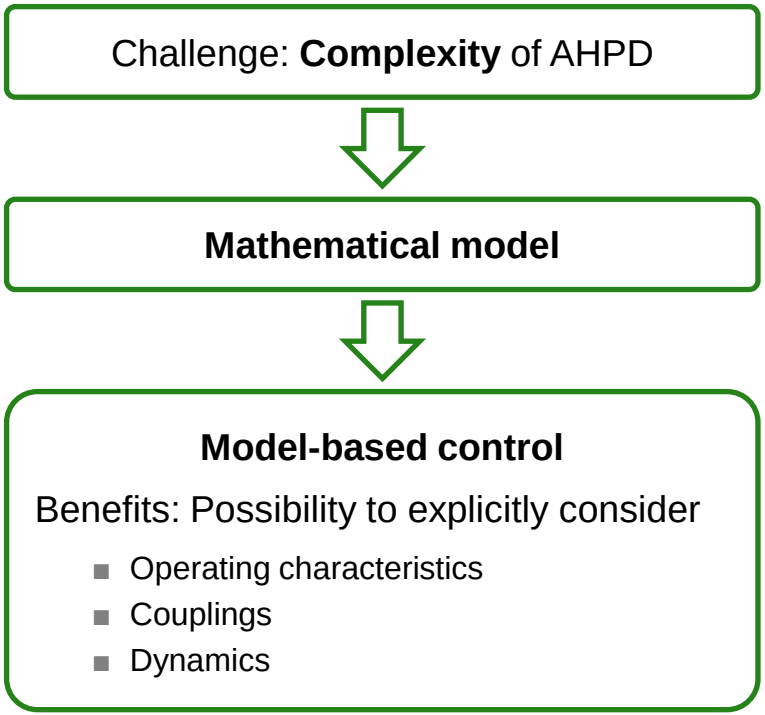
Benefits and challenges

- Heat pumping device (HPD) = heat pumps and chillers
- Principle: Use high temperature heat to lift heat from a low to a higher temperature level
- Benefits:
  - Mainly thermally driven → less electricity
  - Versatile integration (different heat sinks/sources)
- Challenges: Complexity
  - High investment costs
  - Many input (and output) variables
  - Operation under varying operating conditions



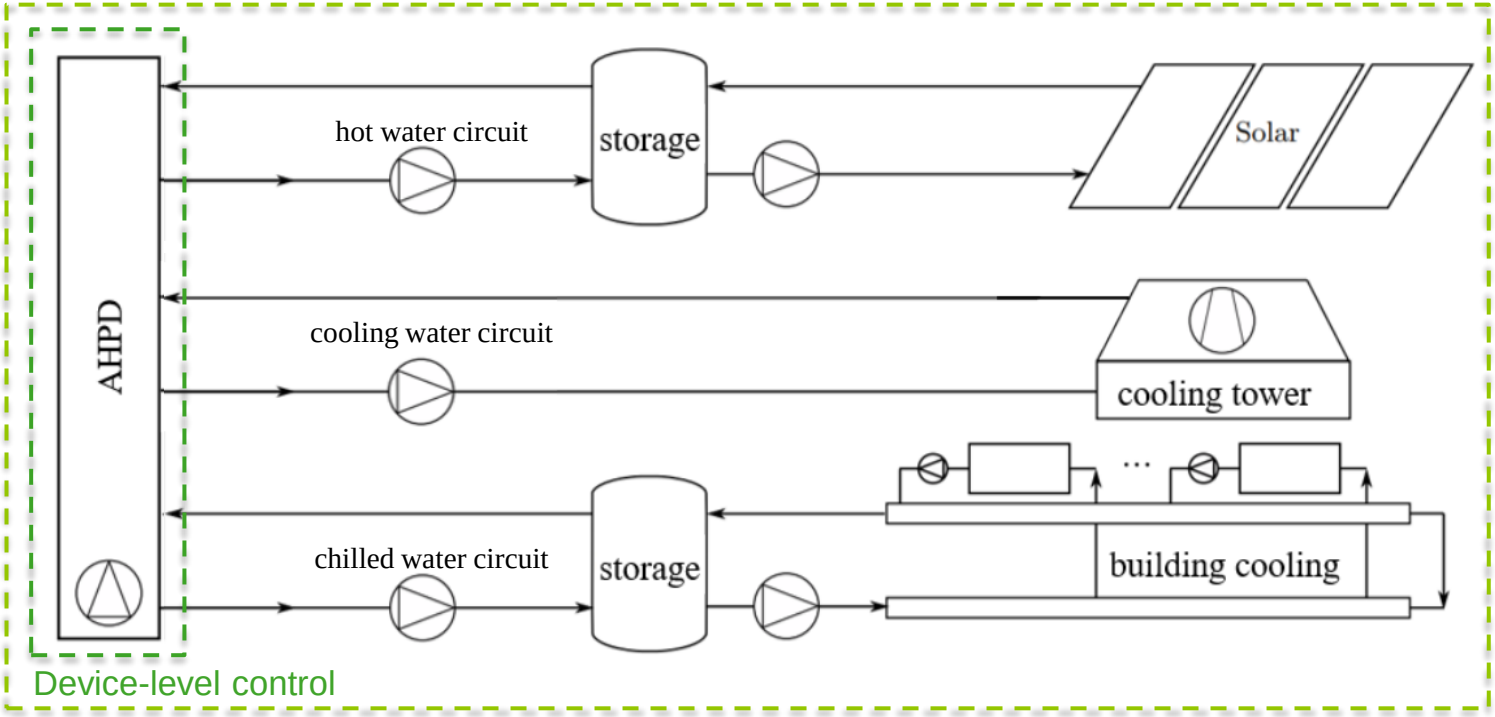
How can control technology help to overcome challenging AHPD operation?

