Total System Control (ToSyCo) for Peak Shaving and Efficiency Enhancement

International Renewable Energy Storage Conference (IRES 2019)

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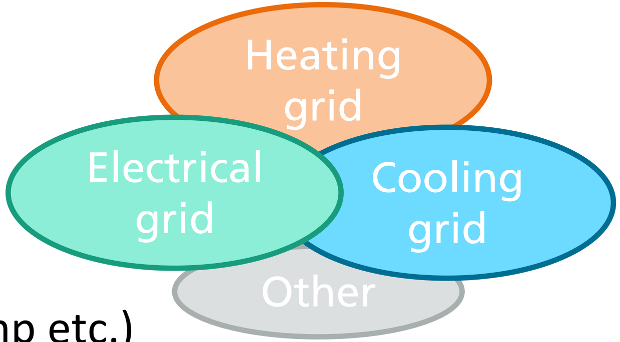
Motivation

- Typical energy infrastructures in industries contain different sectors
  - Electrical grid
  - Heating grid
  - Cooling grid
  - Other (pressured air, vacuum etc.)



- They are coupled by many plants (e.g. chiller, heat pump etc.)
- High costs savings are possible if cross-sectorial operational strategies are used for
  - Peak shaving
  - Efficiency enhancement

Approach

- Motivation
- Basics
- Control approach
- Operational strategies
- Modelling and simulation
- Results
- Summary and Outlook

Basics

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- **Basics**
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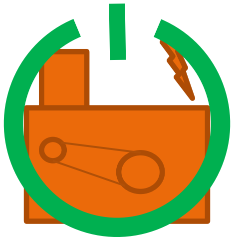
Basics

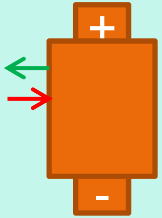
Peak shaving

- Electrical energy costs usually depend on the maximum power consumption peak in a specific interval (e.g. 15 min average)

Switch off consumers



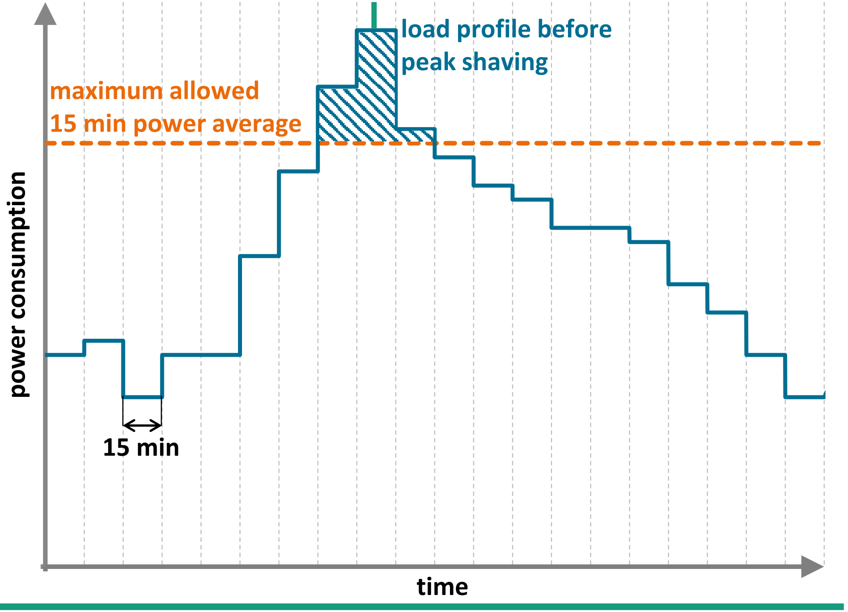
Switch on generators



Use energy storages

influence to production and infrastructure!

no influence to production!



