Levels of Control of Solar District Heating Grids

Results from IEA SHC Task 68 – Subtask B

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Task 68

IEA DHC

Annex TS5

BEST
Bioenergy and Sustainable Technologies

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Solar Academy Webinar – 2024, November 19th / 21st

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The Importance of Advanced Control

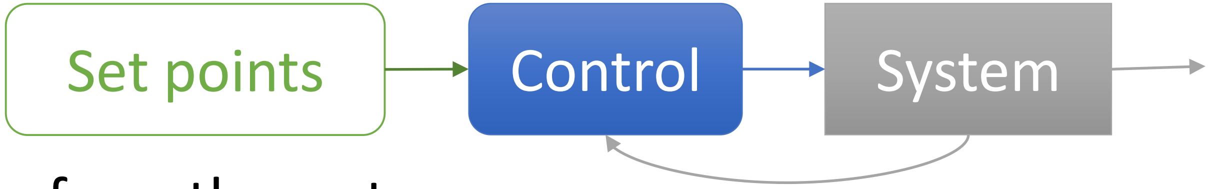
- **Control engineering** is an – often underestimated – **essential prerequisite** for the proper operation of technical systems.
- In the “old” energy system (with flexible fossil fuels available), quite simple control strategies were often sufficient.
- In the “new” energy system, mostly based on season- and weather-dependent renewable energy sources, more elaborate control strategies are required.
- This is particularly true for complex trans-sectorial systems (sector coupling), but already applies to technologies like Solar District Heating (SDH) – in particular if we want to achieve high solar fractions.

Types of Control

- Open-loop control:

  - Use model assumptions about the system and knowledge about (and usually forecasts of) external quantities to set the actuator values
  - Advantage: can react fast to foreseeable changes
  - Disadvantage: models rarely contain all relevant aspects, thus control often somehow shows "faulty" behavior

- Closed-loop control:



  - Use measurement values from the system
  - Advantage: can correct also unexpected disturbances
  - Disadvantage: reacts rather slowly, since system state has to change in order to trigger the controller

Often best to combine both

Overview: The Levels of Control

- Typically, one distinguishes between two levels of control:
  1. **Low-level** (subordinate) control:
     - Control of a single component or relatively simple system
     - Use actor variables to influence the system such that the control variables (internal or output variables) have values close to some set point.
  2. **High-level** (superordinate / supervisory) control:
     - Control of a complex system of interacting components
     - Create a schedule of set points for subsystems / single components, usually based on forecasts (e.g. of energy demand and energy yield)
     - For energy systems, significant improvement requires degrees of freedom (load shift, storage capacities)

