Modeling flexibility and energy market participation of plus energy neighborhoods with PV/heat pump systems

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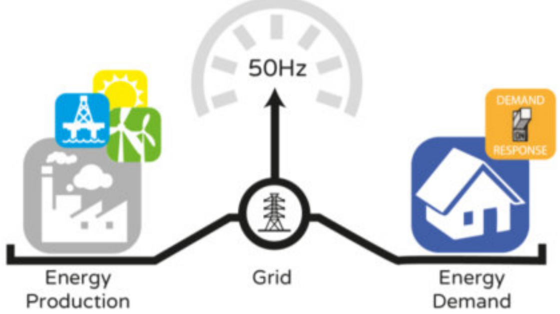
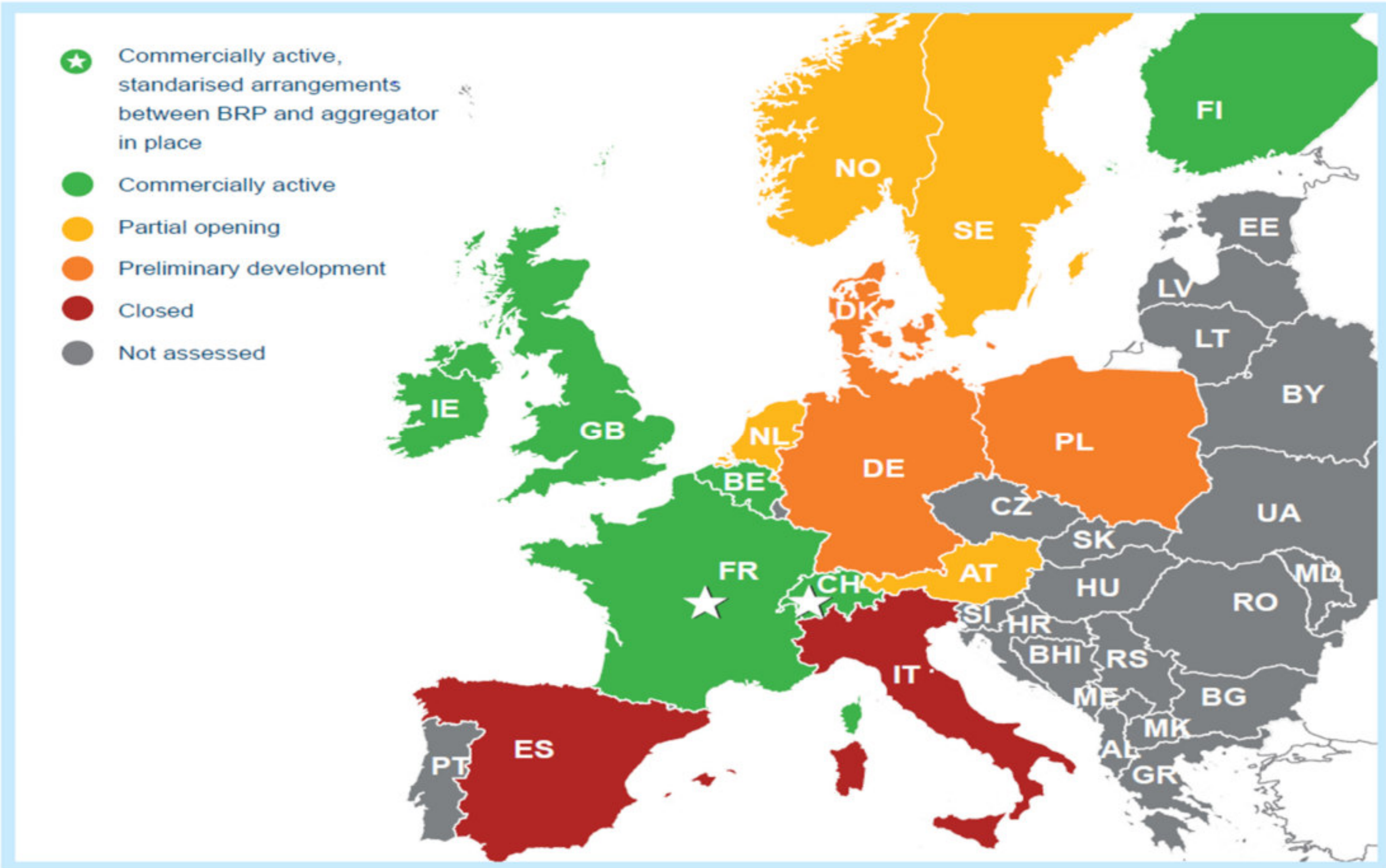


Harnessing DR Potential in Europe at Residential Level



Source: "Mapping Demand Response in Europe Today - 2015", Smart Energy Demand Coalition

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Developments Reducing Barriers to DR with Residential Users

Technology

- Telecommunications
- Control Systems
- Computation Speed

Regulatory

- Market Access
- Market Communication Frameworks

Economic

- Cost-Effective at System Capacity Peaks

Environment

- CO2-Free Replacement for Fossil Fuel Peak Load Plant

Remaining Barriers to DR with Residential Users

Technology

- System Complexity

Regulatory

- System Owner and Market Role Unclear at Local Level
- Technology Neutral Market Access and Pricing Needed

Economic

- Household Bottom-line Effected by Multiple Factors

Environment

- Increased Overall Energy Use vs. System Efficiency

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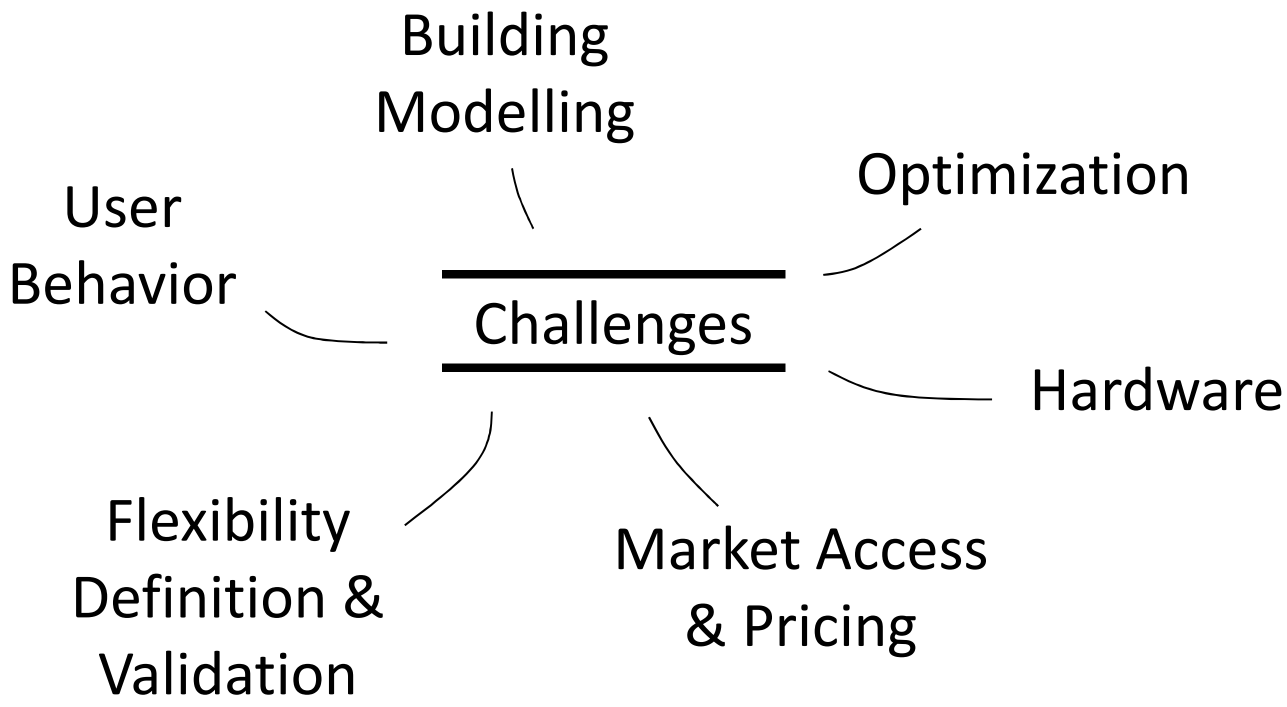
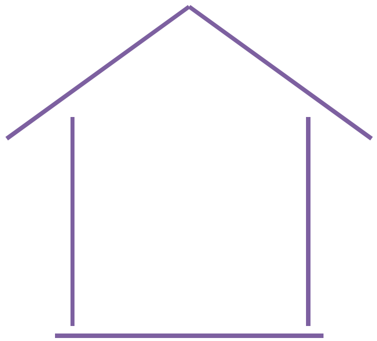
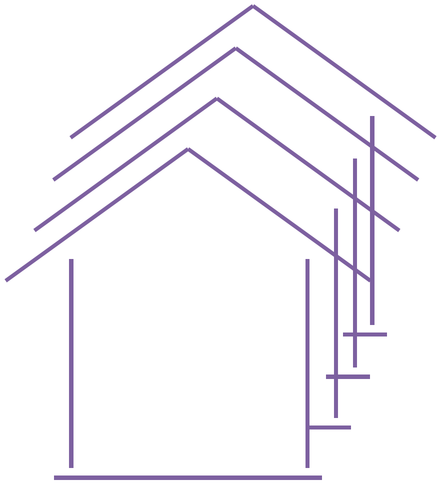
Remaining Barriers to DR with Residential Users



