Demand Response Potential of Zero Energy Blocks of Buildings: Modeling and Testing Results from a Case Study in Germany

Sustainable Places 2018

Sim4Blocks

SUSTAINABLE
PLACES
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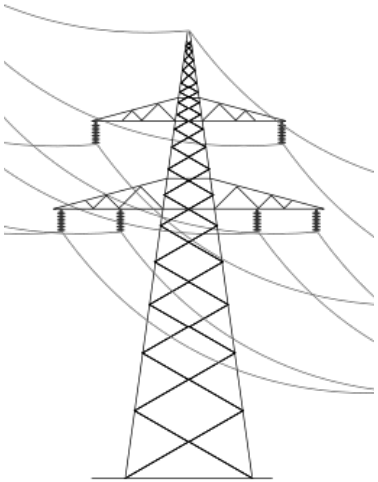
Overview

- Research Problems and Approach
- Modelling and Control
- Optimizing Self Consumption
- Impact of Partizipation in Power Markets
- Conclusions

Simulation-Assisted DR in Building Blocks



Building Model:
- White box
- Grey box
- Black box

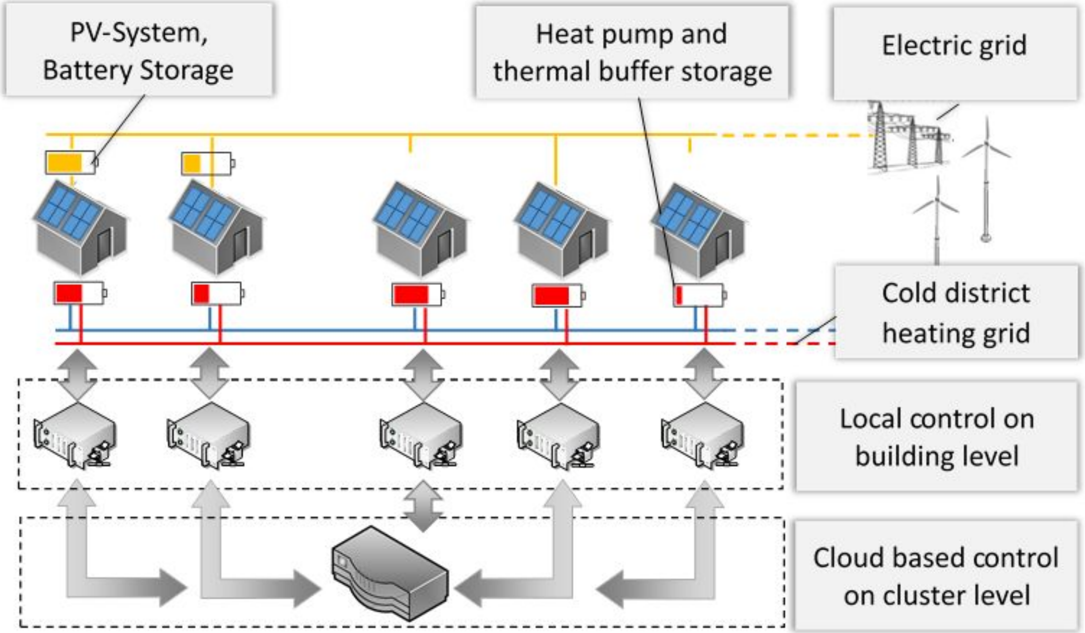
Block Level:
- Flexibility ontology
- Communication framework
- Optimization approach for cluster

Aggregator:
- Valorisation
- Balancing
- Contract structure

Control Approach for Sim4Blocks

- The heat pump and battery storage are controlled by a local energy manager
- Those energy managers can be controlled by signals from a cloud based Virtual Machine (VM)

→ Simulations for MPC will also run in this VM from where access to all monitoring and weather data is available