Both relevant for large-scale solar thermal plants and solar district heating

Control strategies

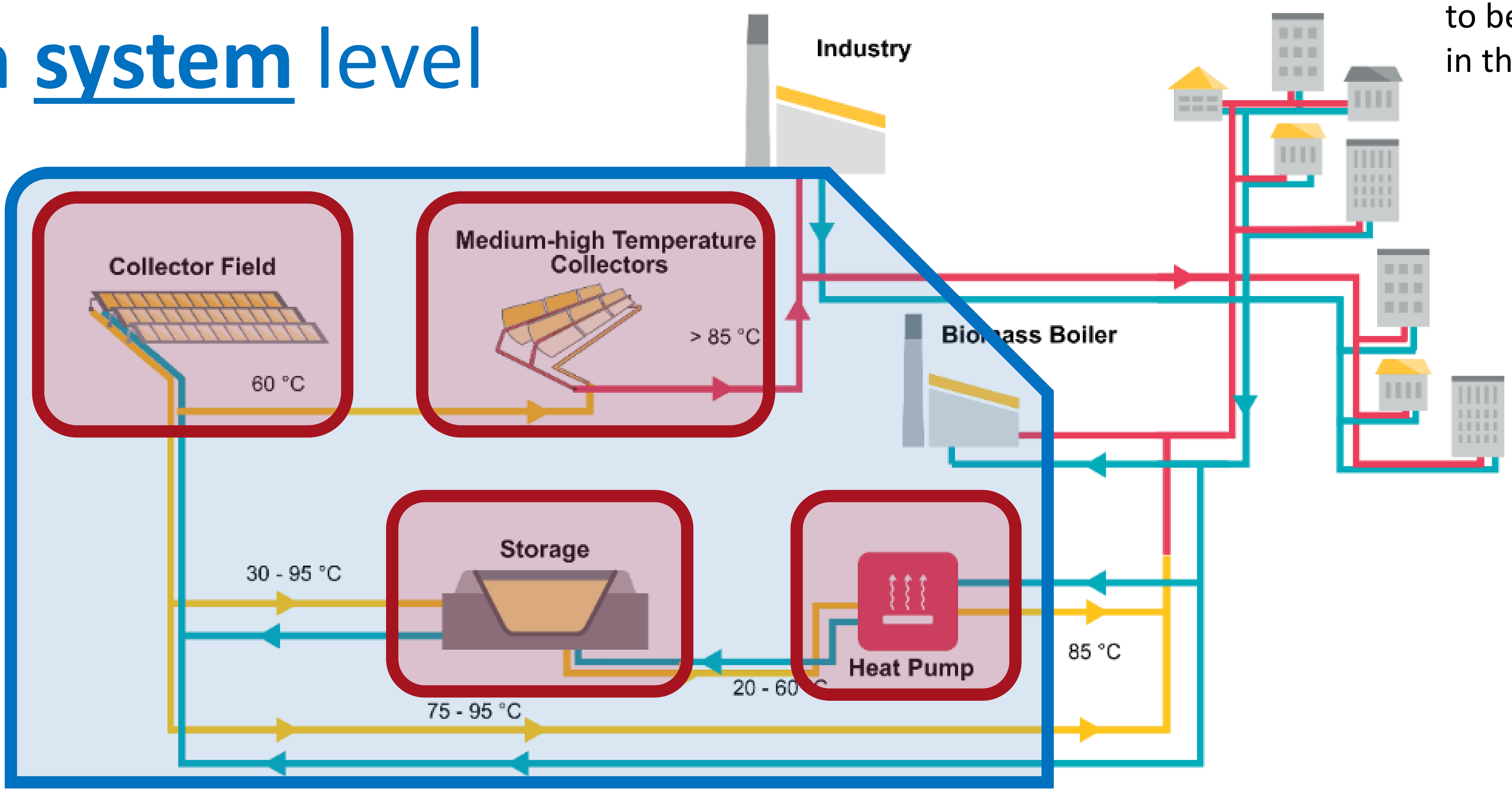
on **component** level

on **system** level

Subtask B: Data preparation & utilization

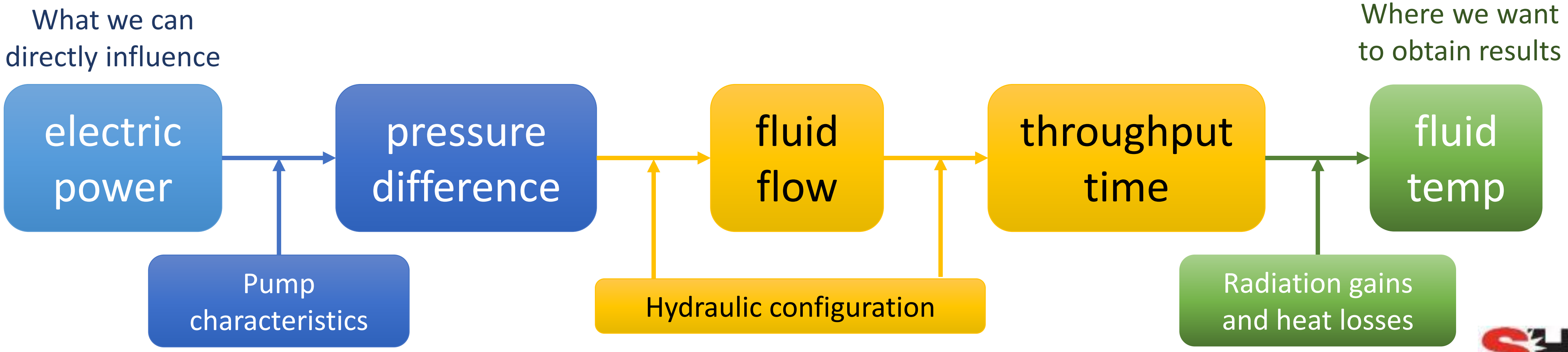
- Gathering/Storing data | Auto. Monitoring/Evaluation | Control

Task 68 **Report RB3** to be published in the first half of 2025



Low-level Control: Basic Principles

- Use actor variables to influence the system such that the control variables have values close to some set point.
- Some examples:
  - **Room heating**: Adjust heating power such that a comfort temperature is met
  - **Solar collector field**: Adjust pump power such that the fluid at the outlet has a pre-defined temperature.



Low-level Control: Simple Approaches

- For some systems, rather simple control strategies work fine:
  - two-point control: turn on the actor device below some threshold of the control variable, turn it off above some other threshold
  - PID control: Adjust actor variable according to the difference Δ between current value and set point, with contributions …
    - **P**roportional to Δ — plausible, but not sufficient
    - **I**ntegral over time of Δ — to get the long-time behavior right
    - **D**erivative of Δ — for reacting on fast changes *(but not very popular)*
- Challenges:
  - nonlinear relations (since **P**, **I** and **D** are linear)
  - interaction of different components
  - Delays

All are present in large-scale solar thermal plants

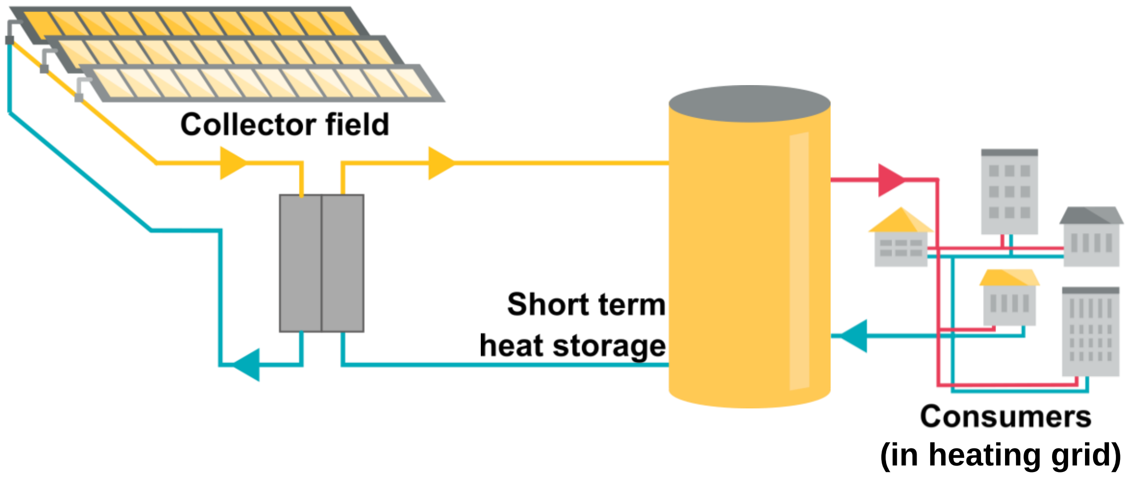
Low-level Control: Advanced Approaches

- Advanced methods for low-level control exist:
  - Advanced rule-based control strategies
    (more elaborate than just two-point control)
  - Fuzzy control (e.g. Mamdani controller)
  - Nonlinear control strategies, also for coupled systems:
    - Exact linearization and flatness-based control
    - Sliding mode control
    - …
- Prerequisite for such methods is domain knowledge:
  - reasonable set of rules *or*
  - mathematical model – should be simple, but still grasp the essential behavior of the system ("as simple as possible, as complex as necessary")