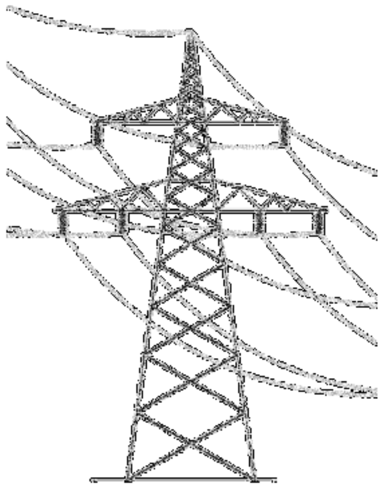
Simulation-Assisted DR in Building Blocks



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



Block Level:
- Flexibility Ontology
- Communication Framework
- Optimization approach for cluster

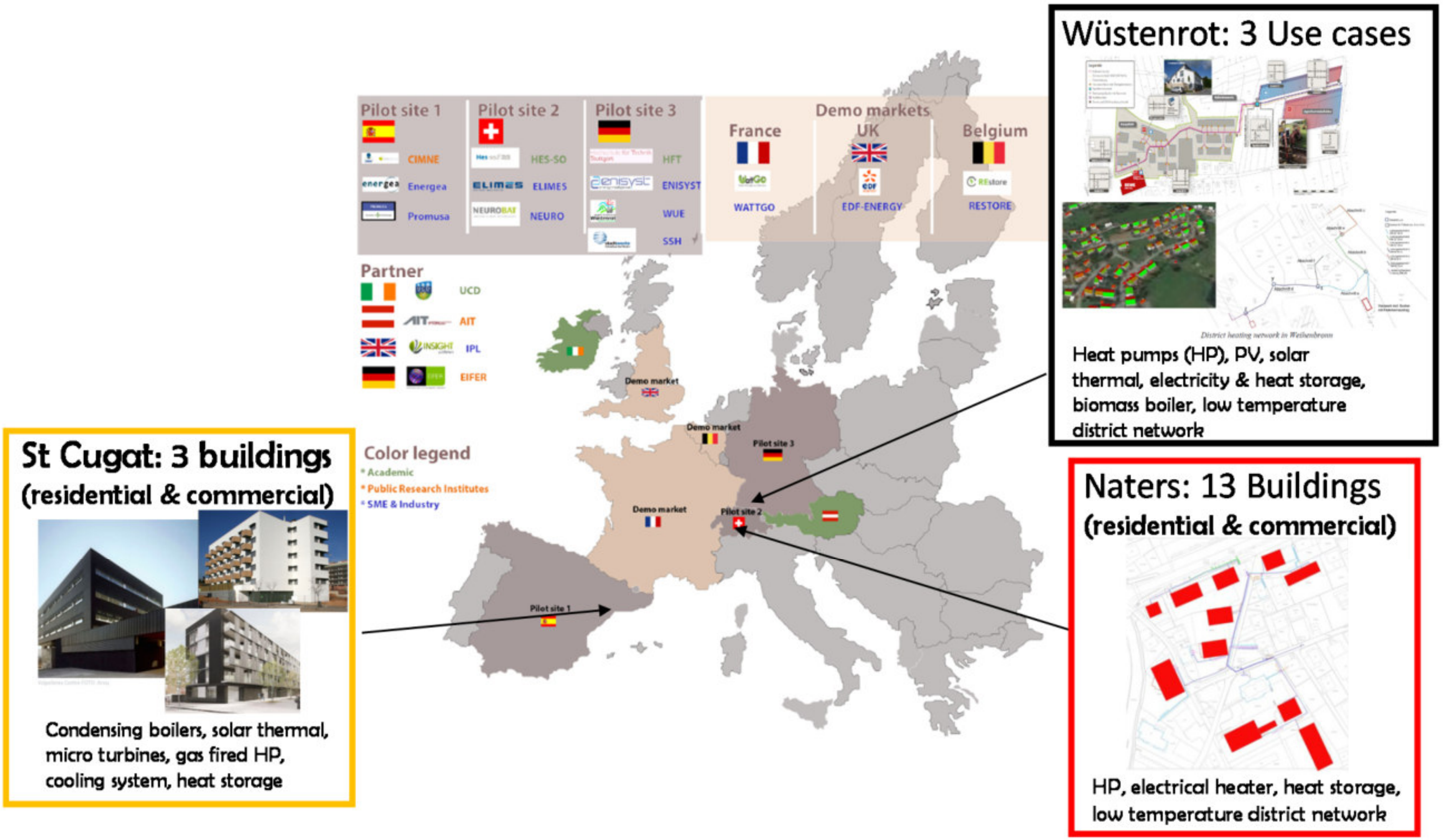


Aggregator:
- Valorisation
- Balancing
- Contract structure

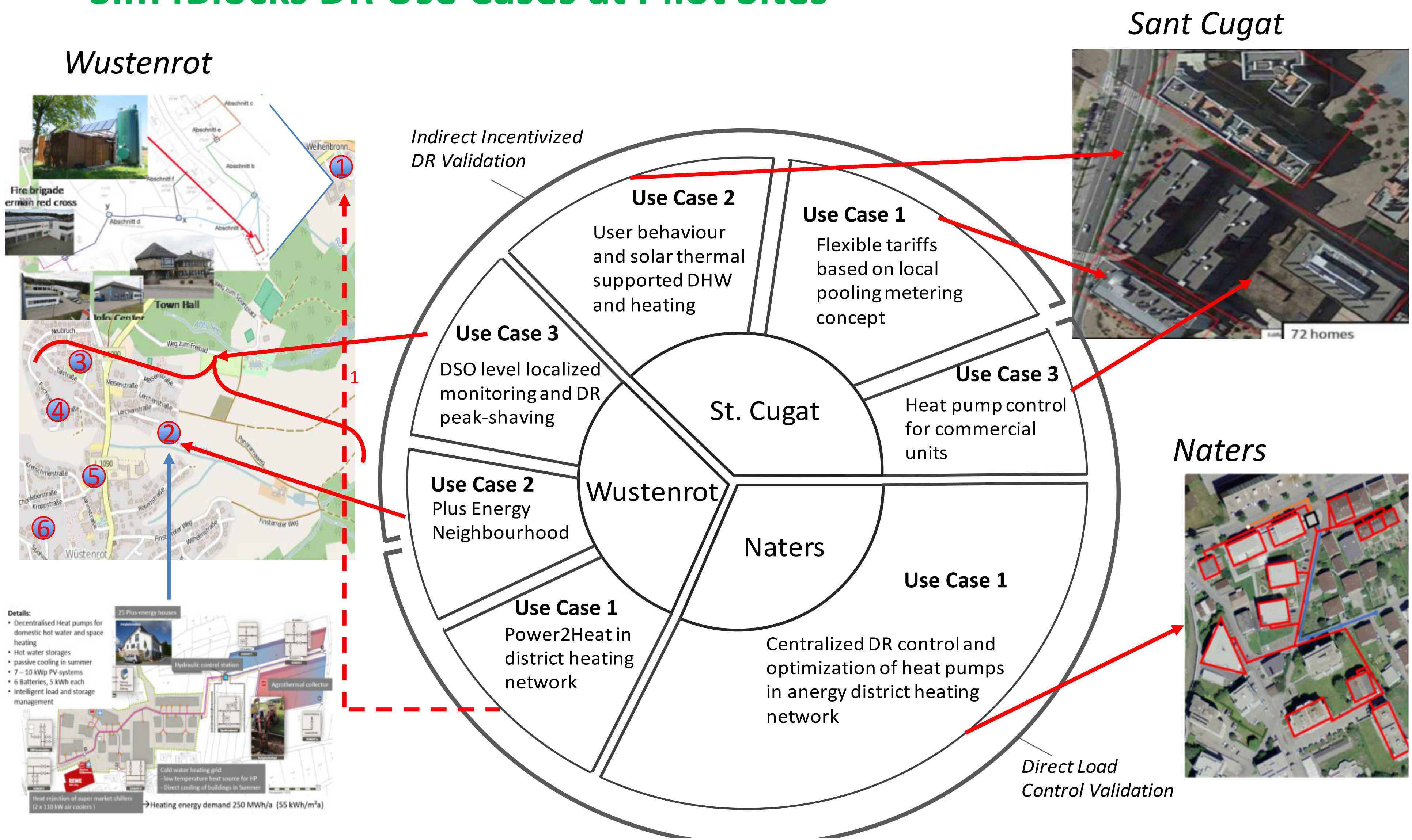
Sim4Blocks DR Services for Specific Use Cases