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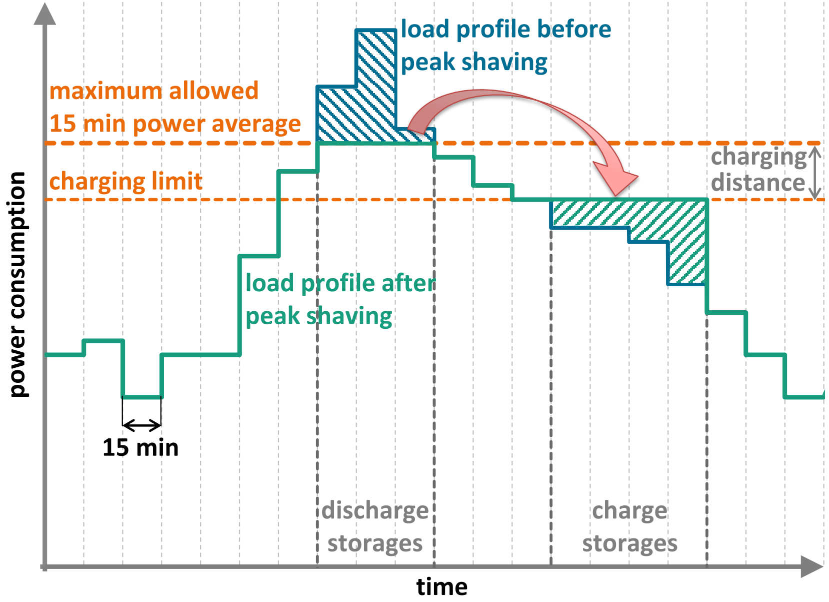
Basics

Peak shaving

- Algorithms for peak shaving
  - regard maximum allowed power consumption by discharging
  - charge storages without exceeding the charging limit
  - optimum utilization of battery capacity
  - include special price models



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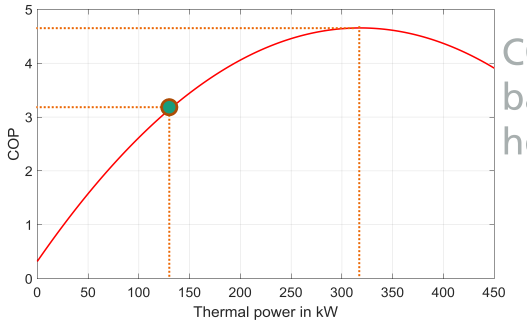
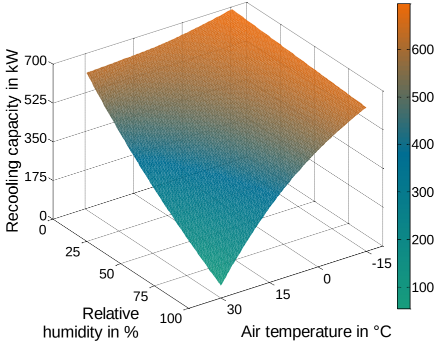
Basics

Efficiency

- Shift operation points to slots with higher efficiency → energy storages needed
- Example: Chiller and recooling plant
  - Chiller's efficiency (COP*) depends on thermal power
  - Recooling plant's efficiency depends on ambient temperature and relative humidity



COP of Chiller based on heat load



Cooling capacity of recooling plant based on ambient temperature and relative humidity

*coefficient of performance: COP = Qth / Pel

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Control approach

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- **Control approach**
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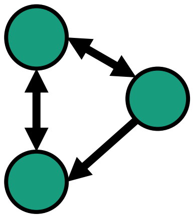

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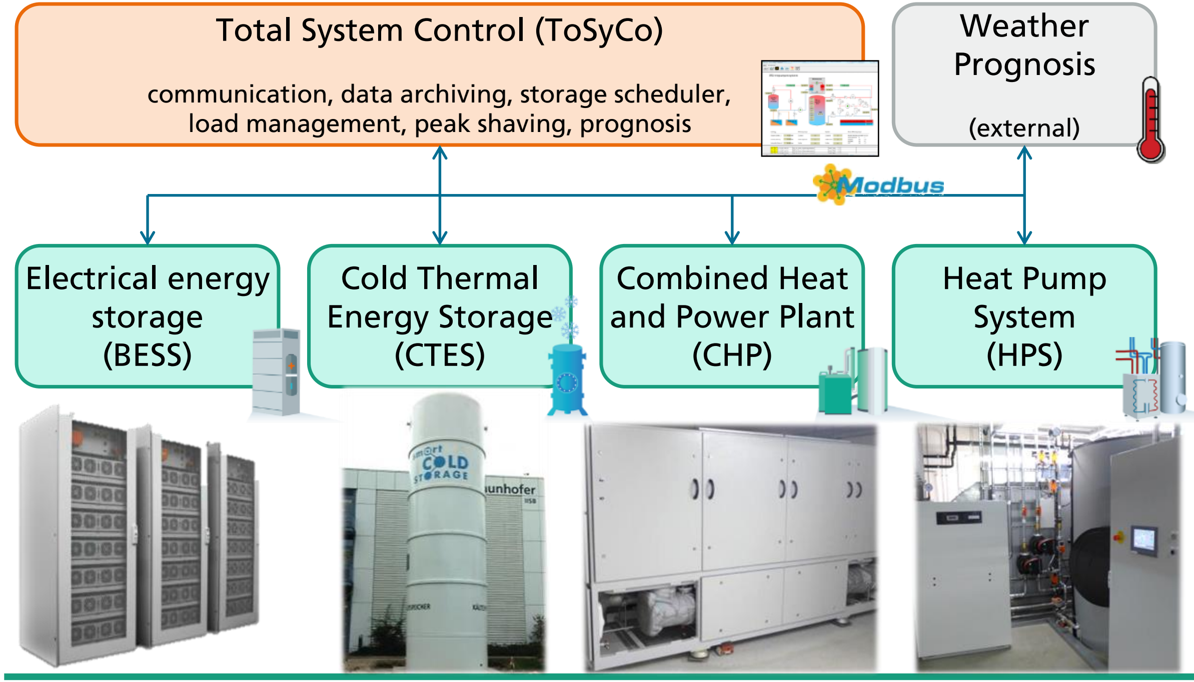
Control approach