Low-level Control of a large-scale solar thermal plant

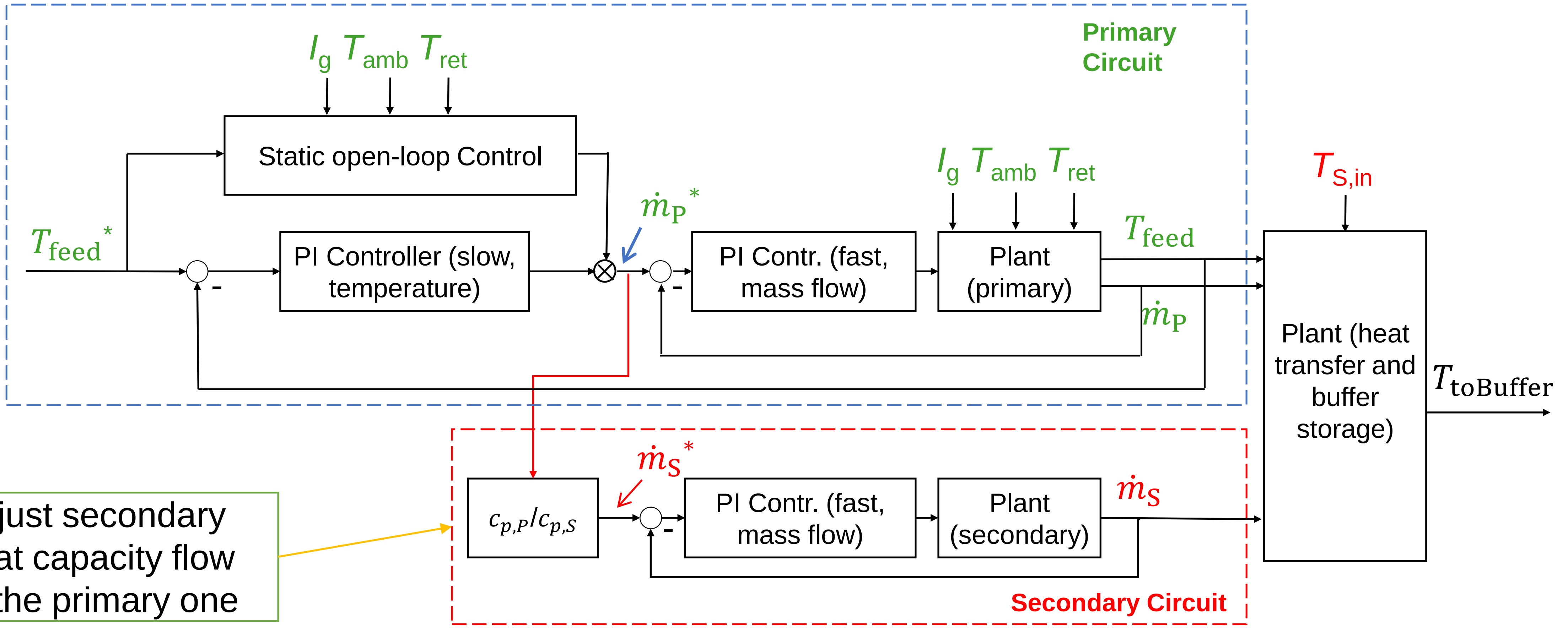
Objective: Model-based Control of solar primary and secondary circuit

- Fast and effective adaptation to changing weather conditions
- Efficient heat transfer from collectors (in the primary circuit) to the storage tank (in the secondary circuit)



Promising strategy: Complement the usual PI(D) controllers by an additional open-loop control element