Model-based control to tackle complexity problem



Model-based control of AHPD

Exemplary application to Solar Cooling system



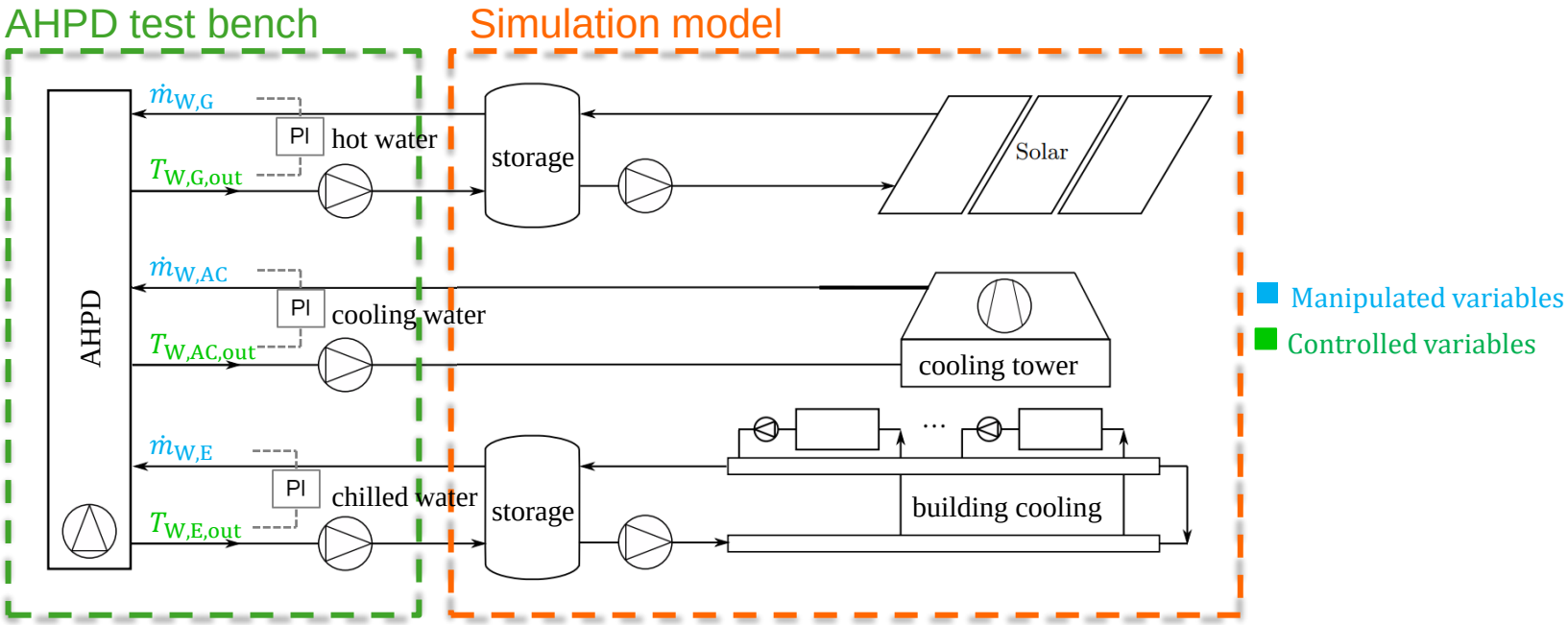
Model-based control on device-level

- Use model-based control for **MIMO* control** of AHPD**:**
  - Use more manipulated than controlled variables
  - Additional degrees of freedom → **extend operating range**