Schematic representation



Global operational strategy (ToSyCo)
- ✓ Load prognosis
- ✓ Storage scheduler
- ✓ Peak shaving

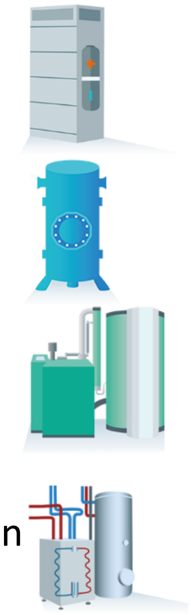
Local operational strategy (PLCs*)
- ✓ Security functions
- ✓ Basic and Stand-Alone operation
- ✓ Physical in-/outputs

*Programmable Logic Controller

Control approach

Regarded plants

- Regarded plants:
  - **Electrical energy storage** (battery system) with 60 kWh* and 100 kW*
  - **Cold thermal energy storage** (80 m^3 water tank) with 460 kWh
  - **Combined heat and power plant** with
    - 150 kW electrical power and 180 kW heating power
    - 24 m^3 **thermal storage system** with 800 kWh
  - **Heat pump system** with
    - 10 kW electrical power consumption and 50 kW heat power generation
    - 3 m^3 **thermal storage system** with 42 kWh



*will be increased to 100 kWh and 500 kW in the future

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Operational strategies

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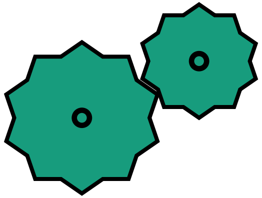

Operational strategies
Electrical Energy Storage

- Battery system is used for
  - dynamic transitions (faster response then thermal storages)
  - filling gaps while thermal plants are started
- No local operational strategy needed

Power electronics and BESS at Fraunhofer IISB

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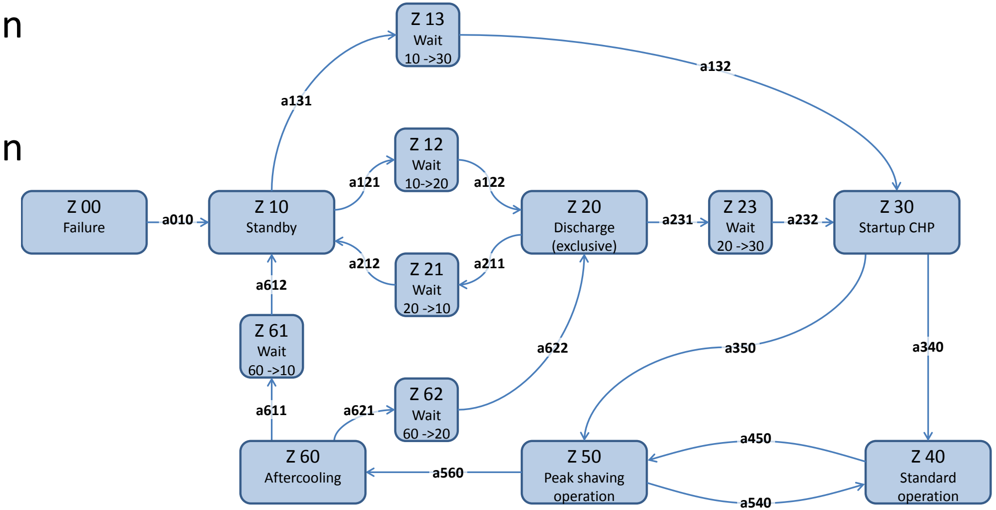
Operational strategies