Low-level Control of a large-scale solar thermal plant



Adjust secondary heat capacity flow to the primary one

Some (Preliminary) Results

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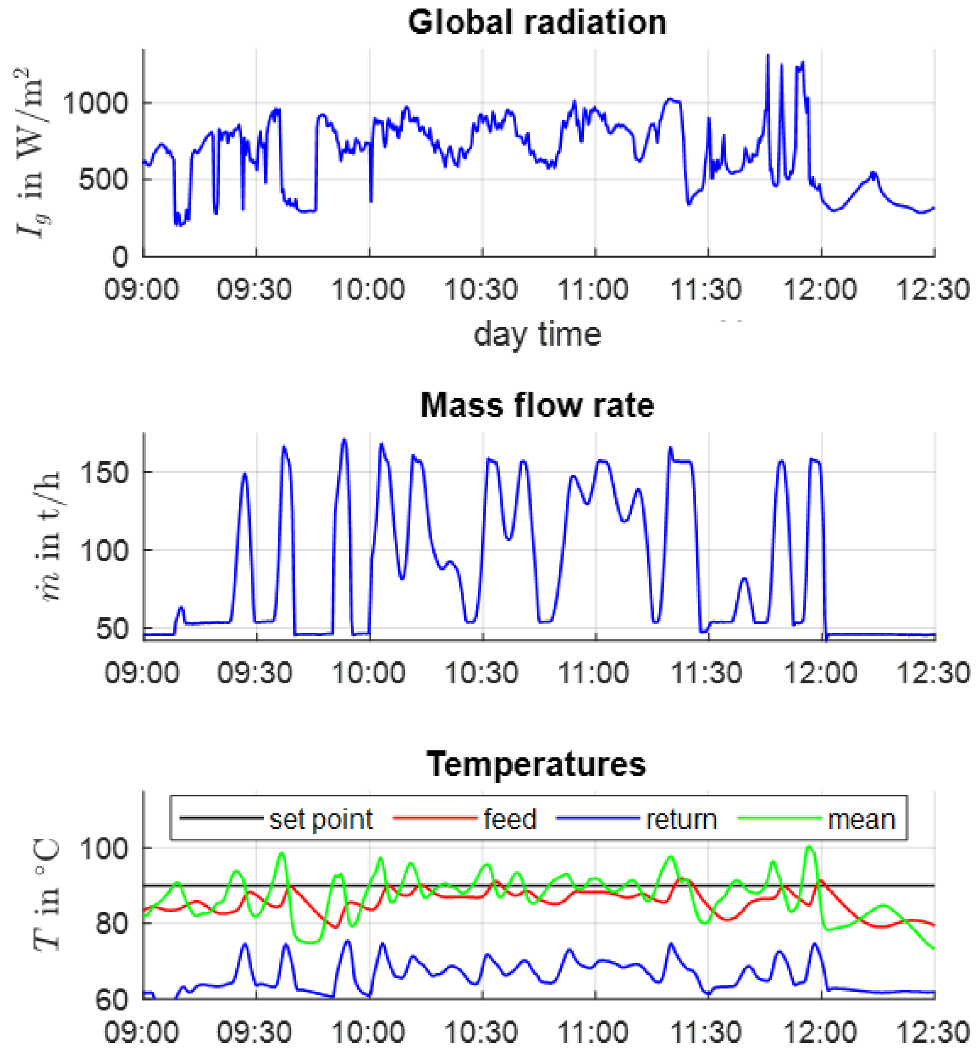
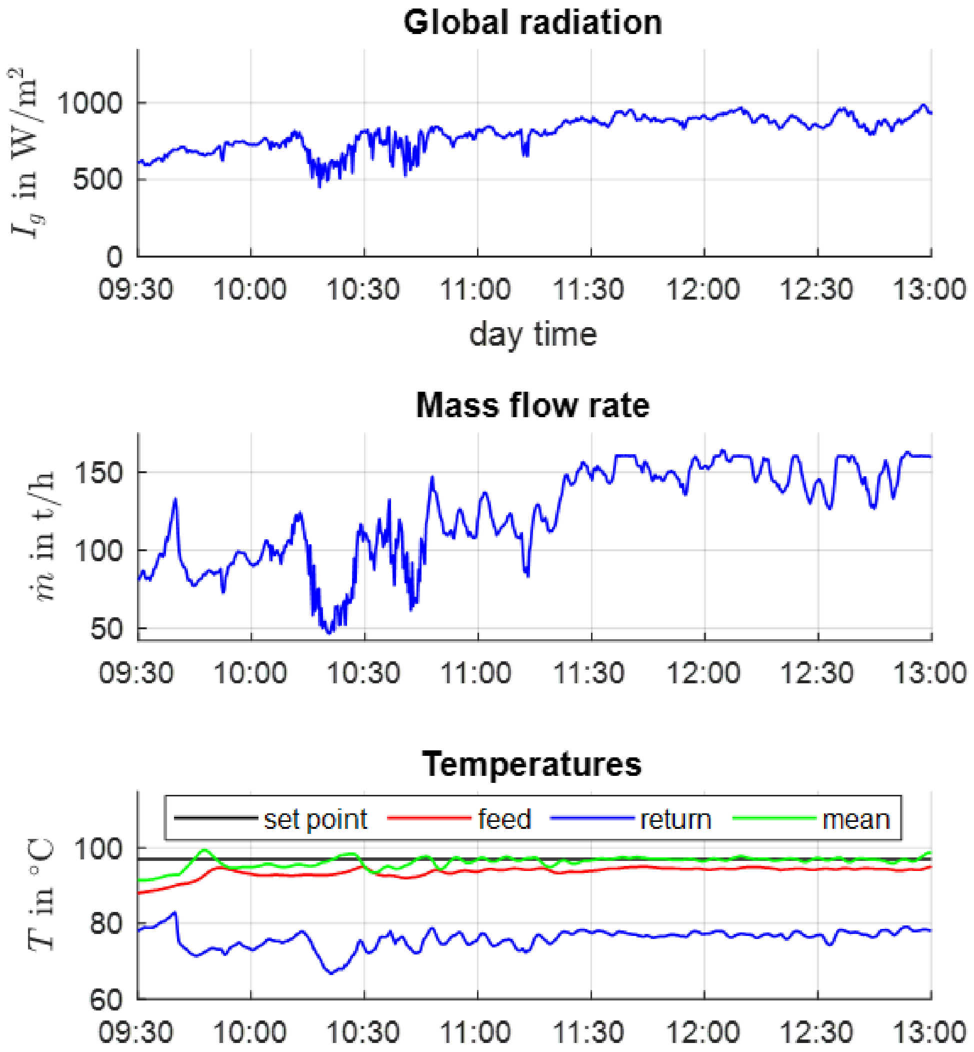
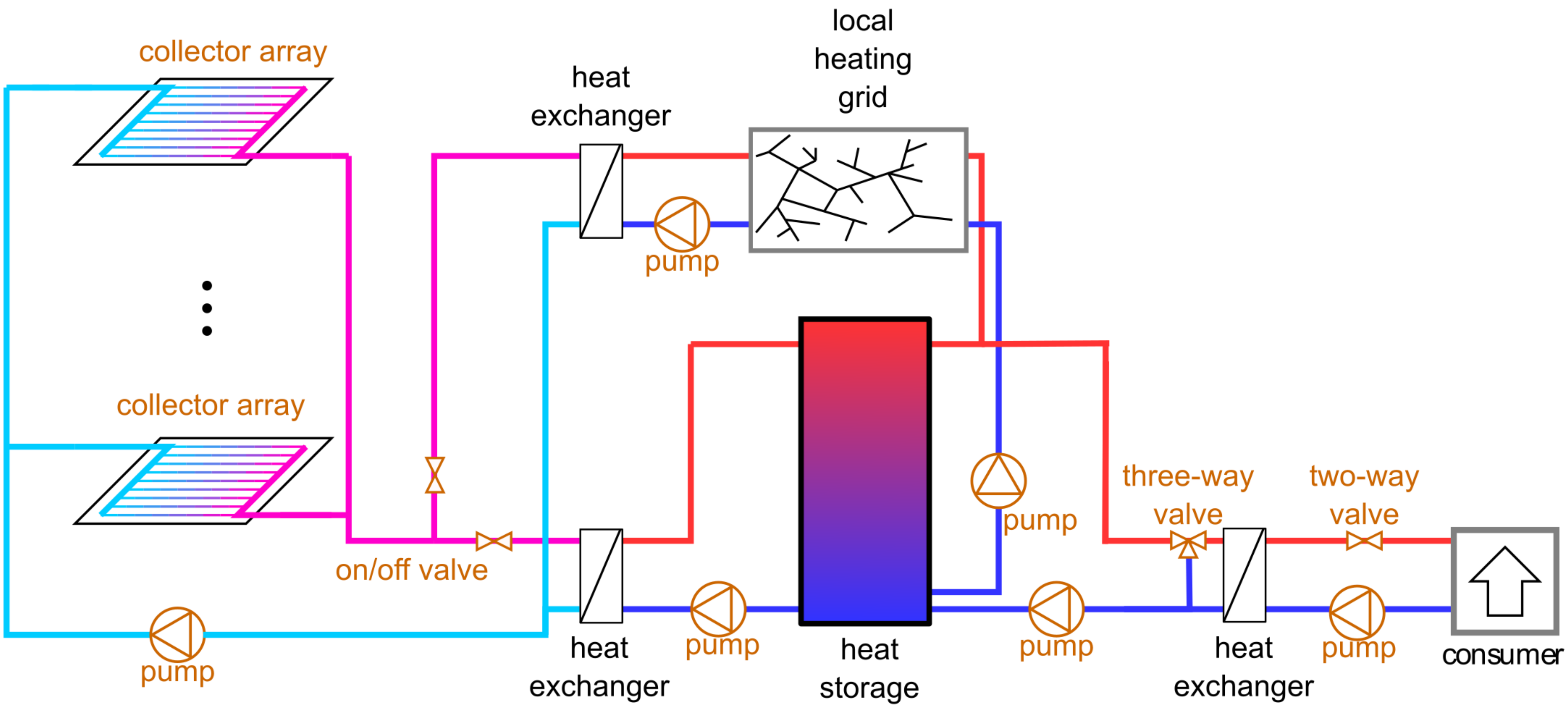
old control strategy