DR SERVICES	DESCRIPTION
Real time pricing	Providing real time information to the tenants so that they can shift their load to the hours when the electric price is more favourable
Load shifting through charging/ discharging **thermal mass** and hot water storage	Load shifting achieved through **remote control of the thermostats** to exploit the full range of set point temperatures for passive and active storage to shift the peaks during higher cost periods.
Thermal load shifting to fit **solar thermal resource**	Real time information to users so that they can use DHW when there is solar energy available
Dynamic optimization or solar PV production for **self consumption at neighborhood level**	PV generation and electric load forecasting for load shifting, optimization of the solar resource and contribution to reserve markets
Real time optimization of the multiple on site energy sources	Optimizing the combination of heating and cooling demand with the on site electric production to fit the energy loads and the most favorable pricing of both the electricity and gas indexed markets

Sim4Blocks DR Pilot Sites



Sim4Blocks DR Use Cases at Pilot Sites



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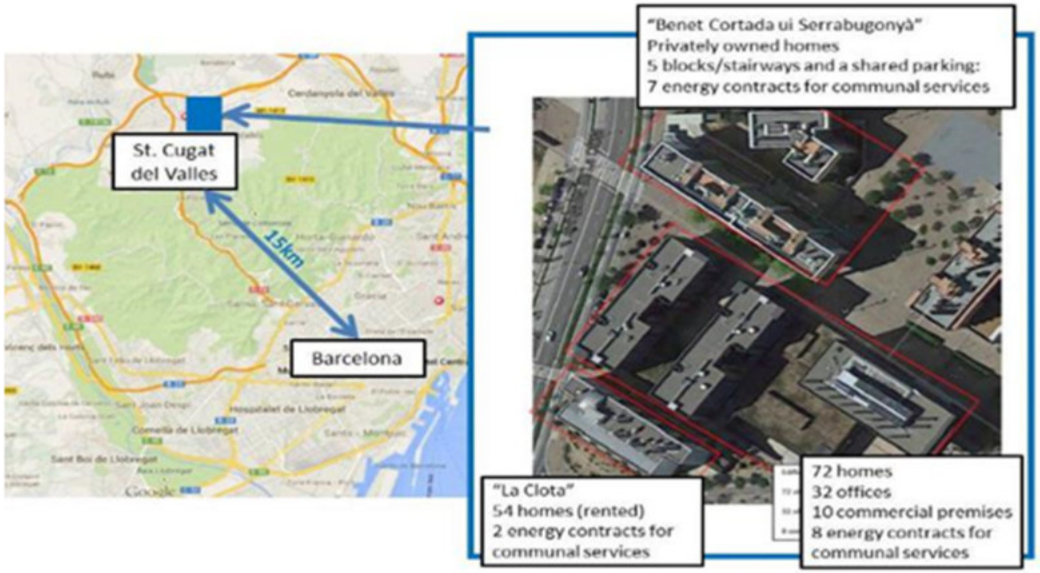
St. Cugat Pilot Site



Actors/Roles

- Residential tenants
- Commercial (offices)
- Energy utility, Maintenance company, Company owning the buildings

USE CASE 1: DR electrical service: Shift appliances manually according to price signals.

➡ *Tenants will access web portal to search tips to save energy and money.*

USE CASE 2: DR thermal service: Control energy used in generating heat and DHW and to carry out recommended energy saving actions.

➡ *Tenants will receive messages via web or WhatsApp when thermal energy (Heating or DHW) is cheap.*

USE CASE 3: Direct load control of electricity use of heat pumps in Volpelleres office spaces

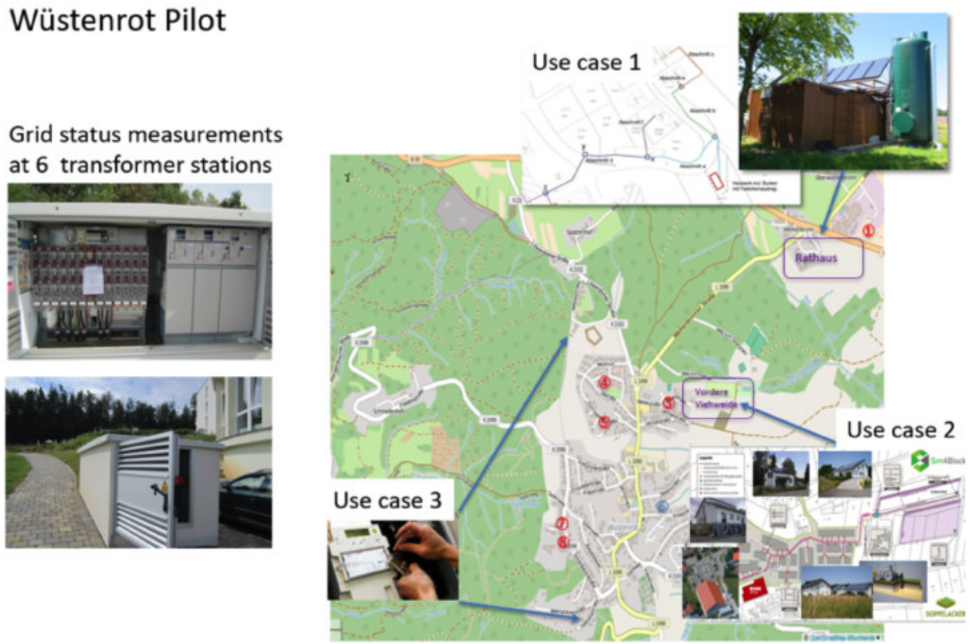
➡ *Office heat pumps run during times of low wholesale market spot prices*

➡ *Test of more short-notice balancing services (e.g. Frequency Restoration Reserve (FRR)).*

Wustenrot Pilot Site

Use cases:

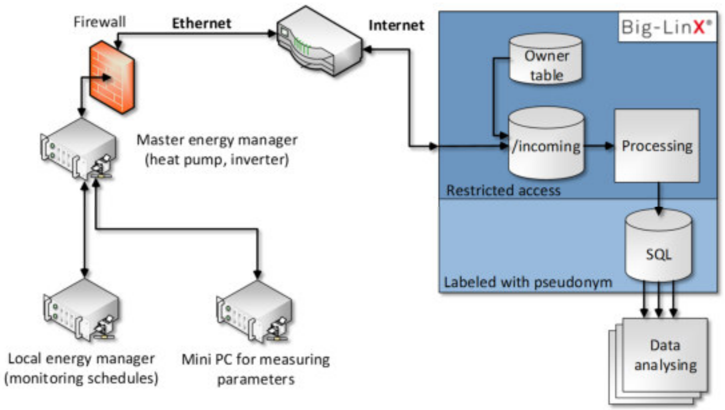
1. Power-to-heat for a biomass heating grid “Weihenbronn”: Intelligent load shifting by active use of a 9 m³ hot water storage and of the thermal mass of connected public buildings, primary and secondary reserve markets
2. Plus-Energy Neighbourhood called “Vordere Viehweide”
3. Distributed other communal and private homes with electrical heating, batteries or heat pumps