Combined Heat and Power Plant

- Finite State Machine (FSM) that allows
  - Standard operation based on heating system
  - Standard operation based on electrical power grid
  - Peak shaving operation



State diagram for CHP's finite state machine

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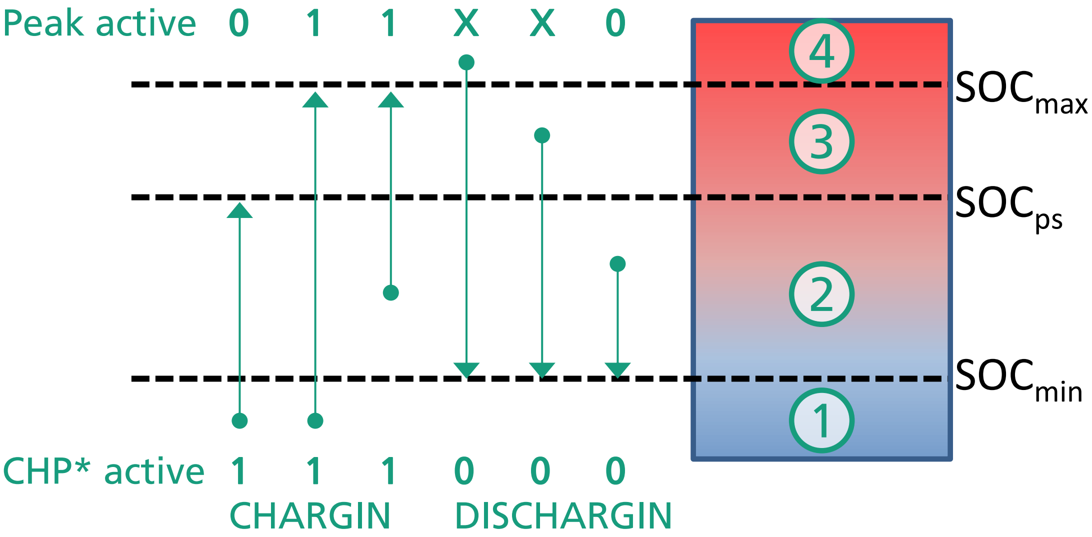
Operational strategies
Thermal Energy Storages

- Division of thermal energy storage into different zones



4 Fully charged

3 Charged if peak isn't active

2 Discharged if peak is active

1 Fully discharged

*Combined Heat and Power Plant

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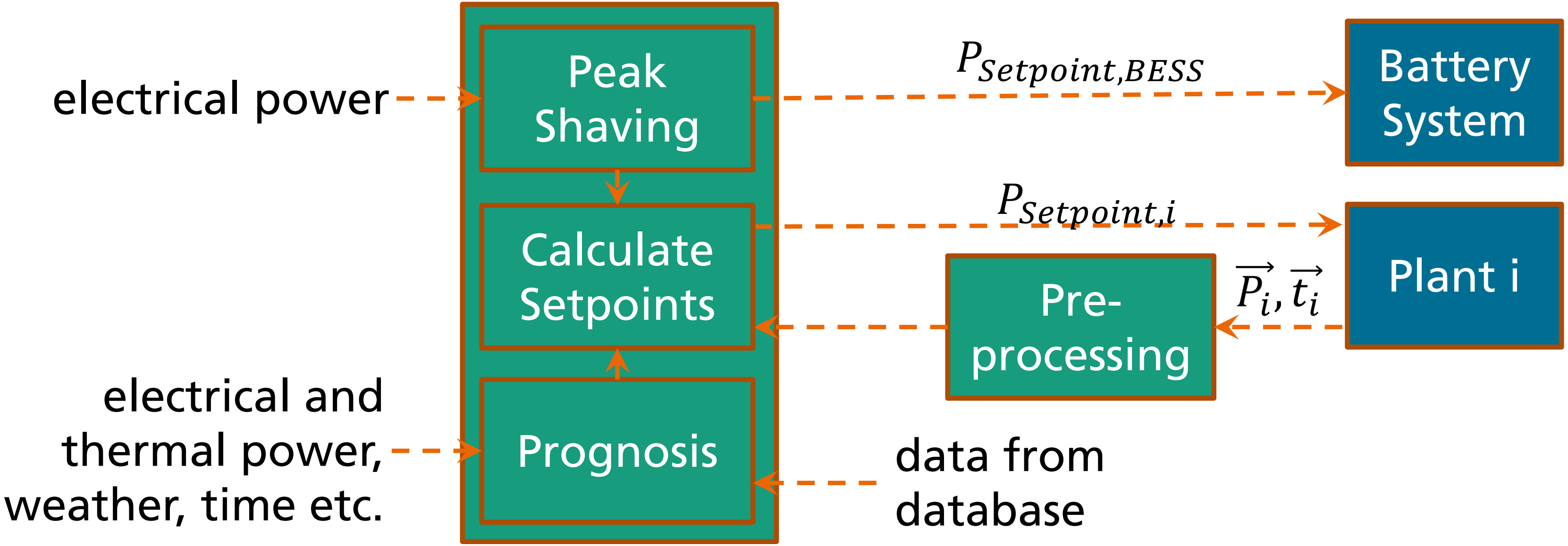
Operational strategies