PV-System, Battery Storage

Heat pump and thermal buffer storage

Electric grid

Cold district heating grid

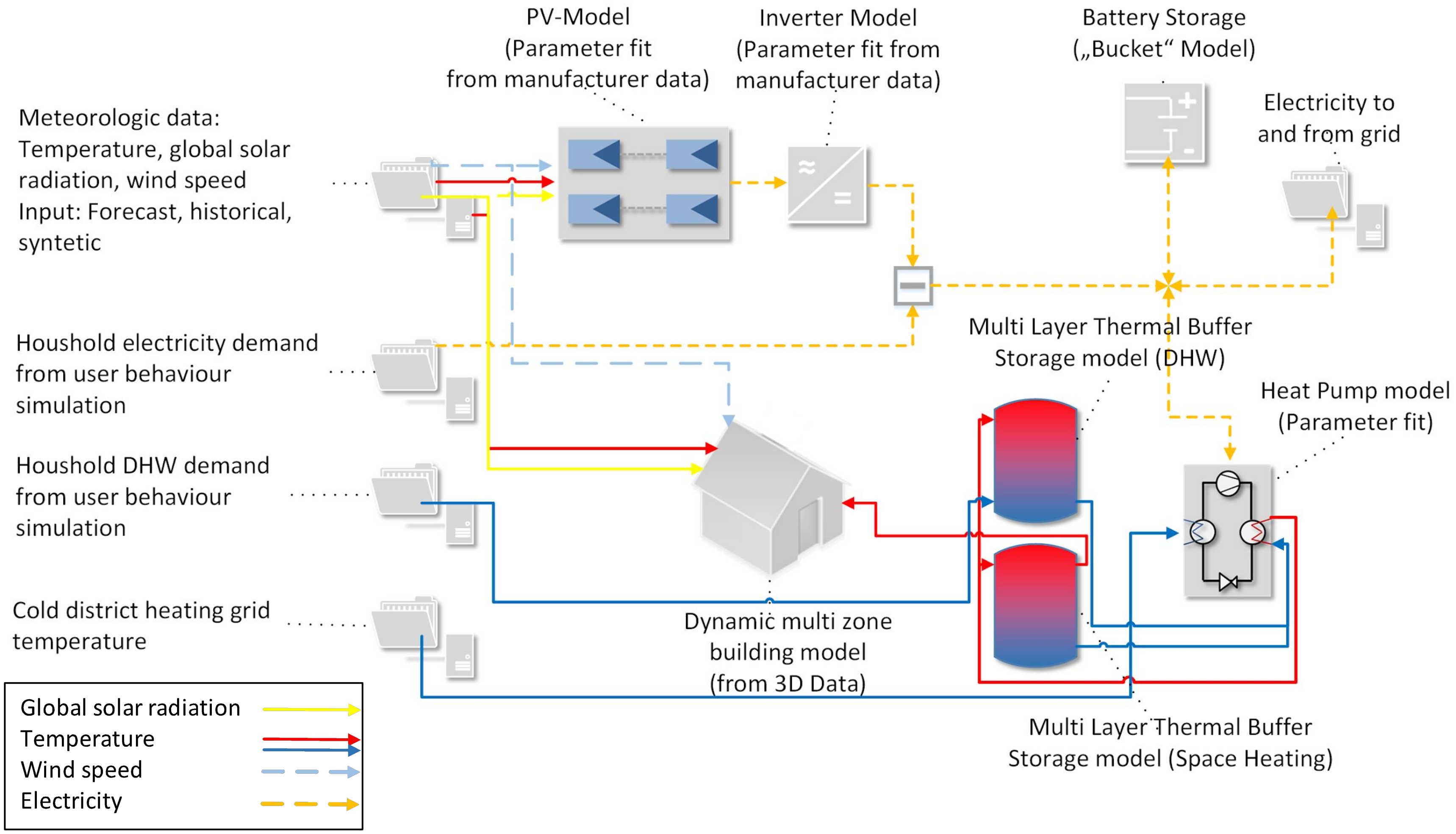
Local control on building level

Cloud based control on cluster level

Collecting Modelling Approaches for a Smart Quarter

- White-Box Model in INSEL
- Four energy system modelling framework applications:
    1. Own consumption optimization with HP and PV Day-Ahead-Market using rule-based heuristic strategies and comparative analysis
    2. Impact of negative aFRR energy use in HPs on PV´self consumption in a self consumption optimization framework
    3. Rule-based heuristic revenue maximization in the aFRR-context with a cluster of buildings. Comparative analysis strategies and pooling effects on energy use and self-consumption
    4. Framework for baseline calculation in cooperating dynamic temperature set-points and PV self consumption optimization

Building Level Model



PV-Model
(Parameter fit
from manufacturer data)

Inverter Model
(Parameter fit from
manufacturer data)

Battery Storage
(„Bucket“ Model)

Meteorologic data:
Temperature, global solar
radiation, wind speed
Input: Forecast, historical,
syntetic

Electricity to
and from grid

Houshold electricity demand
from user behaviour
simulation

Multi Layer Thermal Buffer
Storage model (DHW)

Heat Pump model
(Parameter fit)

Houshold DHW demand
from user behaviour
simulation

Cold district heating grid
temperature

Dynamic multi zone
building model
(from 3D Data)

Multi Layer Thermal Buffer
Storage model (Space Heating)

Global solar radiation
Temperature
Wind speed
Electricity

Control Strategies

Optimized self consumption

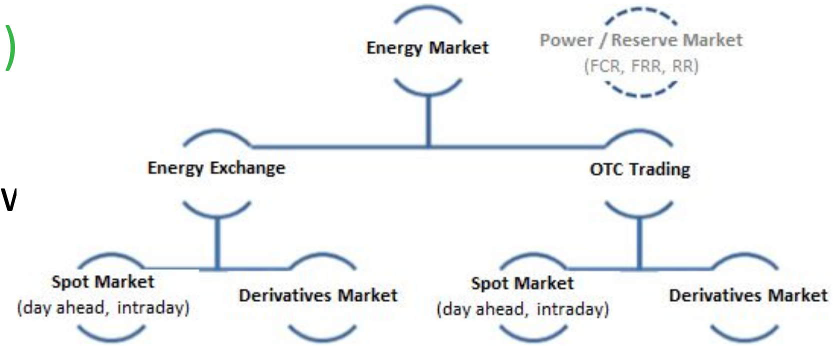
- Today most suitable use case for end customers in Germany because of fixed price feed-in tariffs for smaller PV plants (feed in tariff < electricity price) → might lead to reduced DR flexibility potential

Participation in Energy Markets (spot marked trade)

- End customers could profit from flexible heat pump tariffs linked to the daily electricity price fluctuations
- The direct marketing approach for generated PV energy is most suitable for operators of very old (>20 years) and lager PV-plants (> 100 kWp)

Participation in Power Markets (sec. reserve)

- More difficult conditions to participate in
- Combined building, HP and PV operations shov a potential which was barley tapped until today



Energy Market

Power / Reserve Market (FCR, FRR, RR)

Energy Exchange

OTC Trading

Spot Market (day ahead, intraday)

Derivatives Market

Spot Market (day ahead, intraday)