- Used control method:
  - **Linear MPC** (model-predictive control)
  - Use of linearized dynamic model of AHPD based on [1]
- Comparison
  - to SISO** PI control
  - through Hardware-in-the-Loop (HiL) test runs

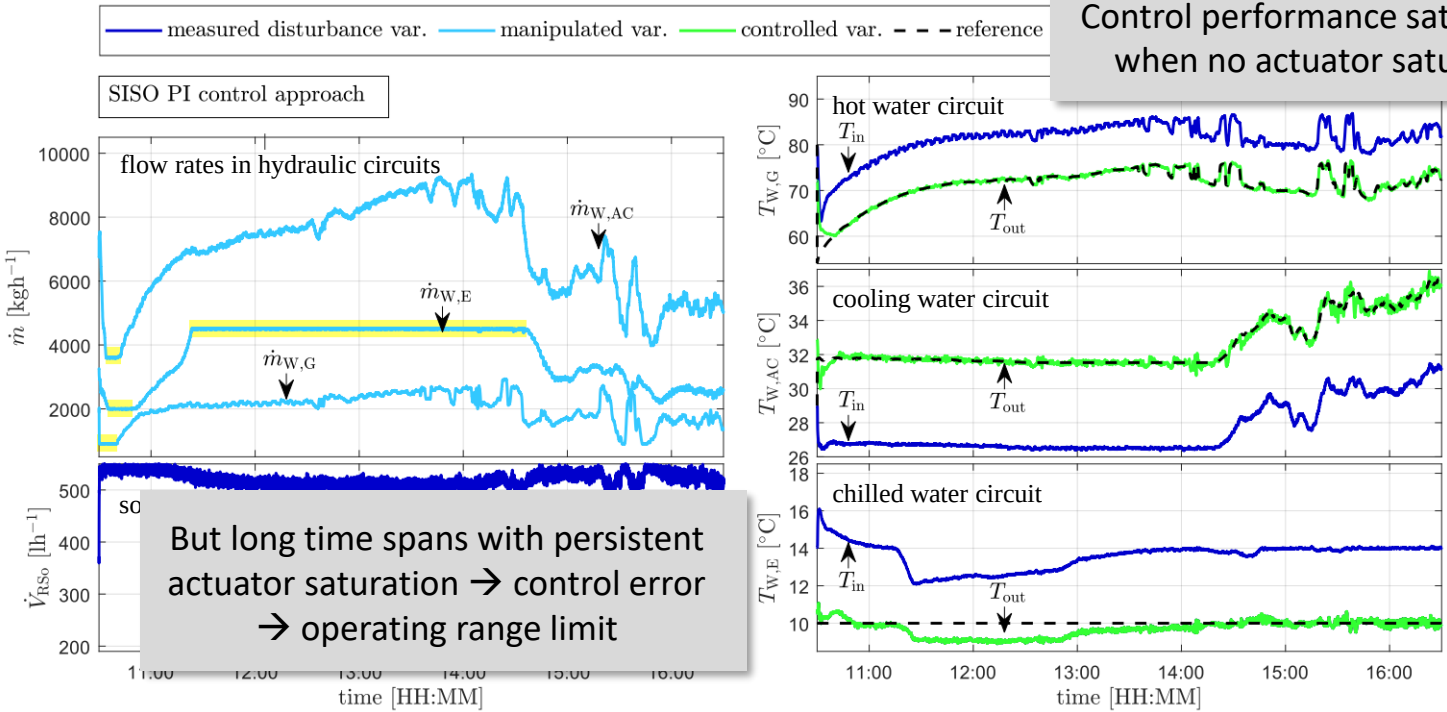
*) MIMO: multi-input-multi-output
**) SISO: single-input-single-output