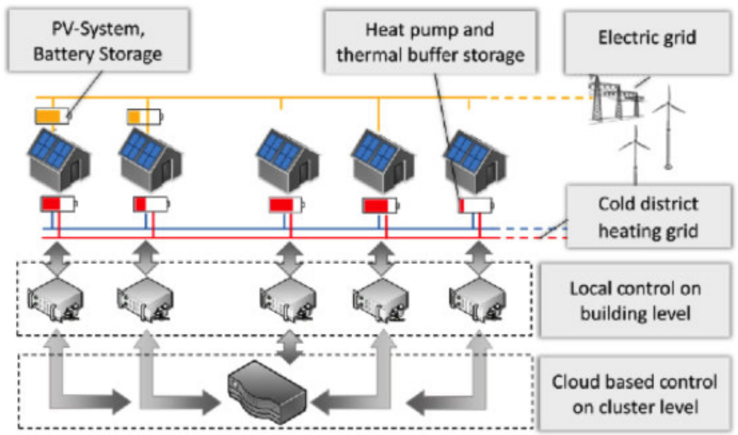


Wustenrot Pilot Site

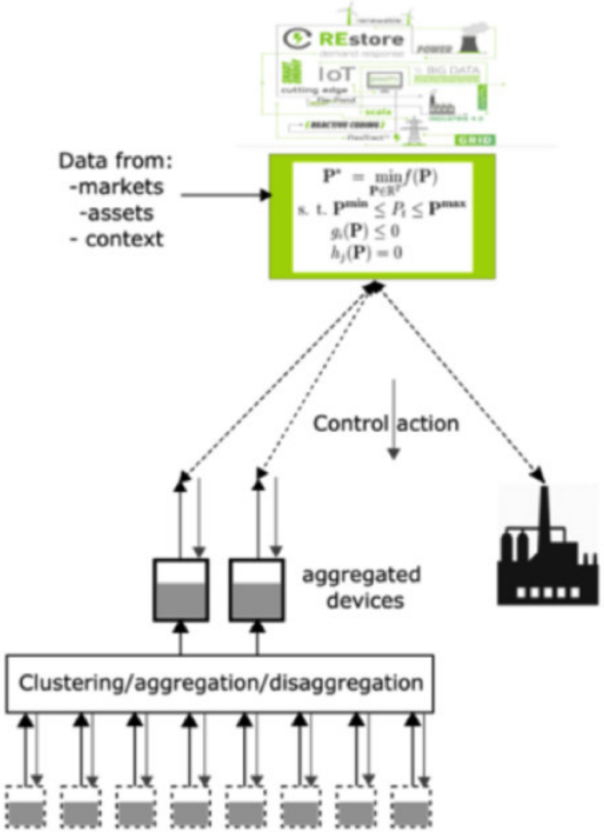
Use case 2 (Plus energy settlement)

- Optimization of the heat pumps electricity profiles for the day ahead marked or self-consumption
- Use of interfaces and alerts to the residents concerning times for optimal shifting of energy use
- Testing of the heat pumps and battery systems ability to provide explicit grid services without direct interaction with the residents (primary reserve, secondary reserve, tertiary reserve and voltage level smoothing for the local distribution grid)





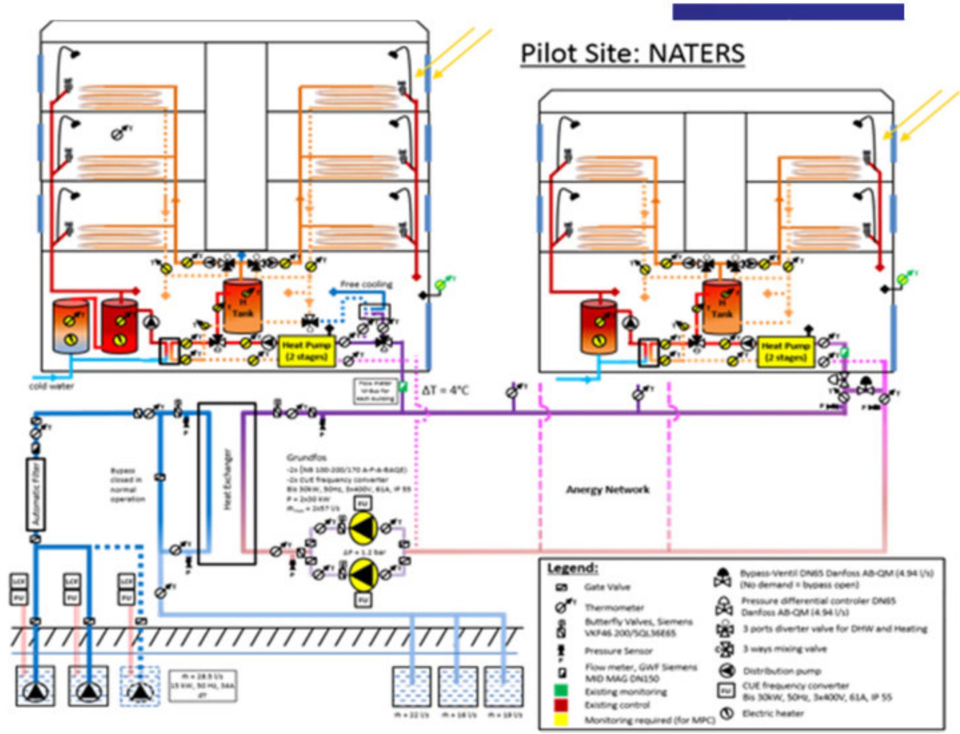
Wustenrot Pilot Site



RESTORE aims to use the local flexibility:
- to test the availability and reliability of DR services for day ahead and intraday market
- to test the utilization of the distributed batteries for the primary reserve market

STADTWERKE Schwäbisch Hall:
- Balance the network for the day ahead and intraday market
- Test the effect of user activation through APP based information system, motivating them to shift their loads according to the availability of renewable electricity in the grid
- Test the effect of enlarged flexibility by using the buildings thermal mass as active storage in interaction with the residents through the user APP developed in WP6

Naters Pilot Site



Actors/Roles

- Anergy network owner and provider
- Planning and maintenance company
- Electricity provider
- Building’s owner

USE CASE: DR electrical service .

- Aggregator for national DR services => use many “Naters like” sites for DR
- Aggregator for local DR services => use the flexibility for renewable energy
- Real time billing system => give more flexibility to users

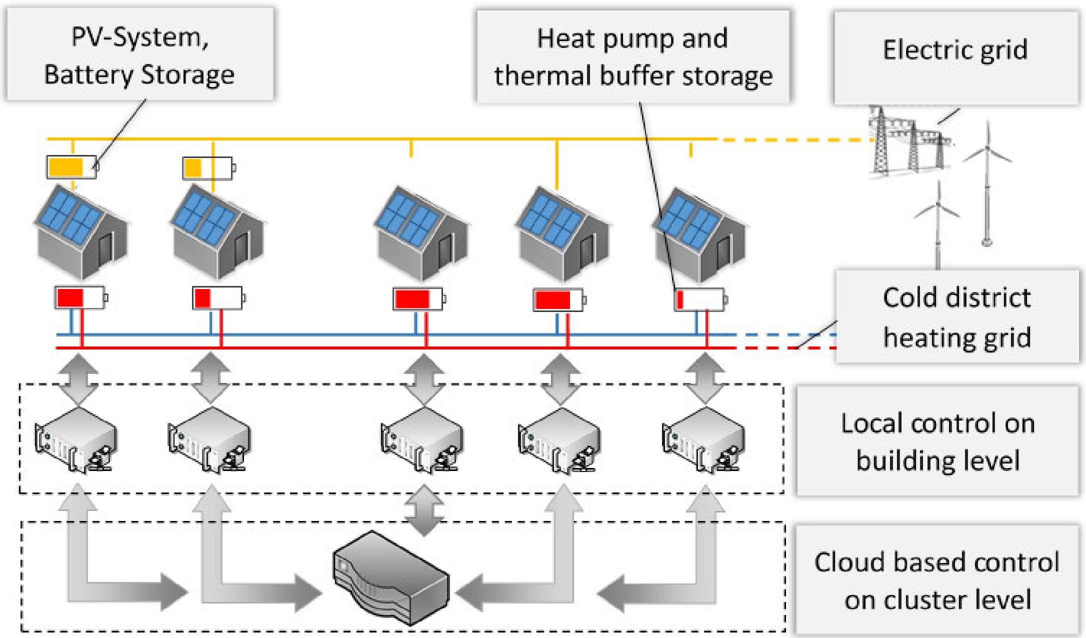
USE CASE: DR thermal service .