Derivatives Market

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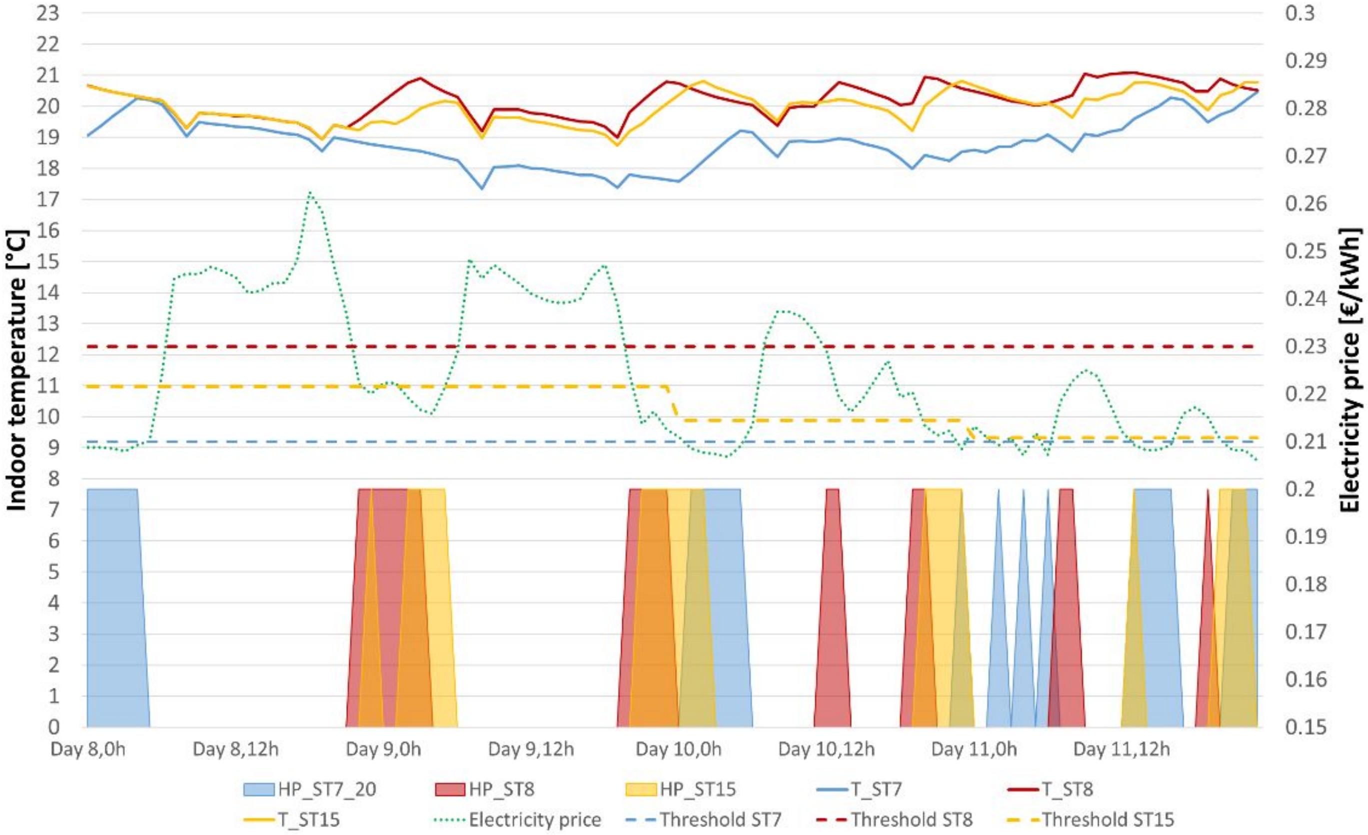
Self Consumption Optimization with HP and PV Day-Ahead-Market Using Rule-Based Heuristic Strategies and Comparative Analysis

- Model based on a real existing single-family building in Wüstenrot

- 3 setpoint temp. scenarios for 16 different strategies (temperature and electricity price thresholds)

Setpoint controls	20± 0 °C	20± 1 °C	20± 2 °C
Strategy 1	No limit. Static price of 0.22 [€/kWh]. HP works whenever necessary.		
Strategy 2	No limit. Day-ahead dynamic prices. HP works whenever necessary.		
Strategy 3	HP works whenever necessary, with a limit of 0.21 [€/kWh]		
Strategy 4	HP works whenever necessary, with a limit of 0.23 [€/kWh]		
Strategy 5	HP works whenever necessary, with a limit of average price of the day.		
Strategy 6	HP works whenever necessary, only during the night.		
Strategy 7	HP works always with a limit of 0.21 [€/kWh] if T_{air} <21 °C.	HP works always with a limit of 0.21 [€/kWh] if T_{air} <22°C.	
Strategy 8	HP works always with a limit of 0.23 [€/kWh] if T_{air} <21°C.	HP works always with a limit of 0.23 [€/kWh] if T_{air} <22°C.	
Strategy 9	HP works always if price is lower than av. of the day and T_{air} <21°C.	HP works always if price is lower than av. of the day and T_{air} <22 °C.	
Strategy 10	HP works always during the night if T_{air} <21°C.	HP works always during the night if T_{air} <22 °C.	
Strategy 11	HP works always with a limit of 0.21 [€/kWh] if T_{air} <22 °C.	HP works always with a limit of 0.21 [€/kWh] if Tair <23 °C.	
Strategy 12	HP works always with a limit of 0.23 [€/kWh] if T_{air} <22 °C.	HP works always with a limit of 0.23 [€/kWh] if T_{air} <23 °C.	
Strategy 13	HP works always if price is lower than av. of the day and T_{air} <22 °C.	HP works always if price is lower than av. of the day and T_{air} <23 °C.	
Strategy 14	HP works always during the night if T_{air} <22 °C.	HP works always during the night if T_{air} <23 °C.	
Strategy 15	HP works always if price among the lowest 25% of the day and T_{air} <21 °C.	HP works always if price among the lowest 25% of the day and Tair <22 ° C.	
Strategy 16	HP works always if price among the low. 25% of the day and T_{air} <22 °C.	HP works always if price among the low. 25% of the day and T_{air} <23 °C.	

Self Consumption Optimization with HP and PV Day-Ahead-Market Using Rule-Based Heuristic Strategies and Comparative Analysis



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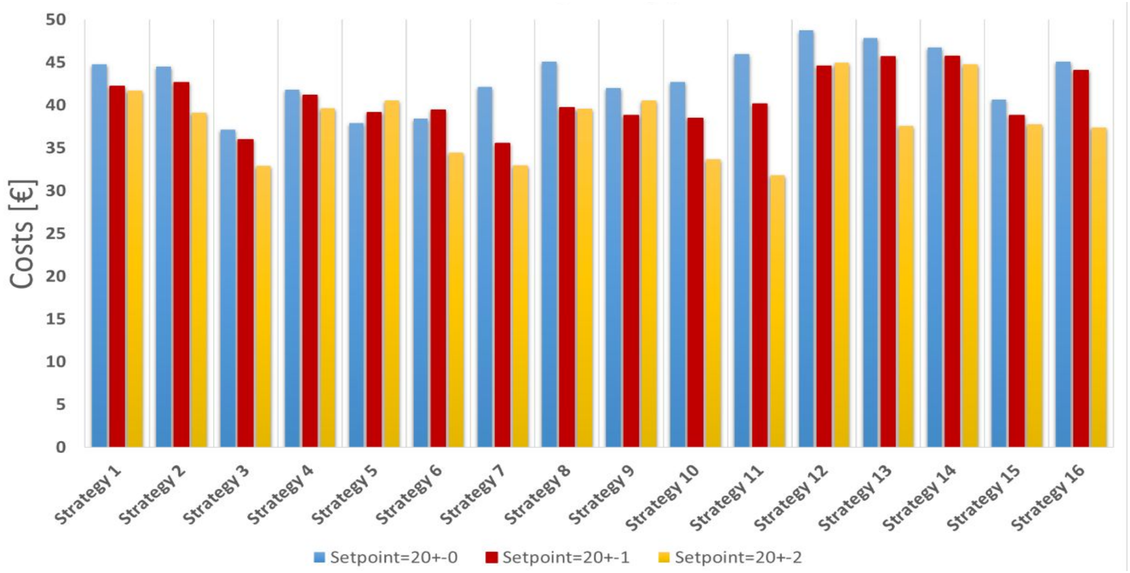