[1] S. Staudt et al., *Control-oriented modeling of a LiBr/H2O absorption heat pumping device and experimental validation*, Journal of Process Control, Volume 128, 2023

HiL test run with SISO PI controller



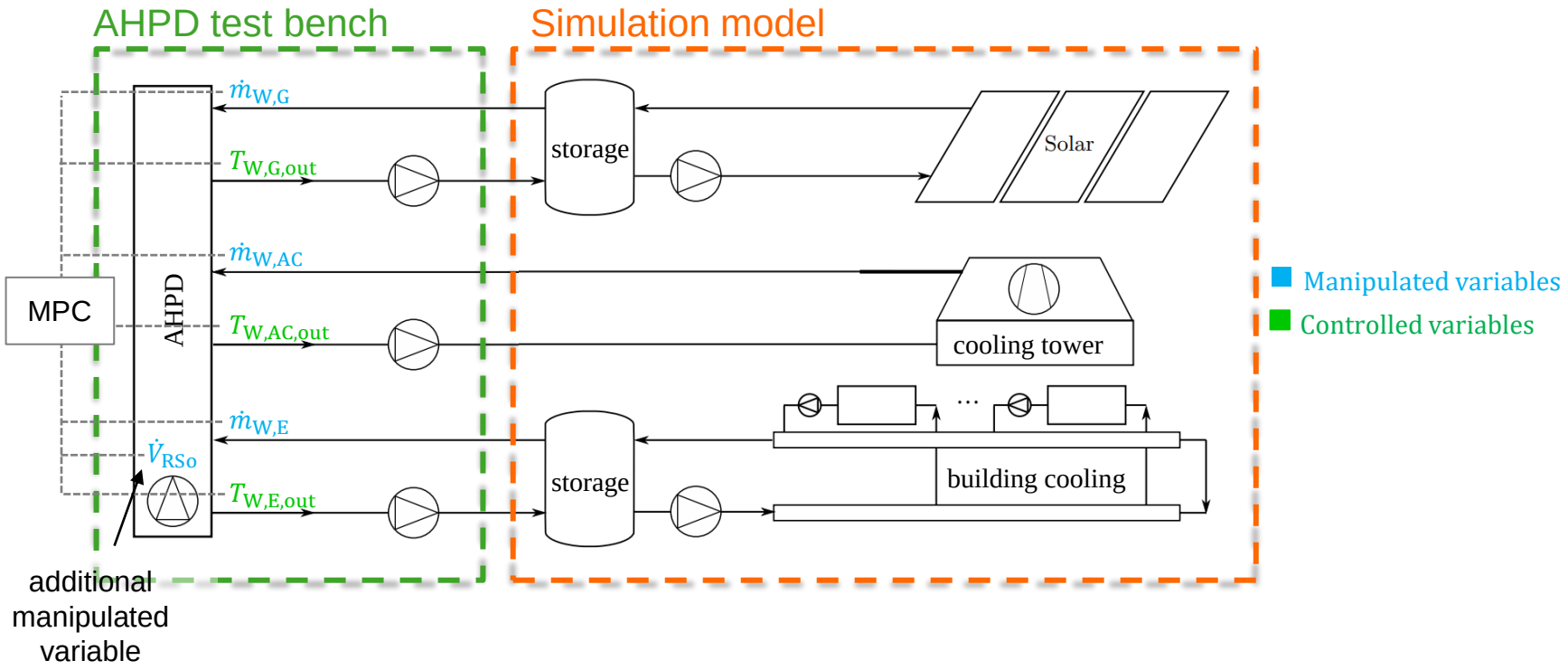
HiL test run with SISO PI controller



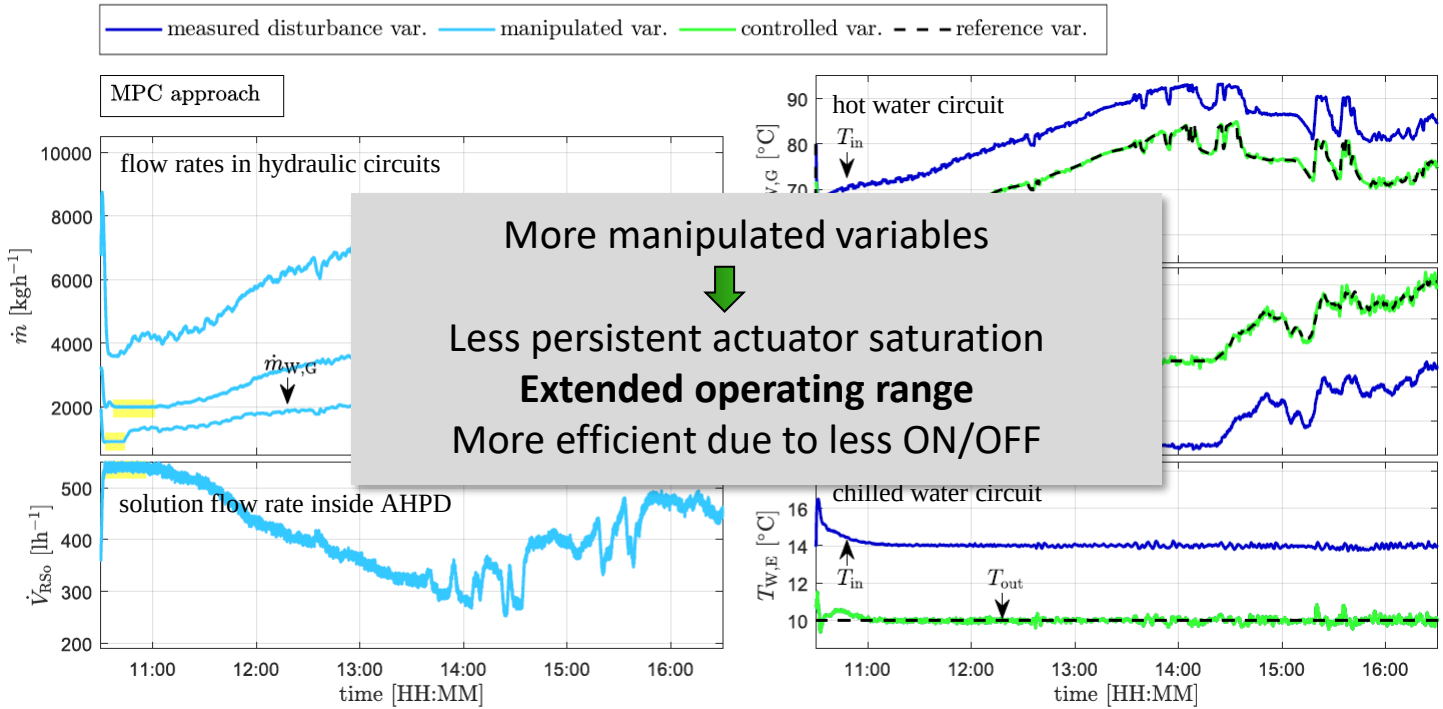
Control performance satisfactory when no actuator saturation

But long time spans with persistent actuator saturation → control error → operating range limit

HiL test run with MIMO MPC controller



HiL test run with MIMO MPC controller



Model-based control on system-level

- System-level control: Find operating strategy for overall energy system
  - When to turn ON/OFF?
  - At which capacity/heat flow rate?
  - At which temperature level?