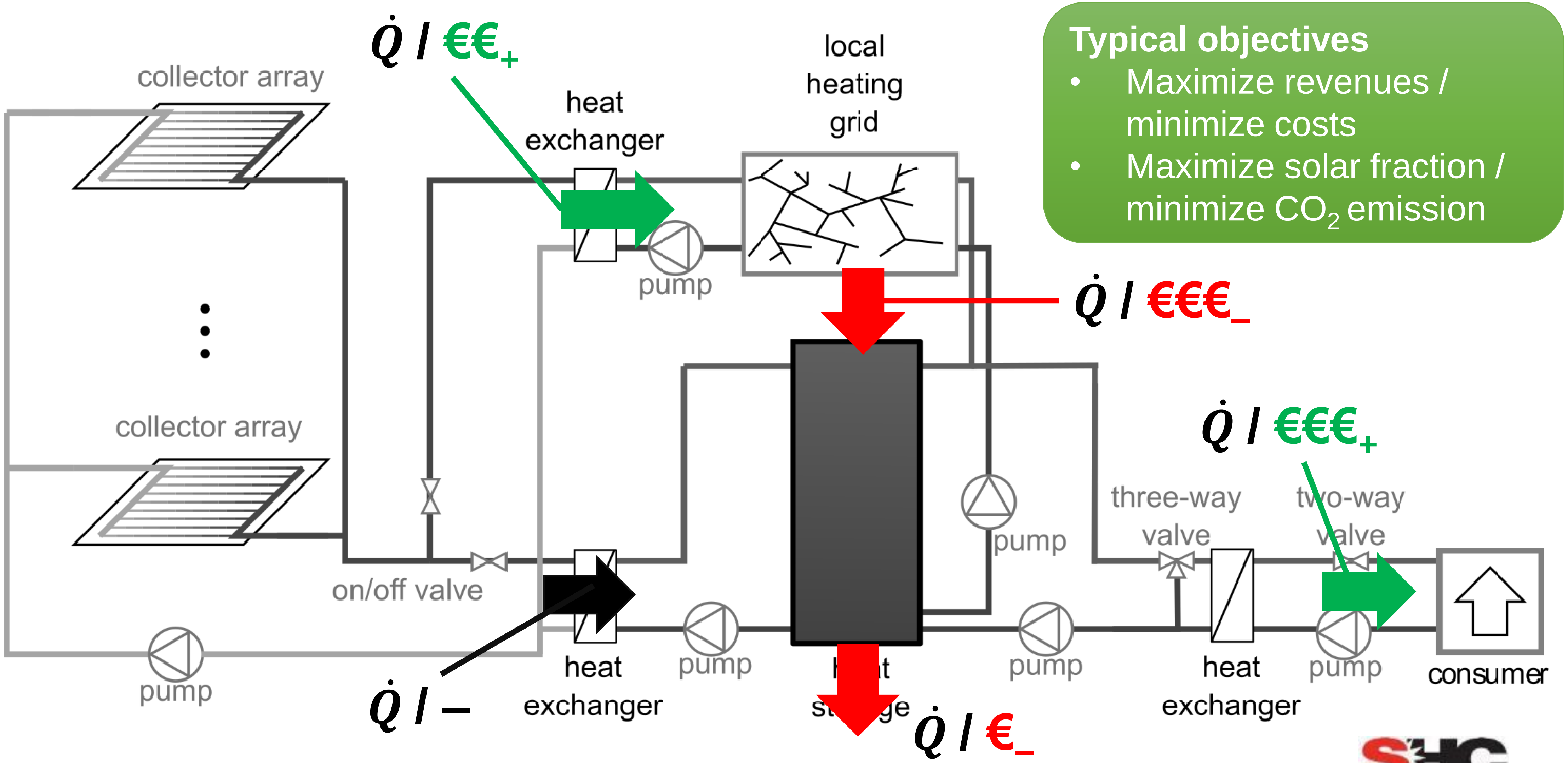
new control strategy



High-level Control: Solar District Heating



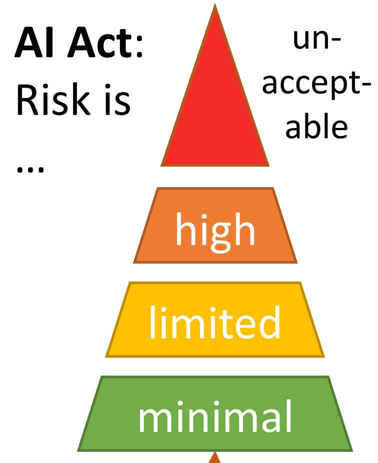
High-level Control: Solar District Heating



Typical objectives

- Maximize revenues / minimize costs
- Maximize solar fraction / minimize CO_2 emission

High-level Control: Some strategies



- Control of a complex system of interacting components:
  - Create a **schedule** of set points for the subsystems / single components
  - Make use of **forecasts** and energy **storages**, if present
- Possible Strategies:
  - **Rule-based** (classical decision trees, fuzzy logic rules, …)
  - **Artificial-Intelligence-based** *(active field of research):*
    - Universal and potentially very powerful
    - Domain knowledge rather hard to integrate
    - Large computational effort for training, but fast execution is often possible
    - Usually very low transparency: black box methods → trust issues
  - **Optimization-based approaches**:
    - General approach, can handle several energy sectors (heat, electricity, chemical energy carriers) and many different technologies at once
    - Less transparent than rules, more transparent than typical AI;
    - Need considerable computational resources during execution
    - Require quite some effort and mathematical skills for development *(but fortunately, some very bright people work on this topic)*

Decision-tree learning, neural networks, Bayesian machine learning, …

Mixed-integer Linear Programming (MILP), quadratic programming, stochastic optimization, …

Results: Rule-based vs. Optimization-based

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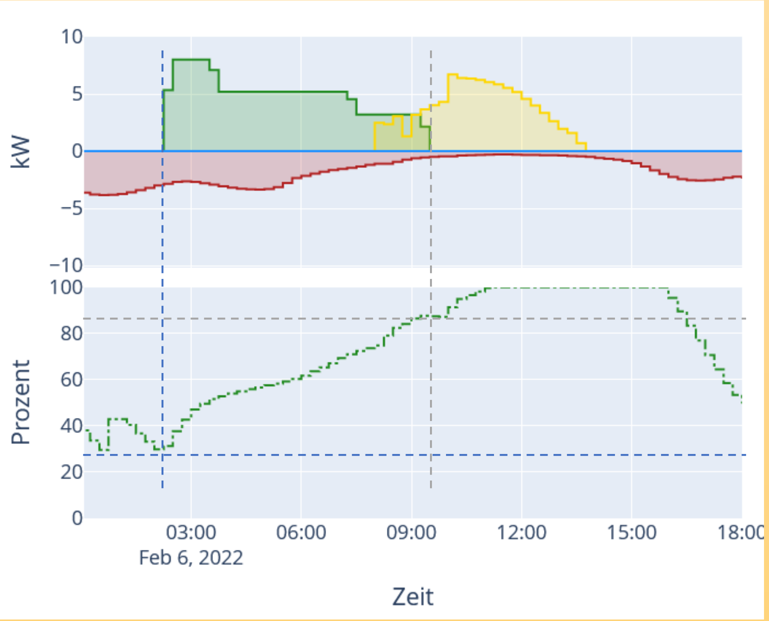
System:
Combination of a biomass boiler with a solar thermal plant and a buffer storage tank