- Dynamic price thresholds instead of fixed price thresholds (to prevent low activations or overheating of the building)

- Cost savings up to 25% may be achieved by using optimal strategies, increasing the self-consumption ratio, having almost no influence on the thermal comfort and achieving significant peak reductions on the grid

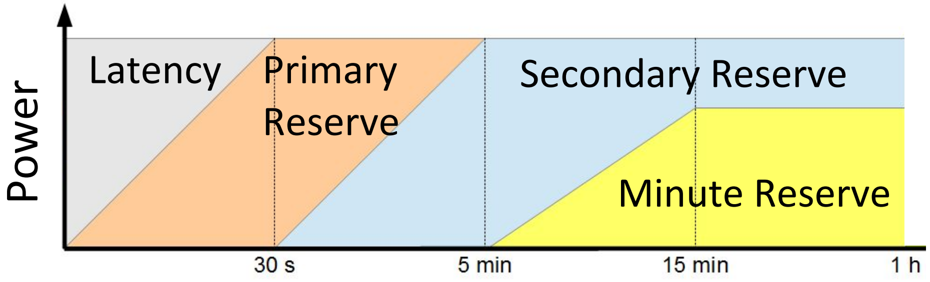
Power markets: Secondary Reserve (aFRR)

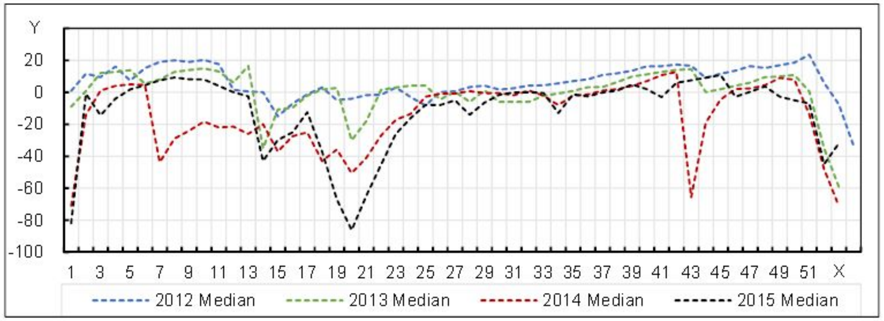
- Secondary reserve power market in Germany = Frequency restauration reserve (aFRR)
- The demanded power in the secondary reserve market is volatile
- Offers and bids are placed for an entire week
- Distinction between peak (HT, Monday – Friday, 8:00am to 8:00pm) and off peak (NT)
- Duration of a demand for negative power from the grid is a complicated function of the demand and of the structure of plants and other bidders

→ Activation calls are very hard to predict

→ Cheaper bids are activated first

→ Very cheap providers will be called upon almost constantly with few interruptions





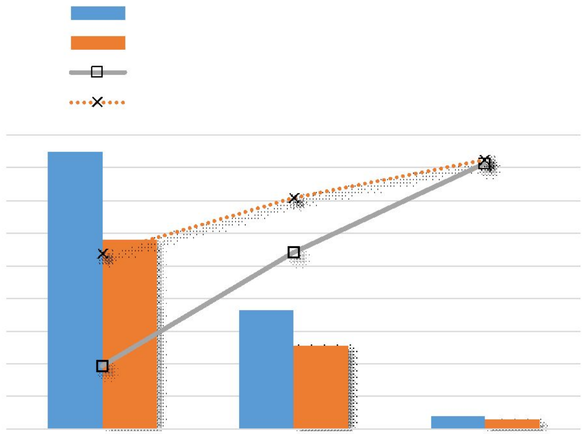
Price NT tariff

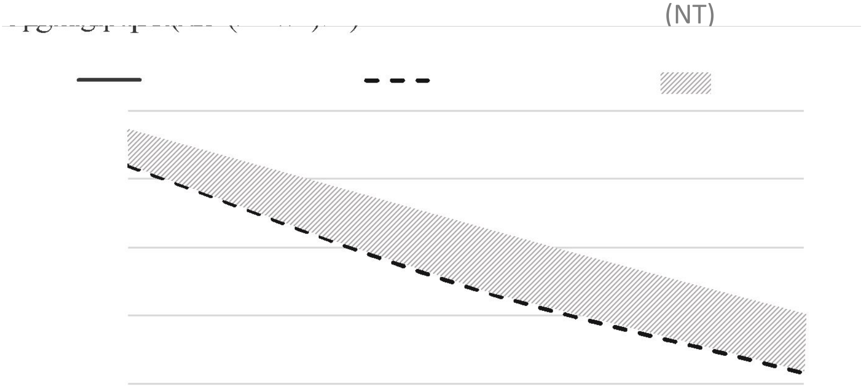
Impact of Negative aFRR Energy Use for HPs on PV Self Consumption

- The simulations show a good load shift potential
- 30% of the electrical load could be shifted in both cases, positive and negative DR
- For positive DR only minor losses of comfort must be tolerated (≤ 1K room temp. reduction)
- For negative DR 9 % efficiency reduction → up to 38 % higher load shift potential (NT,-10€/MWh)
- 1 min activation call duration
- Heat pump cycle times are much longer than the Ø secondary reserve power activation