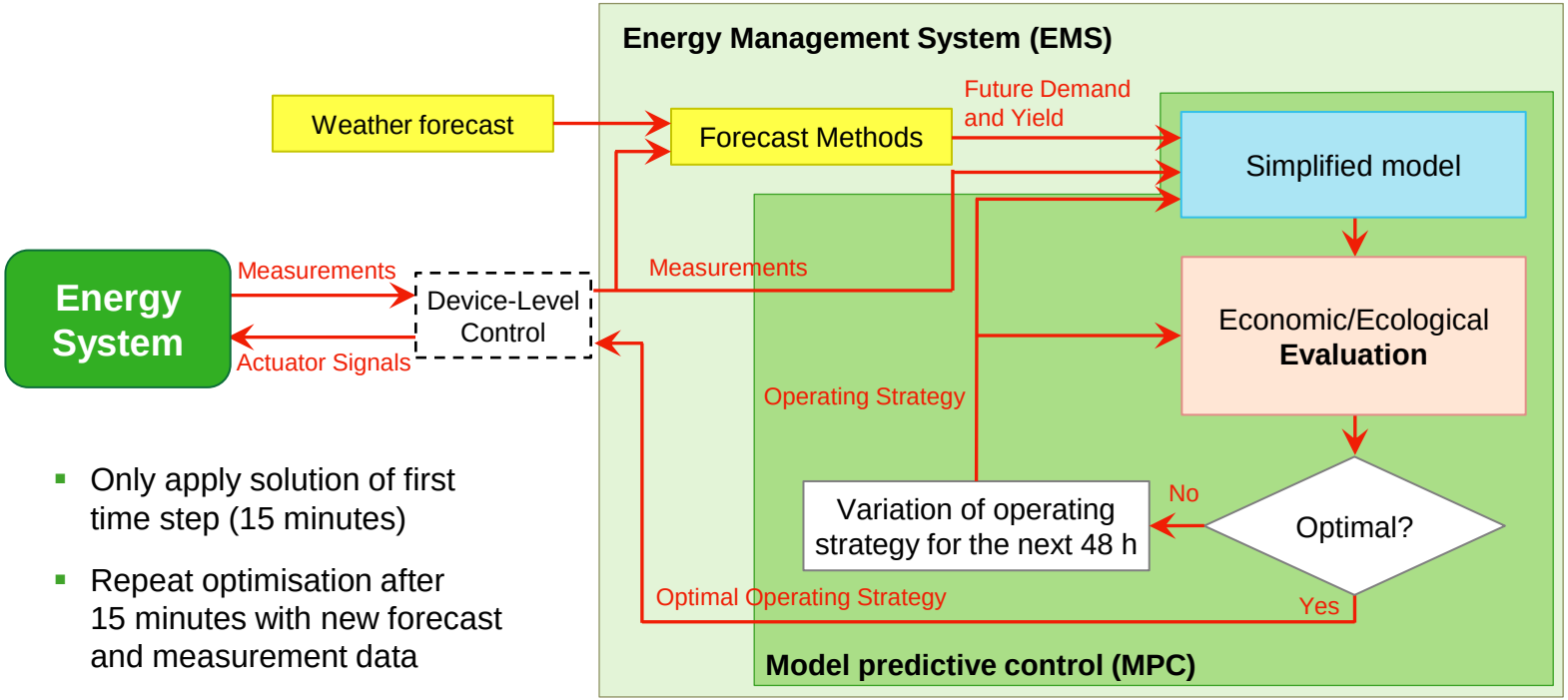
  → Set points for device-level controllers

- State-of-the-art: Expert-rule-based control approaches

- More advanced: Predictive, optimization-based supervisory control

  → BEST **Energy Management System (EMS)**

Energy Management System (EMS)