- Predictive maintenance => better use the installations
- Improved system efficiency => reduce the energy consumption
- Reduced thermal system infrastructure expansion => use flexibility for more users

Control

- 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



Modeling approach

- Realization in the simulation environment INSEL (components based on FORTRAN or C++ code) → for MPC operations in a VM; access to the database via Ruby script
- Dynamic models of the plus energy settlements buildings is created based on 3D data (via SimStadt tool) → each building has different systems
- Detailed white box models for those 6 buildings which are monitored intensively → Validation of each building based on measured data
- Possibly simplified models for the other buildings, which are not intensively monitored and controllable
- Load profiles and prognosis methods → A suitable approach has to be determined (historical data, regression, user behavior models, etc.)

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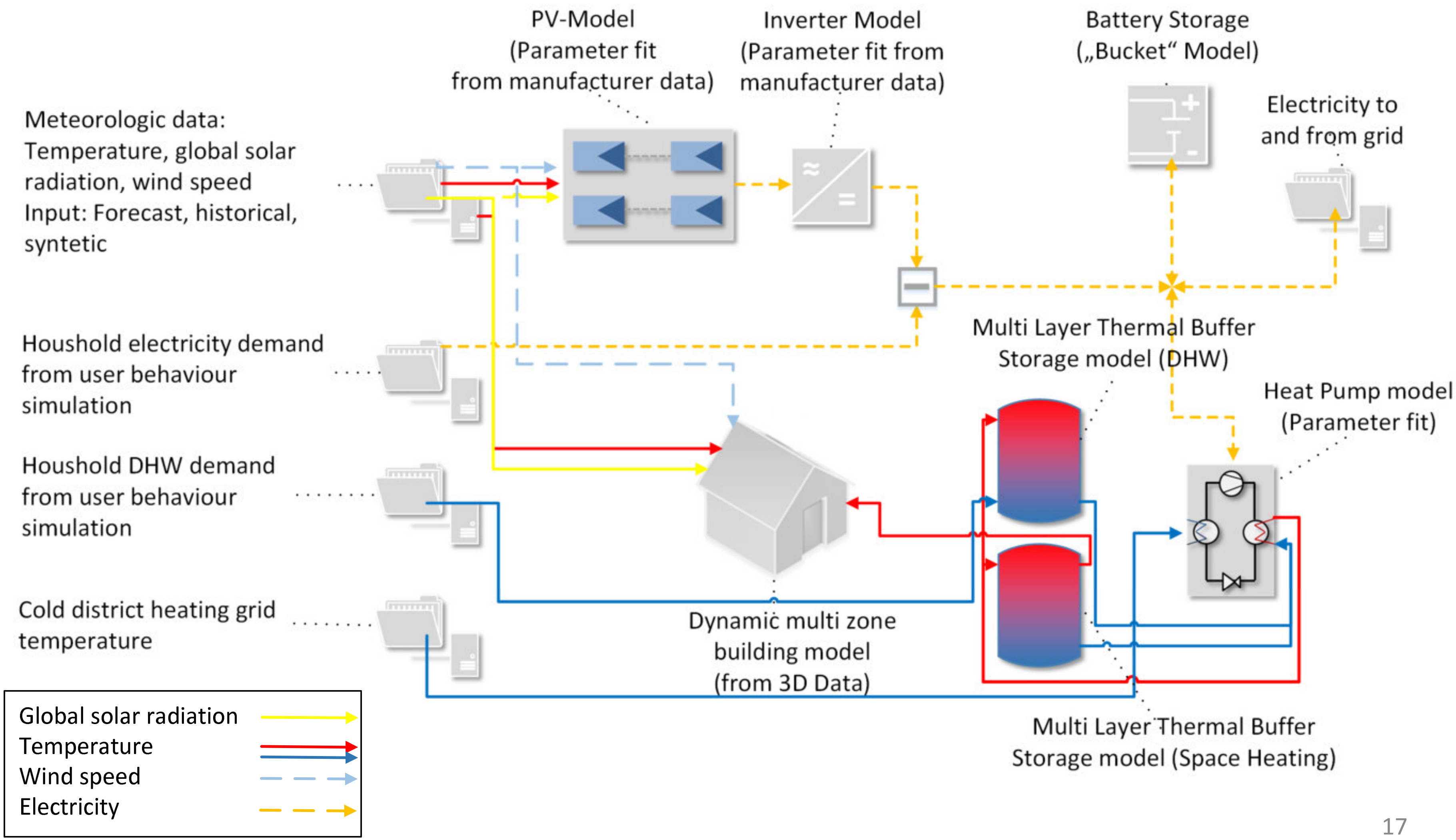
Model on building level



Planned control strategies

Optimized self consumption

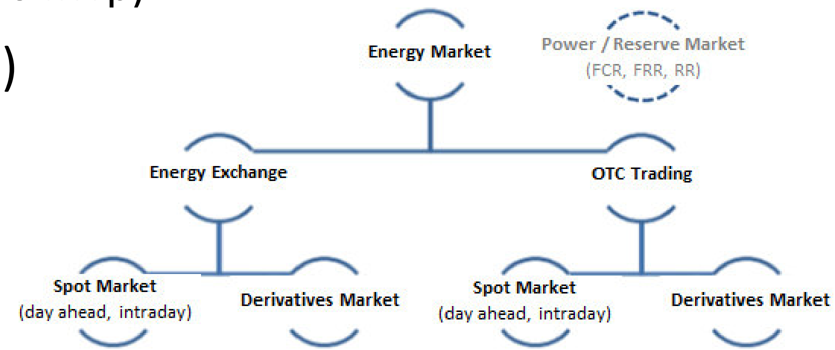
- Today most suitable use case for end customers in Germany because of fixed price feed-in tariffs for smaller PV plants (feed in tariff < electricity price) → might lead to reduced DR flexibility potential

Participation in Energy Markets (spot market 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 larger PV-plants (> 100 kWp)

Participation in Power Markets (sec. reserve)

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



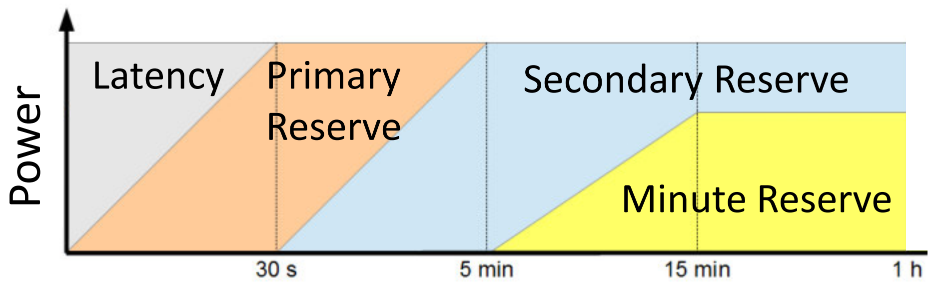
Power markets: Secondary reserve

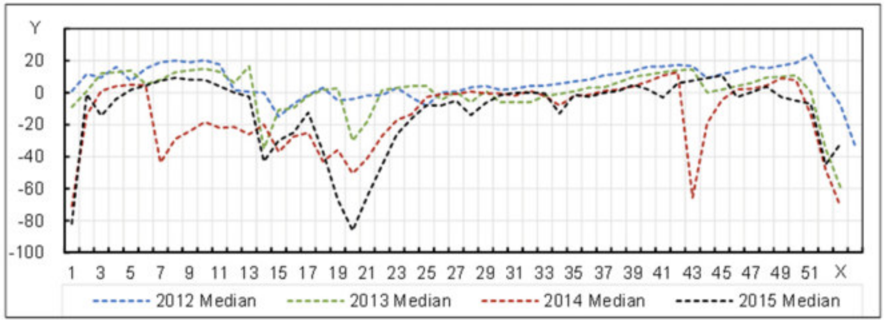
- Secondary reserve power market in Germany = Frequency restauration reserve (FRR)
- The demanded power in the secondary reserve market is volatile
- Offers and bids are placed for an entire week
- Distinction between peak (HT, Monday – Friday, 8:00am to 8:00pm) and off peak (NT)
- Duration of a demand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