→ Reduction of heat pumps life and efficiency

→ Solution: Heating rods, heat pump pool, incorporation of battery storage





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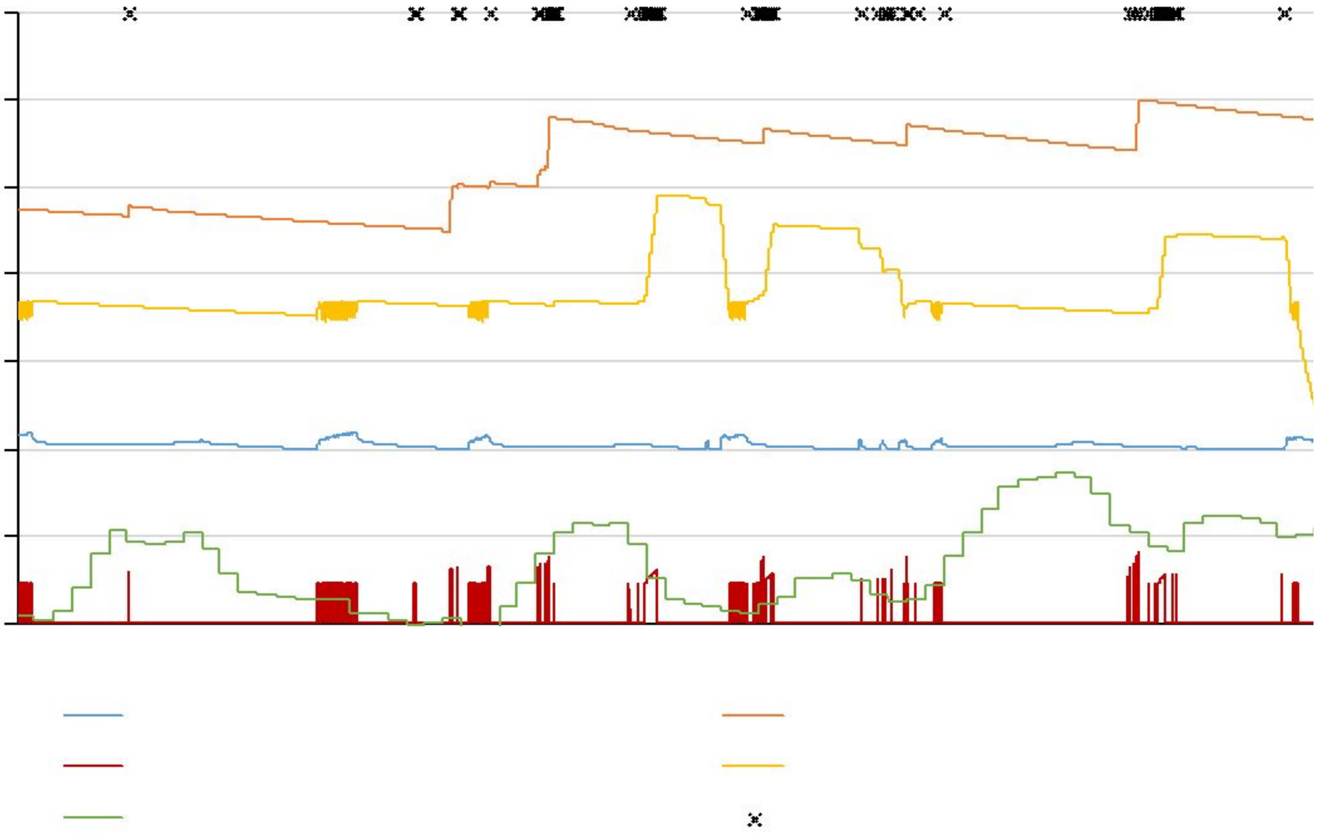
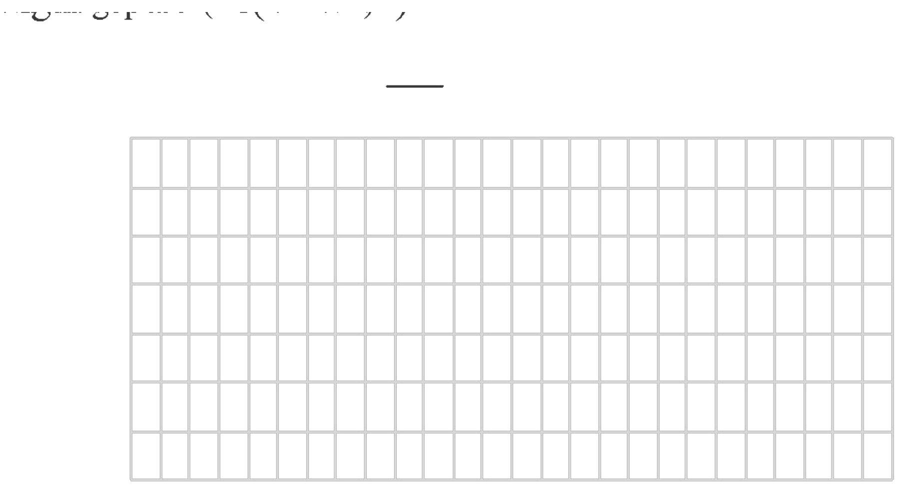
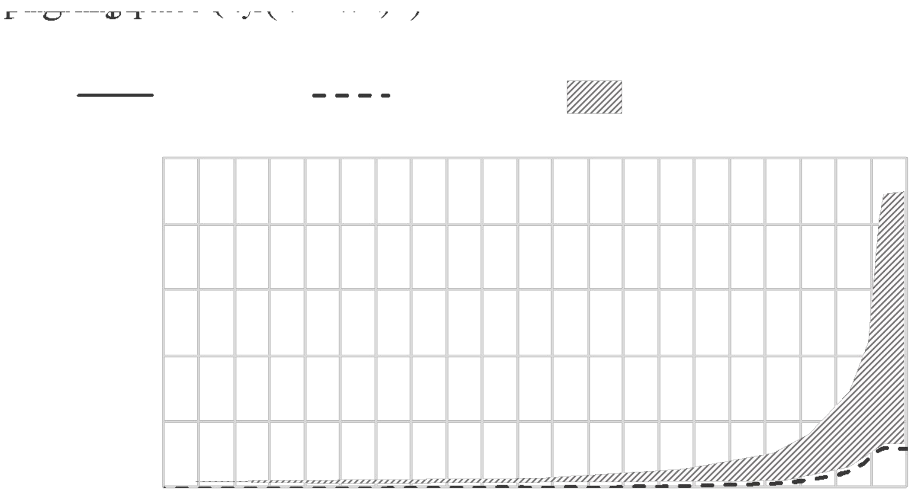
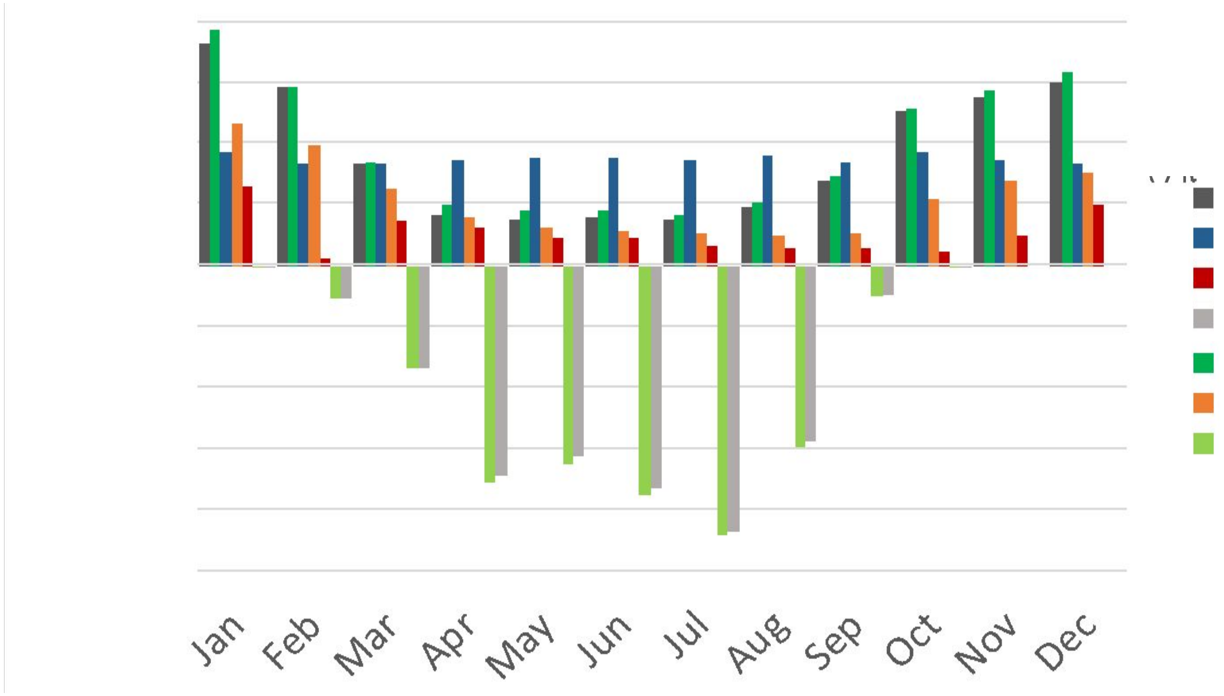