- Only apply solution of first time step (15 minutes)
- Repeat optimisation after 15 minutes with new forecast and measurement data

Extension of EMS for varying temperatures

EMS based on solving mixed-integer **linear** problems (MILP) → linear models necessary

e.g. thermal energy transfer:

$$\dot{Q} = c_{\mathrm{p}} \cdot \dot{m} \cdot (T_{\mathrm{in}} - T_{\mathrm{out}})$$

decision variable

Currently: fixed temperatures

$$T_{\mathrm{in}} = \mathrm{const}, \quad T_{\mathrm{out}} = \mathrm{const}$$

However, AHPD's characteristics are temperature-dependent!

→ Extension of EMS for varying temperatures **(Multi-Temp EMS)**

decision variable

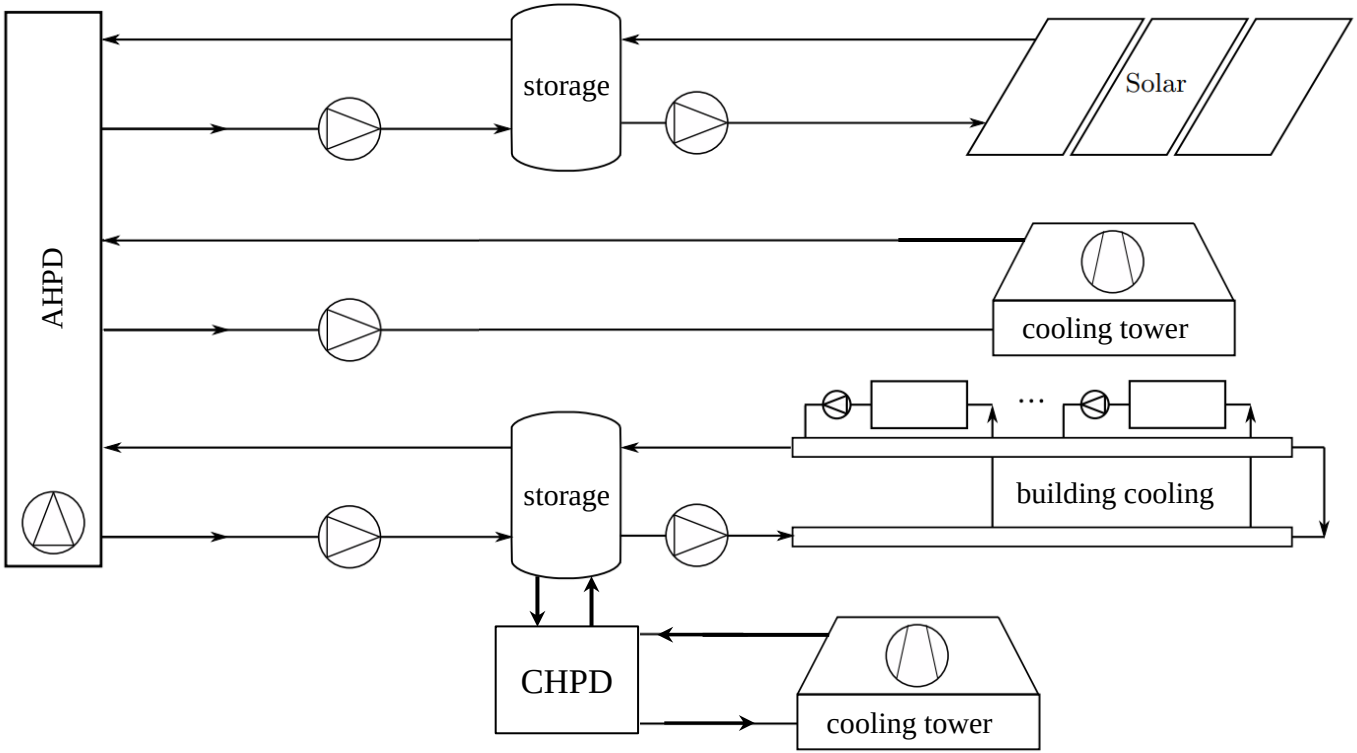
model required → steady-state model based on [1]