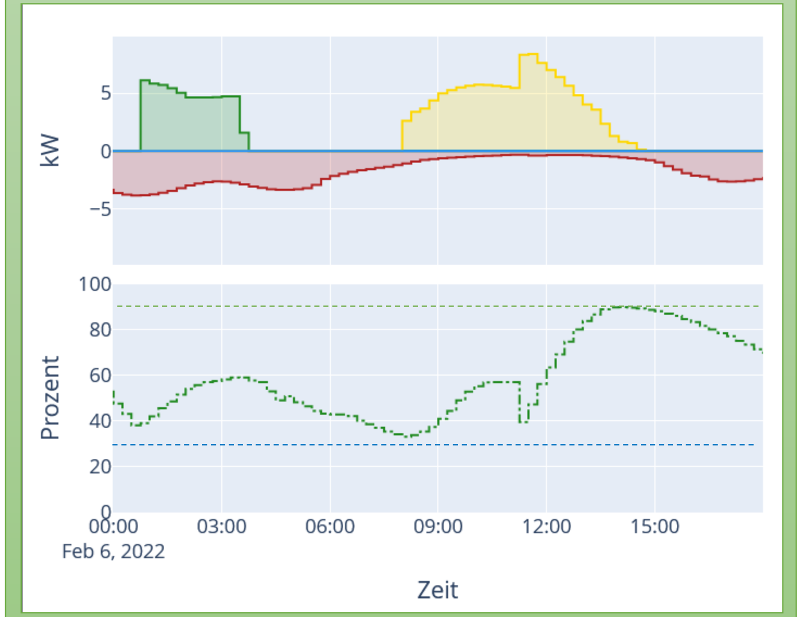
- Biomass boiler power
- Solar thermal power
- Power of heating circuit
- Power for freshwater
- State of the buffer storage tank

Rule-based



Simple two-point control leads to overheating of the storage tank (and to wasting solar energy)

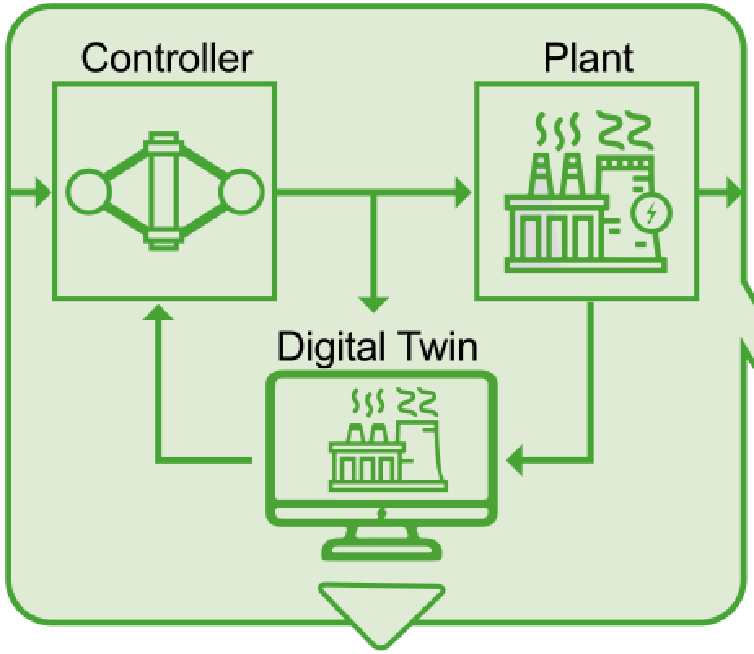
Optimization-based



Predicted solar yield is taken into account by the optimization;
no overheating of the buffer occurs