Financial Gains on a Household Level from Negative aFRR





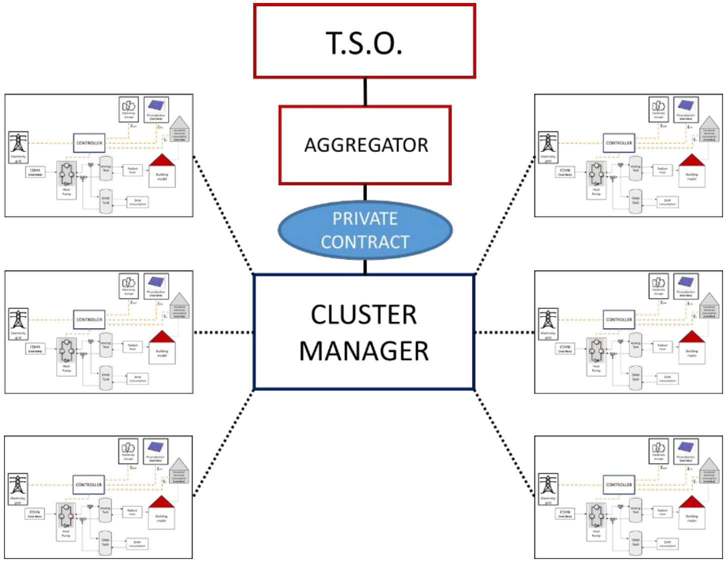
Results for PV and Heat Pump



Heat pump share of total electricity consumption (11014 kWh): 35%
Annual contribution secondary reserve aFRR to heat pump electricity: 50%
PV own consumption with aFRR: 31%
PV own consumption without aFRR: 33%
Additional electricity demand with aFRR (losses COP and storage): 7%