$$\dot{Q} = \sum_{i=1}^{N_i} \sum_{j=1}^{N_j} z_{i,j} \cdot \dot{Q}_{max}\,(T_{\mathrm{in},i}, T_{\mathrm{out},j}) \qquad T_{\mathrm{in},i} = \mathrm{const}, \; T_{\mathrm{out},j} = \mathrm{const}$$

$$= \sum_{i=1}^{N_i} \sum_{j=1}^{N_j} \dot{Q}_{i,j} \quad (\dot{Q}_{i,j} = c_{\mathrm{p}} \cdot \dot{m}_{i,j} \cdot (T_{\mathrm{in},i} - T_{\mathrm{out},j}) \qquad \sum_{i=1}^{N_i} \sum_{j=1}^{N_j} z_{i,j} \leq 1$$

[1] S. Staudt et al., *Control-oriented modeling of a LiBr/H2O absorption heat pumping device and experimental validation*, Journal of Process Control, Volume 128, 2023

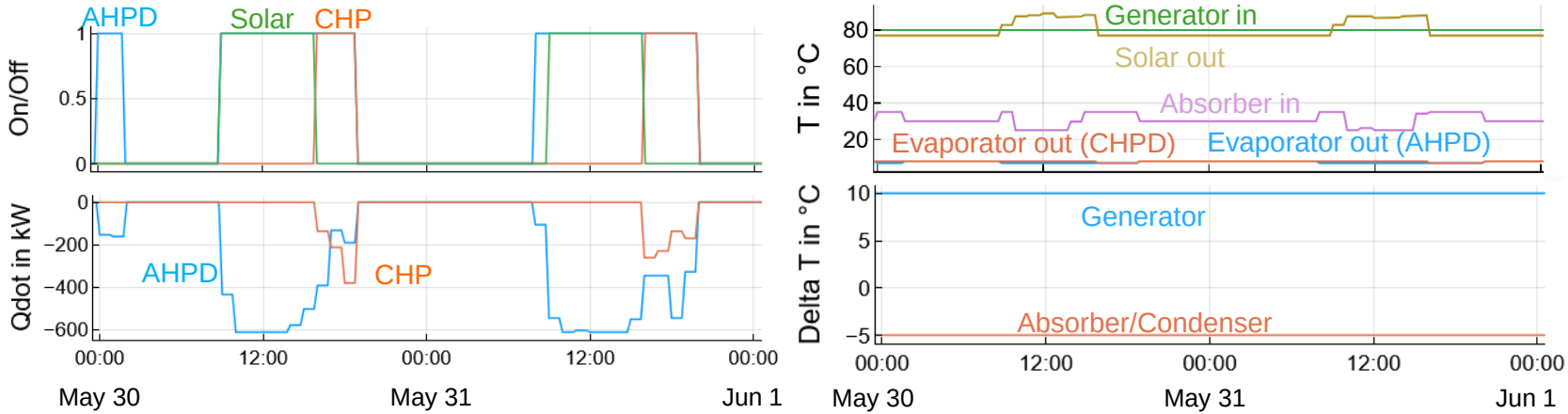
Preliminary results for system-level control of Solar Cooling System with Multi-Temp EMS



Preliminary results for system-level control of Solar Cooling System with Multi-Temp EMS

- Currently under investigation: Validation of Multi-Temp EMS through Co-simulation with TRNSYS

Exemplary set points of EMS sent to TRNSYS (first results):



- Next steps: Comparison of Multi-Temp EMS to other system-level control approaches (Expert-rule-based and Fixed-Temp EMS)

Conclusion & Outlook

- Model-based control can help to tackle challenging AHPD operation
- Facilitates use of MIMO control **to extend operating range**
- Allows consideration of (temperature-dependent) operating characteristics for system-level control **to increase efficiency**
- **Outlook**:
  - Validation of Multi-Temp EMS & comparison to alternative control approaches in simulation
  - Validation of device- and system-level control approaches in field tests

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