Peak shaving



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Operational strategies

Efficiency enhancement

- Increase efficiency
  - charge if ambient temperature is low
  - discharge if ambient temperature is high
  - move chillers operation points to ranges with high COPs

80 m³ vacuum isolated cold energy storage at Fraunhofer IISB

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Modelling and simulation

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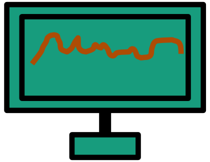
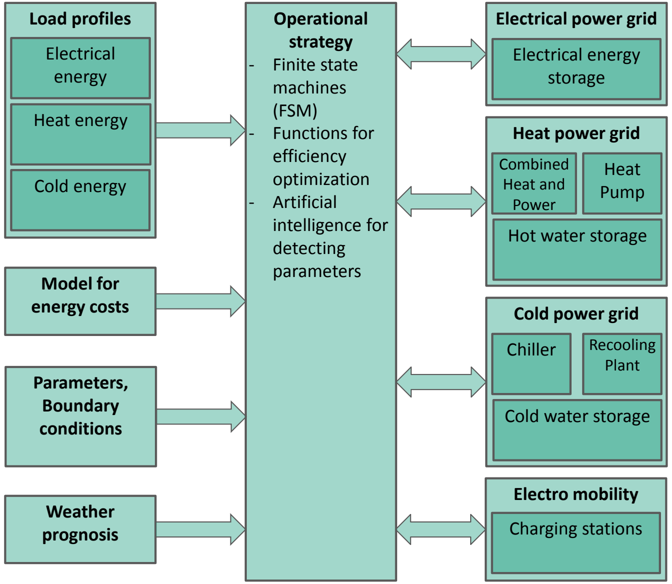


Modelling and simulation

- Black-/Greybox-models for the components
- Simulation of the complete operational strategy
    - Finite state machines
    - Efficiency optimization
    - Artificial intelligence
- Evaluation of “typical” scenarios (e.g. CHP + BESS)
- Extract knowledge for integration into real systems