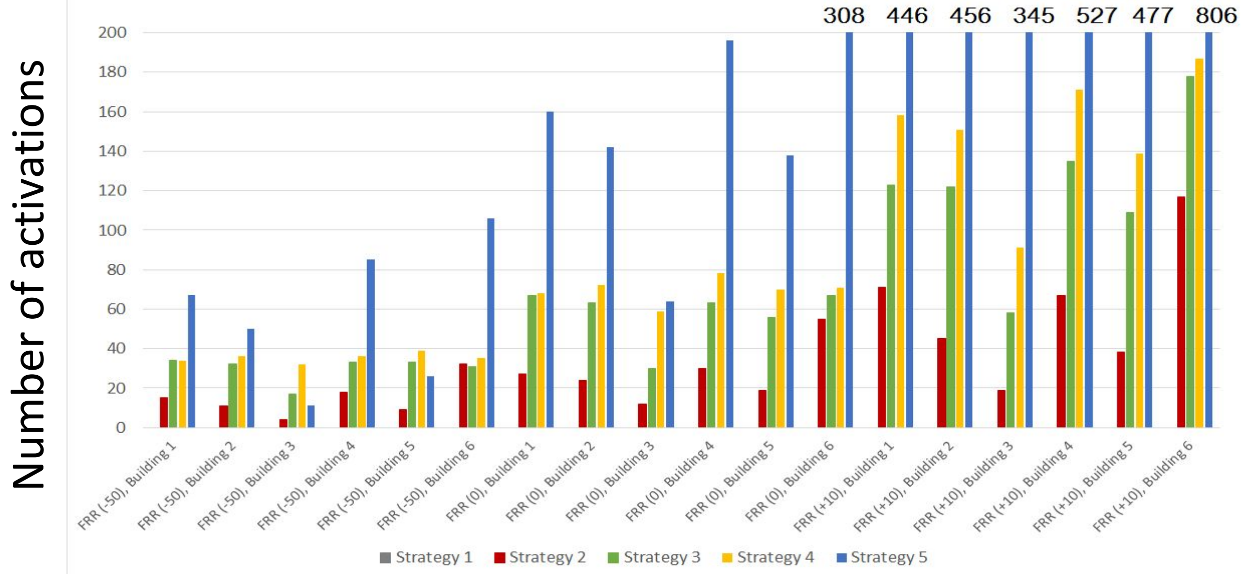
Rule-Based Heuristic Revenue Maximization in the aFRR-Context With a Cluster of Buildings: Comparative Analysis Strategies and Pooling Effects on Energy Use and Self Consumption, Aggregated Operation and Optimization

- Cluster management strategies for 6 buildings were examined (focus on February 2016)
- Different strategies with various price scenarios: negative, zero, and positive cost → vary in their number of activation calls and their duration
- Cluster manager makes the decision whether the buildings should be activated or not when an activation call is received
- Two main approaches:
  1. Cluster manager provides the aggregator with as much energy as it can → Any building will activate its heat pump after fulfilling specific requirements (strategy 2,3,4)
  2. The cluster manager always has to provide the aggregator with a certain (and constant) amount of power, deciding which buildings will be activated depending on some criteria



Strat.	FRR(-50) Price: -50 €/MWh	FRR(0) Price: 0 €/MWh	FRR(+10) Price: +10 €/MWh
1	Normal control, no activation calls.		
2	Activate HP if electrically self-sufficient and T_{air} below 21 °C.		
3	Activate HP if electrically self-sufficient and T_{air} below 22 °C.		
4	Activate HP if electrically self-sufficient and T_{air} below 23 °C.		
5	Choose the 3 buildings with the lowest temperature.		

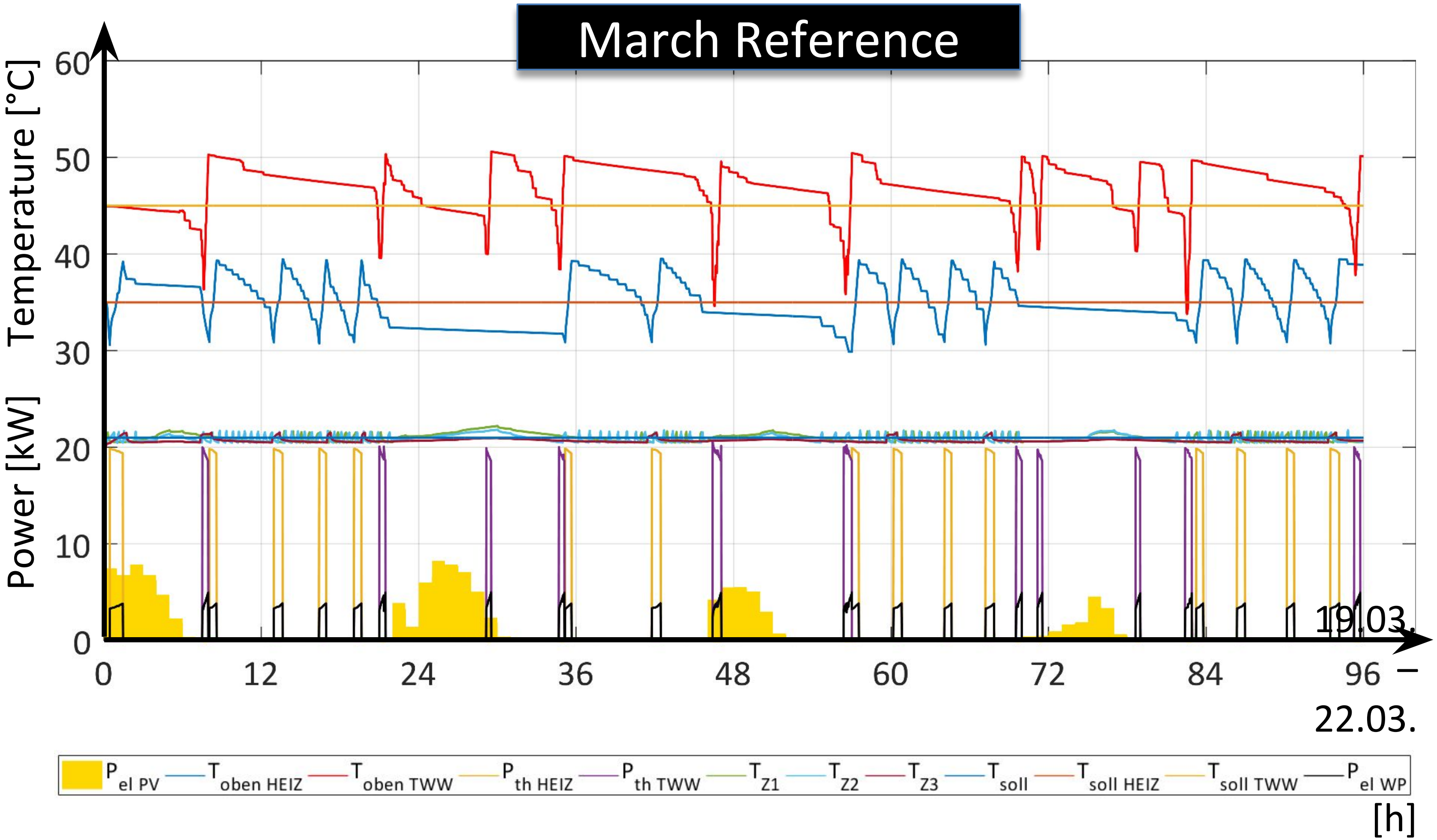
Rule-Based Heuristic Revenue Maximization in the aFRR-Context With a Cluster of Buildings: Comparative Analysis Strategies and Pooling Effects on Energy Use and Self Consumption, Aggregated Operation and Optimization