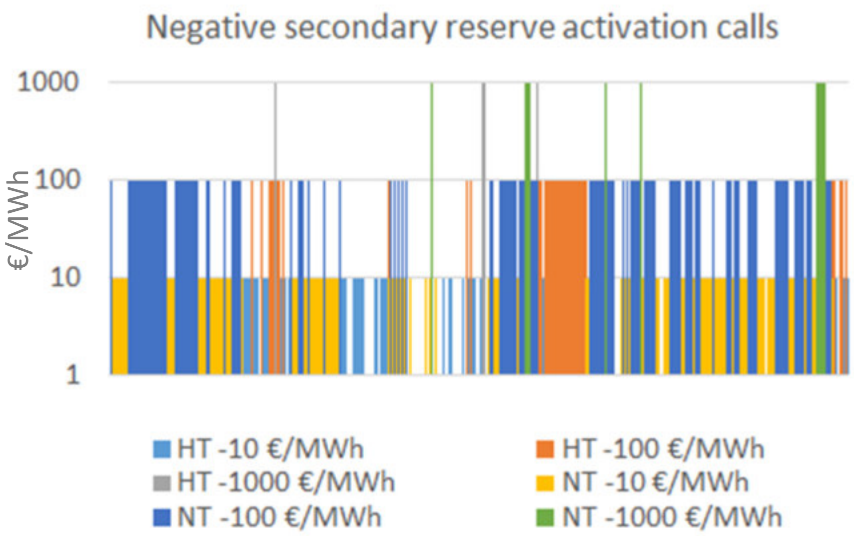


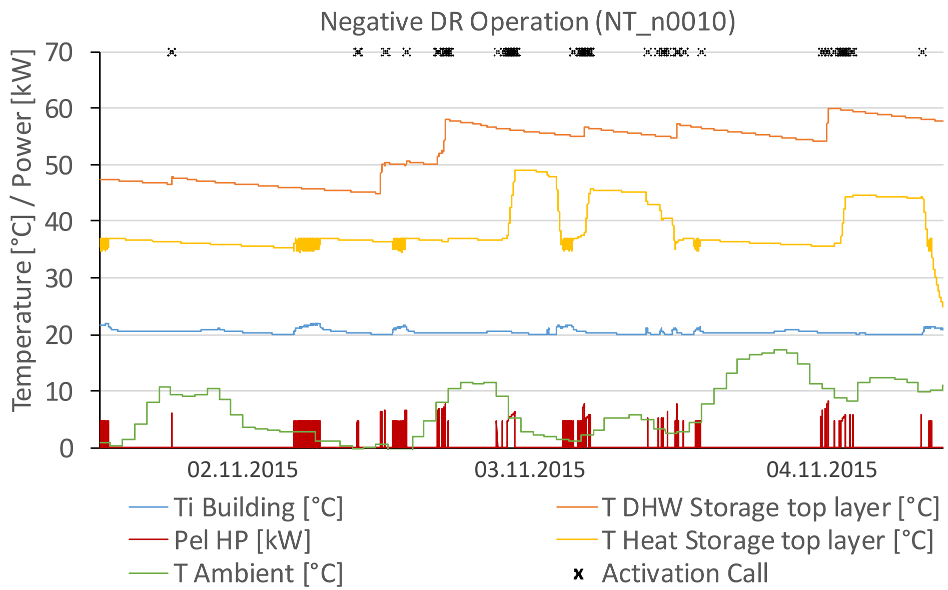


Price NT tariff

Secondary reserve: First simulation results

- Coupling of a simulation model (single family residential building) with data from the German secondary reserve market → Examination of load shift potential
- Negative DR: Increase of the storages temperature set points and hysteresis
- Positive DR: Avoidance of the heat pump operation until room and DHW temperatures fall below a certain point (e.g. -1; -2 K)



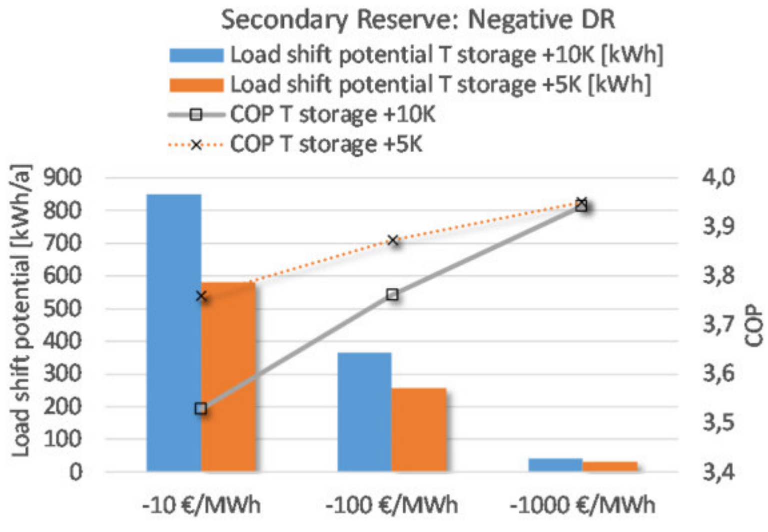


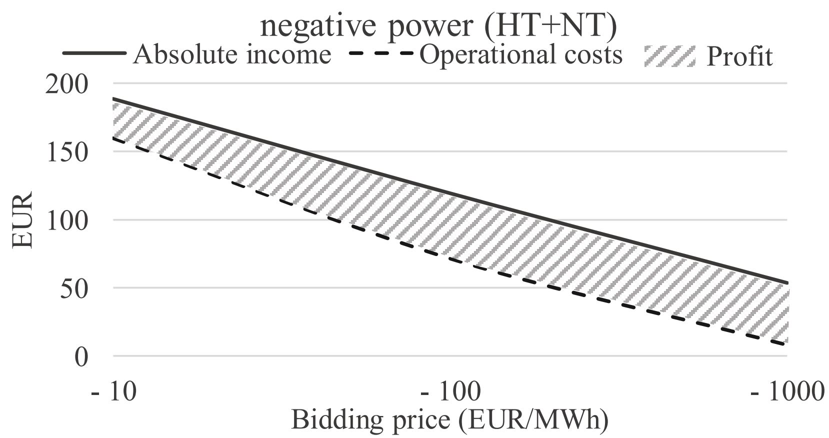
Secondary reserve: First simulation results

- 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

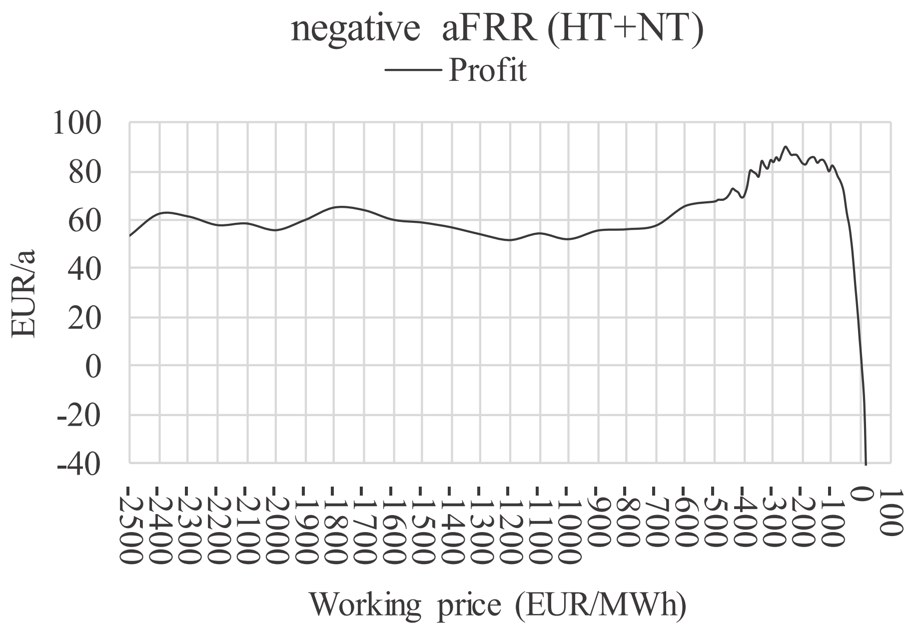
→ Reduction of heat pumps life and efficiency