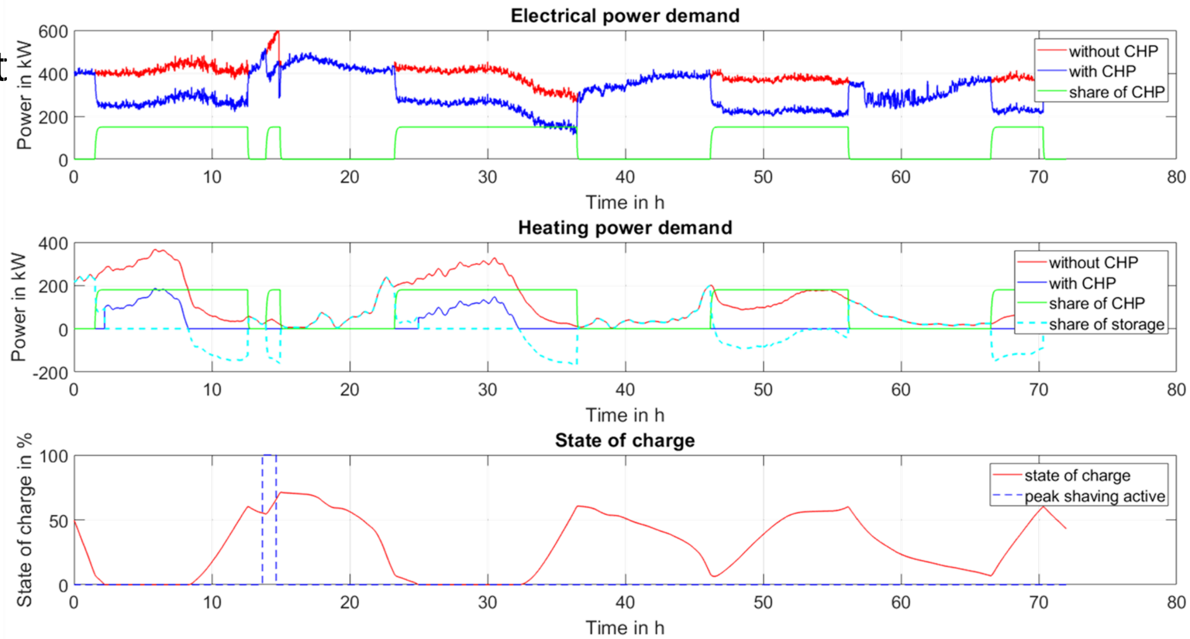


Schematic representation of simulations for ToSyCo

Modelling and simulation

Example: CHP

- Example: Combined Heat and Power Plant (CHP) and 24 m³ thermal energy storage
  - P_{CHP} = 150 kW, Q_{CHP} = 180 kW
  - E_{TES} = 840 kWh
  - peak shaving active from t = 13.6 h



Simulation of CHP and thermal energy storage

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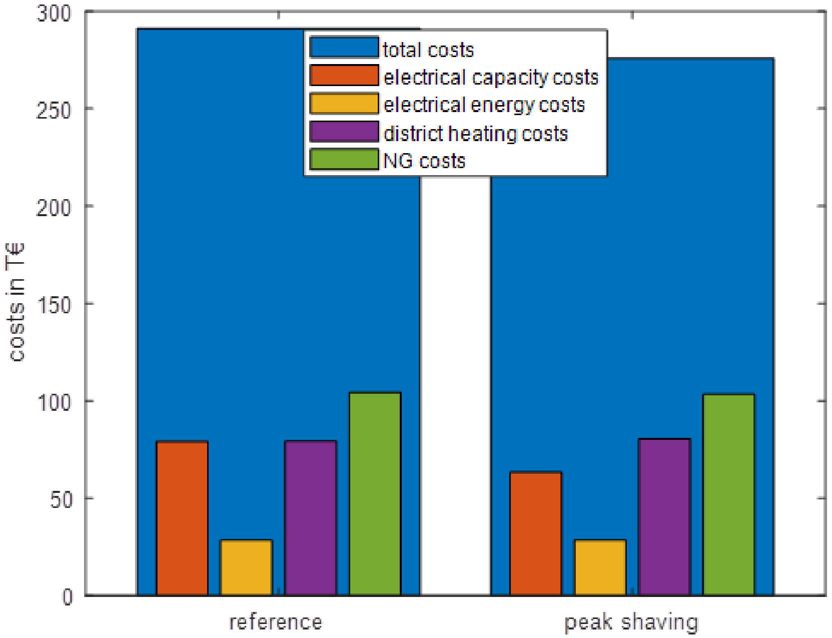
Results

Results

Simulation: Peak shaving

- Reference scenario: Load profile of IISB (2017)
- Peak Shaving with BESS, CHP and TES
- Result:
  - Costs savings: 16 k€
  - Approx. 5 % of full energy costs, 15 % of electrical energy costs
  - No significant influence on "normal" operation