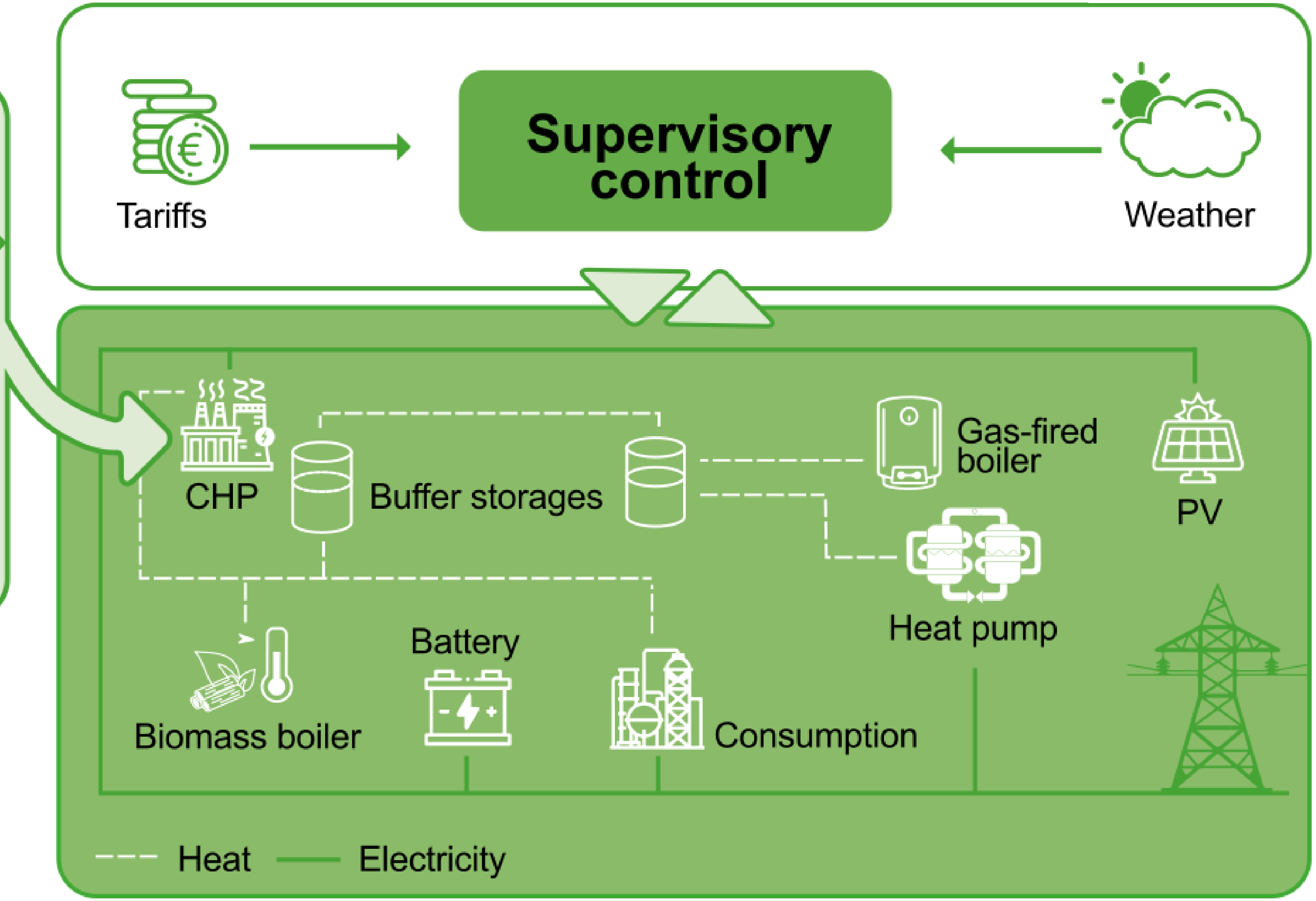
Summary: The Levels of Control

Control of technologies



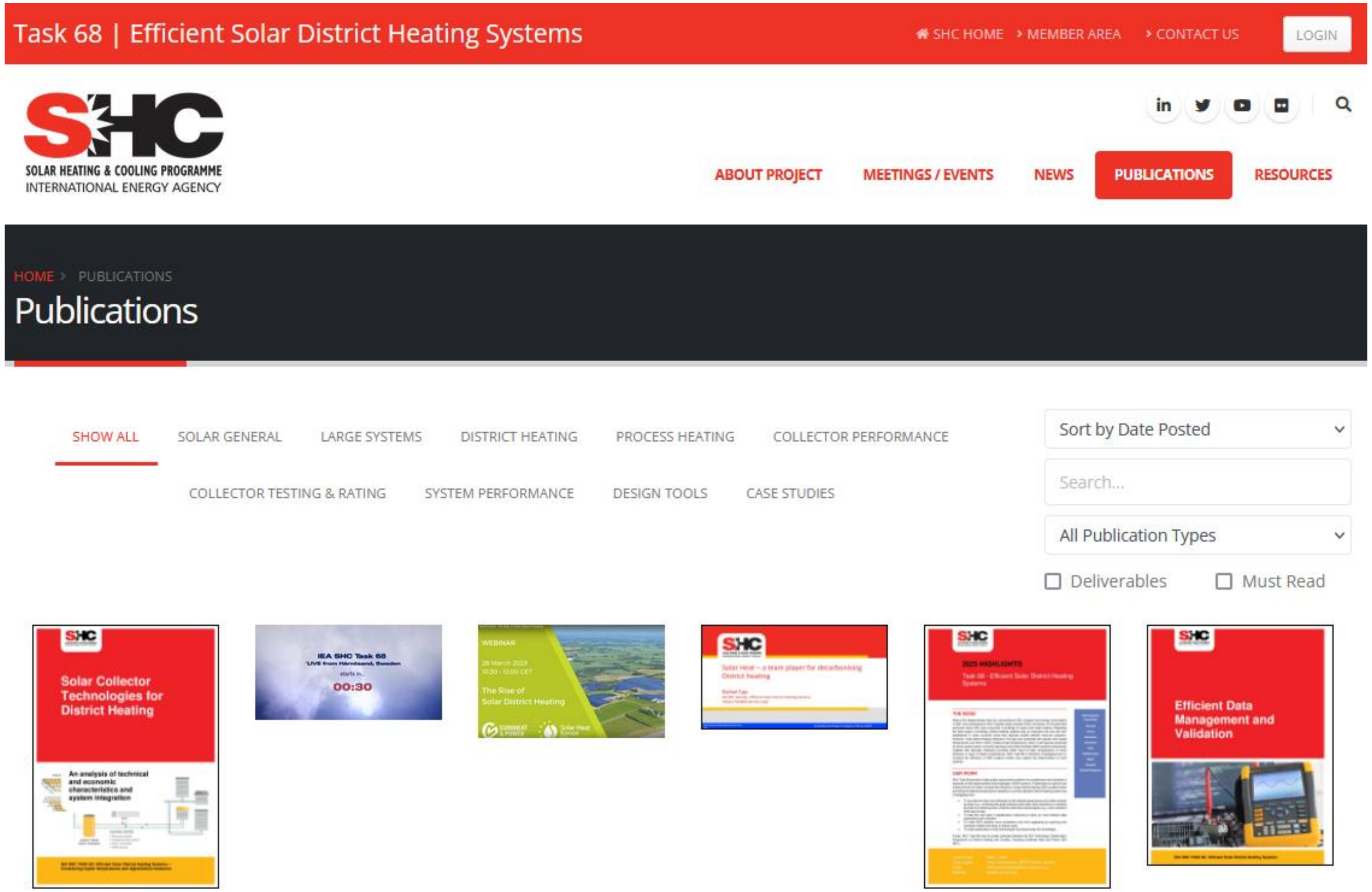
Additional digital services

- Online diagnostics
- Predictive maintenance
- ...



For further reading …

- Fact sheets from IEA SHC Task 55 (available on https://task55.iea-shc.org/publications):
  - A-D4.1 Supervisory control of large-scale solar thermal systems
  - B-D3.1 Control of large-scale solar thermal plants
- Report RB3 from IEA SHC Task68 to be published 2025, will be available on https://task68.iea-shc.org/publications



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https://www.iea-dhc.org/2019-2024-annex-ts5

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Webinar
IEA SHC Solar Academy:

Boosting the Efficiency of Solar Thermal District Heating with Digitalization, Advanced Control and Open Data

19 November 2024
2 PM GMT/UTC

21 November 2024
6 AM GMT/UTC

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