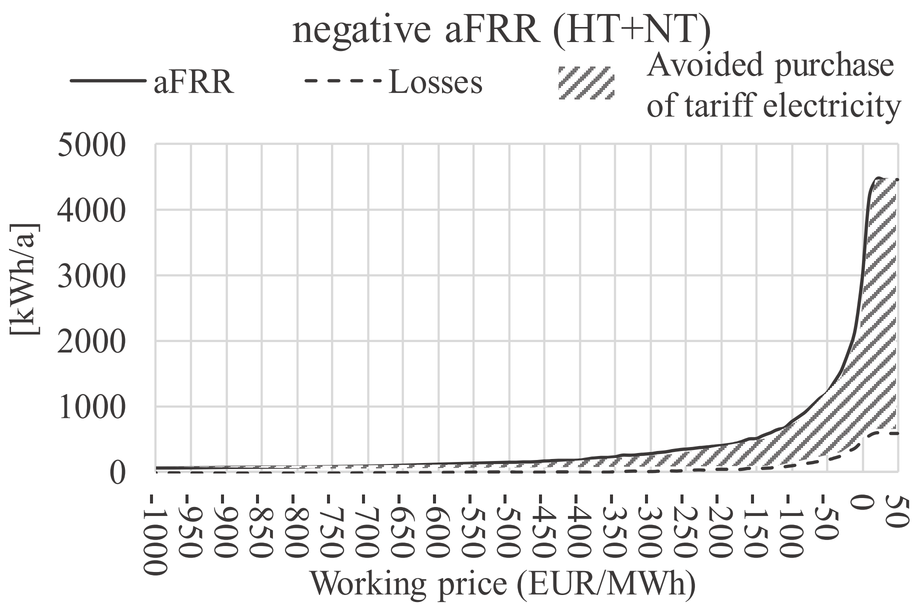
→ Solution: Heating rods, heat pump pool, incorporation of battery storage



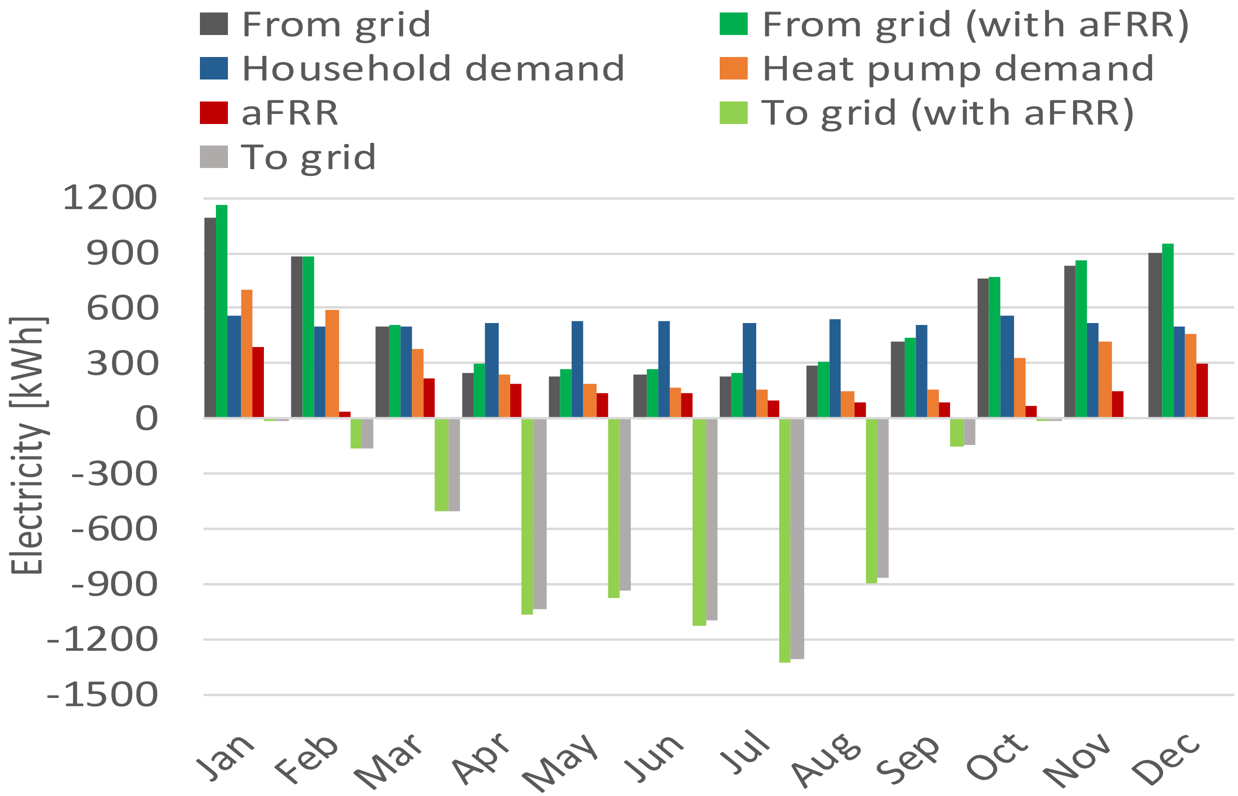


Financial gains on a household level from negative secondary reserve





Results for PV and heat pump



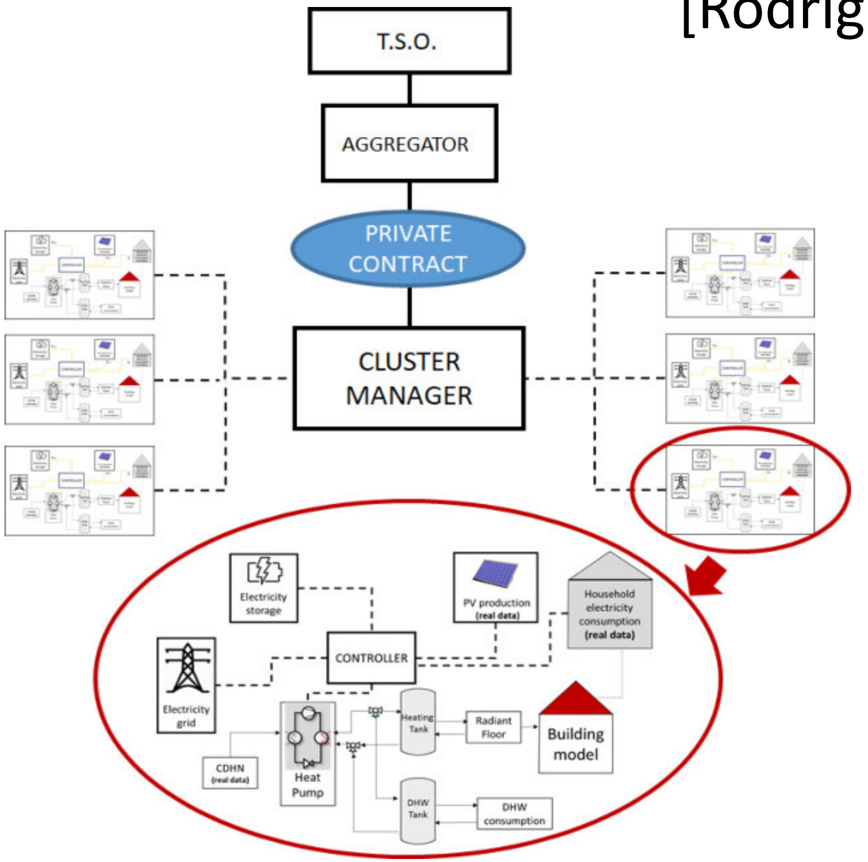
Heat pump share of total electricity consumption (11014 kWh):	35%
Annual contribution secondary reserve SR to heat pump electricity:	50%
PV own consumption with SR:	31%
PV own consumption without SR:	33%
Additional electricity demand with SR (losses COP and storage) :	7%

Research Outlook

Cluster Optimization and Contract Structure

- Fixed rate of power delivery detrimental to resident comfort

[Rodríguez et. al. (forthcoming)]