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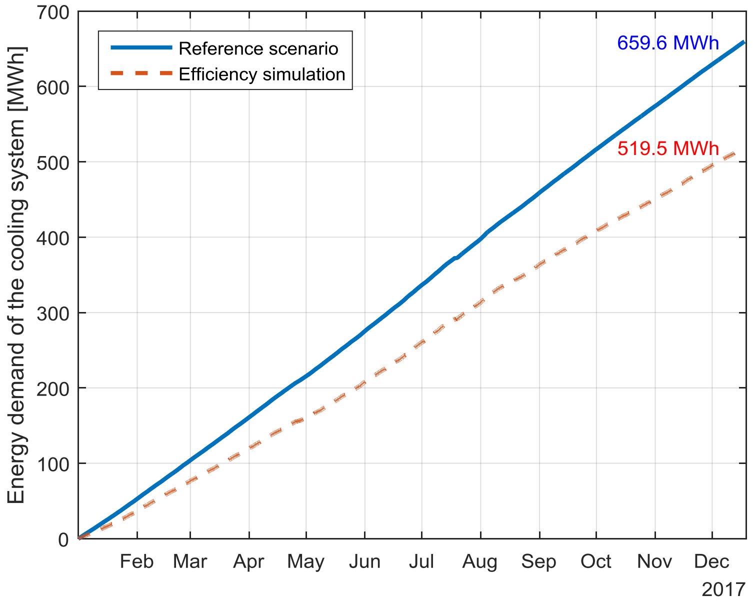
Results

Simulation: Efficiency enhancement

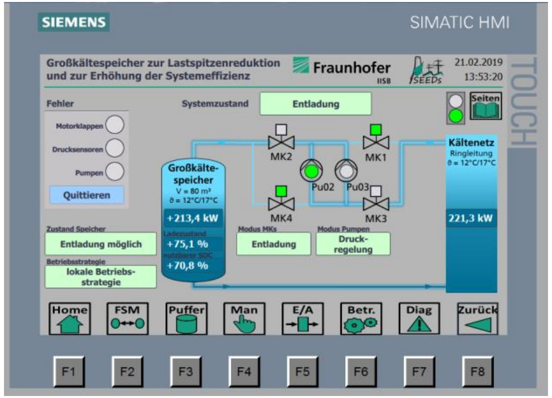
- Reference scenario: Load profile of IISB (2017)
- Efficiency Enhancement with Cold Thermal Energy Storage
- Result:
  - Costs savings: 22 k€
  - Approx. 21 % of energy costs for cold generation

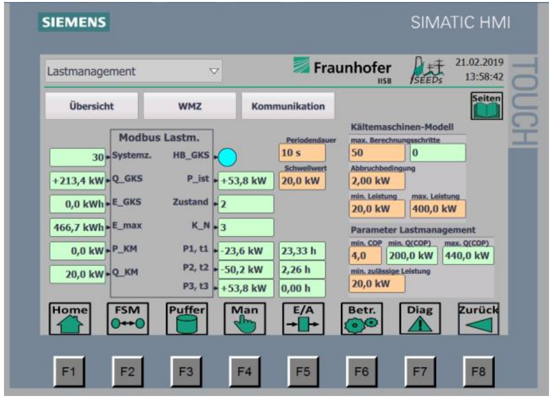


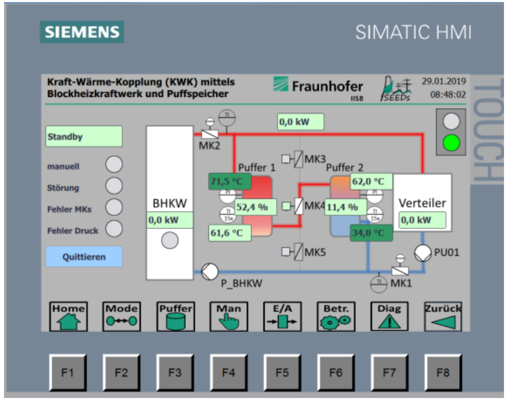
Results

Local operational strategies

- Measurements are not completed yet (actual in process)
- Screenshots of the component‘s HMIs







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Outlook

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Summary and outlook

- ToSyCo as intelligent platform for
  - peak shaving
  - increasing efficiency of energy systems
- Energy systems are very complex because of individual subsystems
- Simulations are needed for developing operational strategies
- High saving potentials (dependent on price model)
- Finalization of ToSyCo at the Fraunhofer IISB is actual in process

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Contact

Thank you for your attention!