	Average activation time [min]	Number of activations
FRR(-50)	3.55	114
FRR(0)	4.50	336
FRR(+10)	14.81	1019

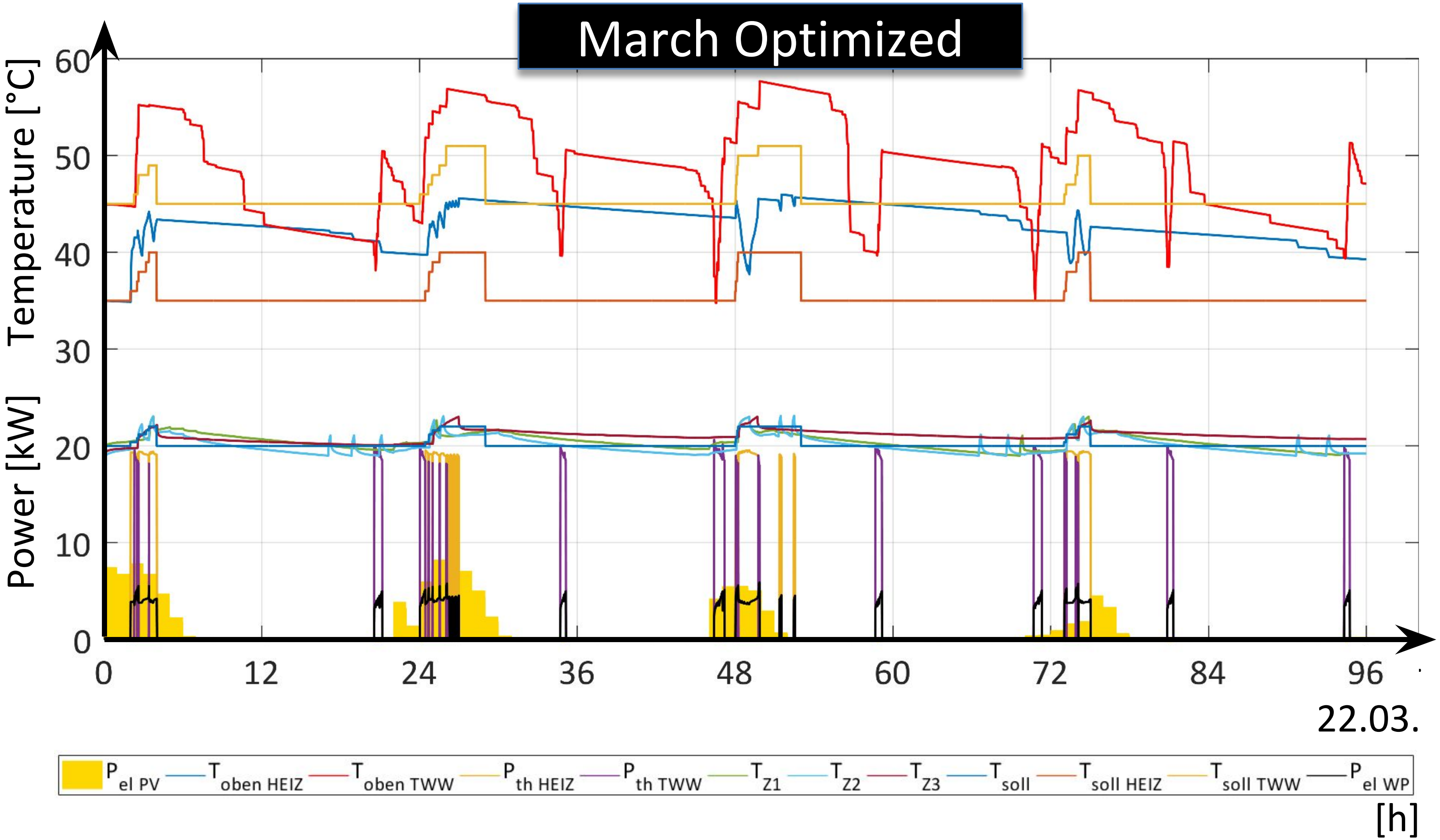
- Strategy 5 involves the highest number of accepted activations due to no temperature constraints (three buildings will always be chosen)
- The higher the temperature threshold, the higher the number of activations
- The differences between strategies 3 and 4 are much smaller than between strategies 2 and 3
- The number of activations generally increased with the price scenarios which have a higher number of activation calls

Framework for Baseline Calculation including Using Dynamic Temperature Set-Points for PV Self Consumption Optimization



March Reference

Framework for Baseline Calculation including Using Dynamic Temperature Set-Points for PV Self Consumption Optimization


March Optimized

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Framework for Baseline Calculation including Using Dynamic Temperature Set-Points for PV Self Consumption Optimization

	January (4d)		March (4d)	
	Reference	Optimized	Reference	Optimized
Demand	81 kWh	82 kWh	54 kWh	52 kWh
PV Production	8,3 kWh		117 kWh	
From Grid	80 kWh	74 kWh	46 kWh	18 kWh
Autarky	**1 %**	**8 %**	**14 %**	**66 %**
EUR Result	-15 €	-15 €	4 €	6 €
From Grid rel.	**100 %**	**94 %**	**100 %**	**38 %**

	January (27d)		March (23d)	
Autarky	**1 %**	**15 %**	**4 %**	**42 %**
From Grid rel.	**100 %**	**101 %**	**100 %**	**64 %**

Conclusions

- PV/heat pump/storage systems in buildings allow participation in day ahead and secondary reserve markets
- PV self consumption ratio is not much affected by DR actions
- Local optimisation of PV/heat pump/storage systems in buildings can strongly increase self consumption and thus reduce grid stress

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www.sim4blocks.eu

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