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Appendix
Tasks of ToSyCo

- Task of ToSyCo
  - Communication to measurement devices and PLCs* for acquiring data
  - Archive values in database
  - Generate reports
  - Call external weather prognosis
  - Create load prognosis for electrical and thermal grids
  - Detect optimum time slots for dis-/charging storages
  - Peak shaving with electrical and thermal energy storages

*Programmable Logic Controller

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Appendix

Tasks of each plant

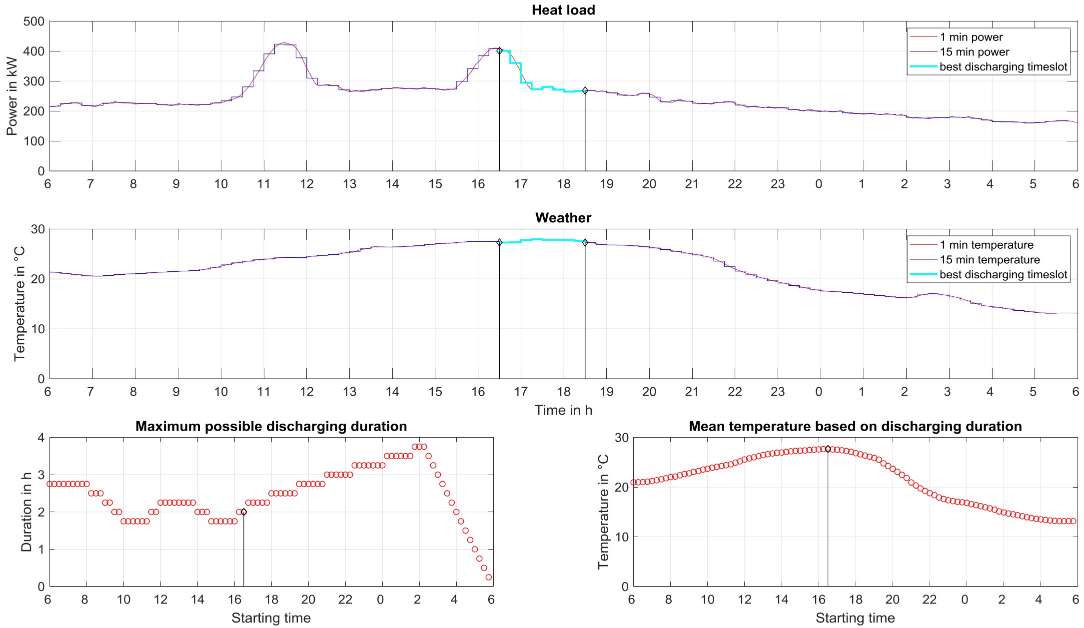
- Task of each plant: Local control (PLC*) for
  - Basic operational strategy
  - Stand-Alone operation strategy
  - Security functions
- Kinds of methods in ToSyCo and local controls
  - Finite state machines for the description of the components states
  - Mathematical optimization functions for detecting the best operation points
  - Artificial intelligence for detecting parameters automatically

*Programmable Logic Controller

Appendix

Cold Thermal Energy Storage

- Increase efficiency
  - charge if ambient temperature is low
  - discharge if ambient temperature is high
- Help in shaving power peaks
  - discharge if peak is active
  - switch off chiller and recooling plant



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Appendix

Calculate SOC of TES

- Energetically calculation of State-of-Charge (SOC)
  - Cold water storage $SOC_{energ} = \frac{1}{H \cdot (T_{max} - T_{min})} \cdot \sum_{k=1}^{N} (T_{max} - T_k) \cdot dh_k$
  - Hot water storage $SOC_{energ} = \frac{1}{H \cdot (T_{max} - T_{min})} \cdot \sum_{k=1}^{N} (T_k - T_{min}) \cdot dh_k$
- Calculation of usable State-of-Charge (SOC)
  - Cold water storage $SOC_{nutz} = \frac{1}{H} \cdot \sum_{k=1}^{N} (T_k < T_{VL,max}) \cdot dh_k$
  - Hot water storage $SOC_{nutz} = \frac{1}{H} \cdot \sum_{k=1}^{N} (T_k > T_{VL,min}) \cdot dh_k$

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Appendix
Communication

- Uniform Modbus TCP communication is used
- Following registers are defined for each component:
  - Bidirectional Heartbeat
  - Setpoint
  - Actual power (electrical equivalent)
  - Actual state (Off, Standby, Charge, Discharge)
  - operating point dependent P-t-Value pairs
    Example: P1 = 100 kW, t1 = 30 min → available Energy: E = 50 kWh

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