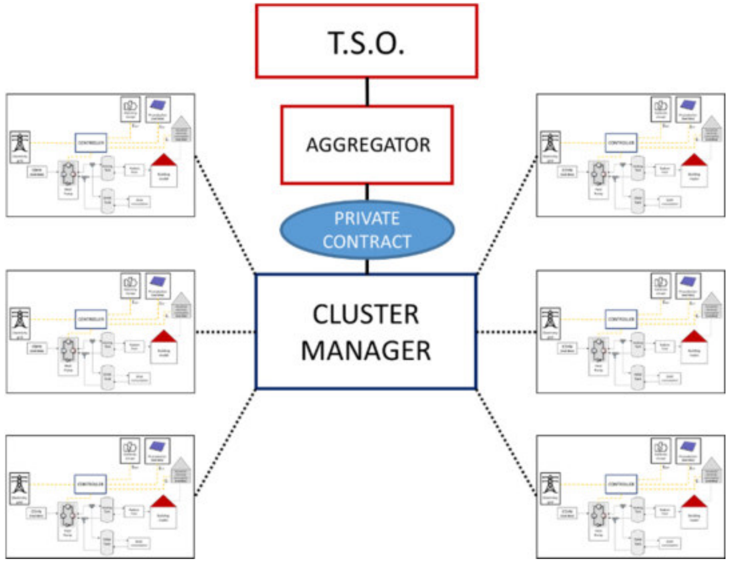


Aggregated Operation and Optimization

First Cluster Management Approach

- 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:

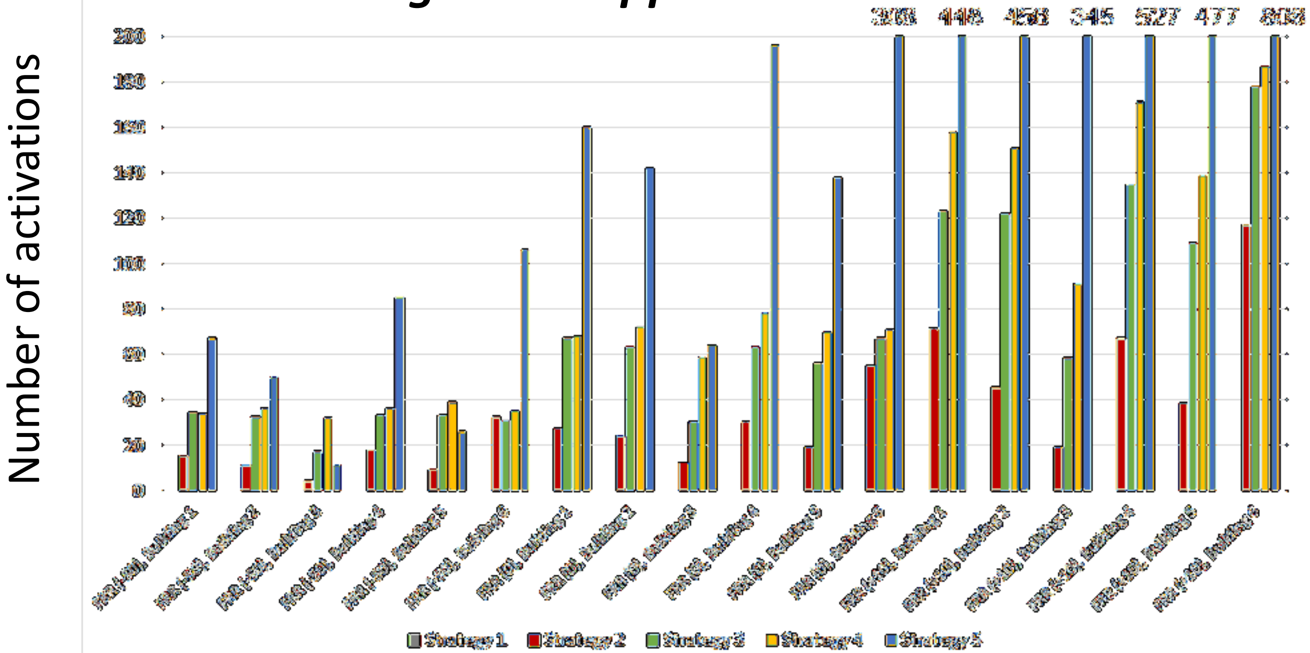
1. Cluster manager provides the aggregator with as much energy as it can → Any building will activate its heat pump after fulfilling specific requirements (strategy 2,3,4)
2. The cluster manager always has to provide the aggregator with a certain (and constant) amount of power, deciding which buildings 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.		

Aggregated Operation and Optimization

First Cluster Management Approach



	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

Day ahead pricing strategies

- Previously mentioned single building model 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 low. 25% of the day and T_{air} <21 °C.	HP works always if price among the low. 25% of the day and T_{air} <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.

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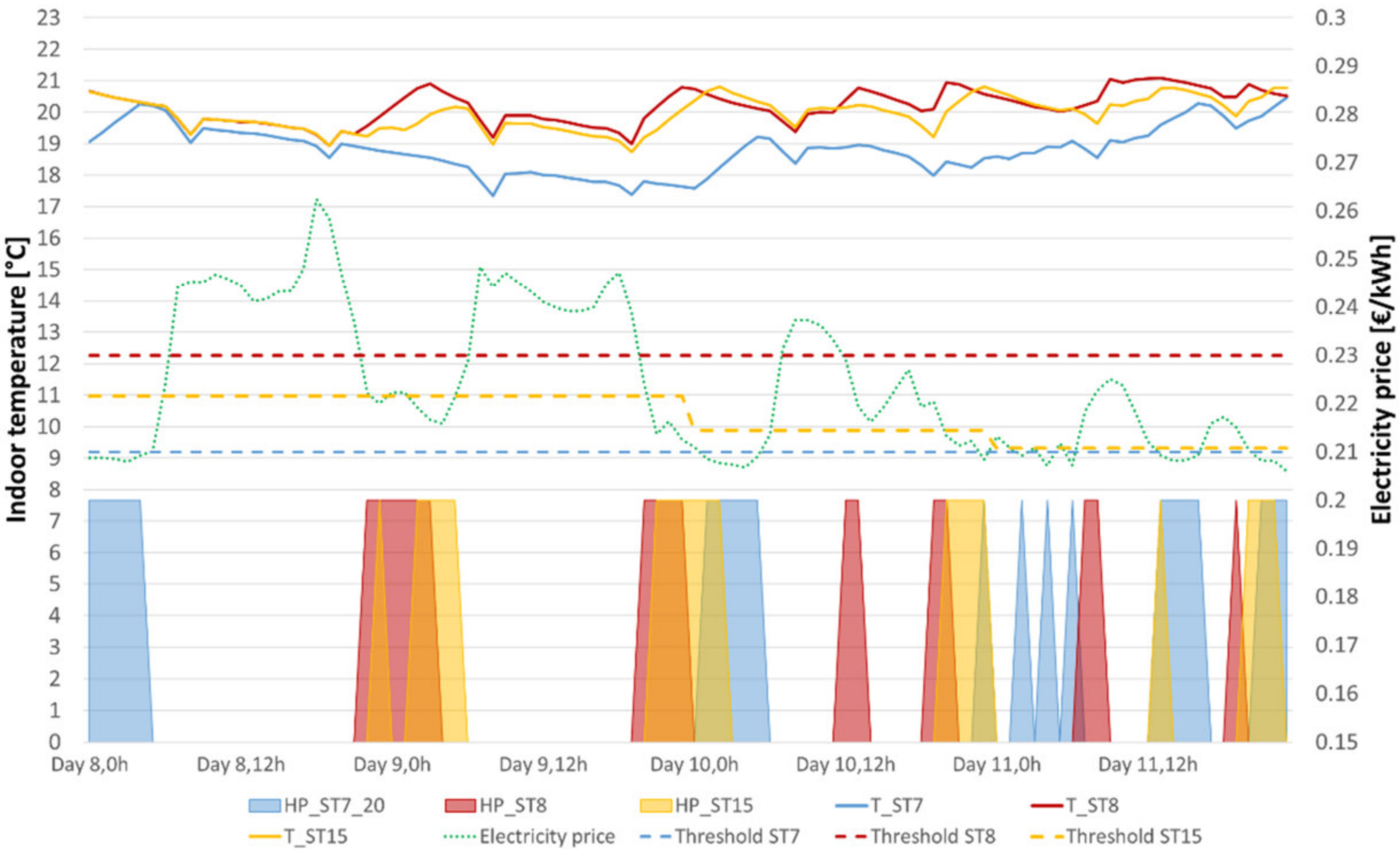
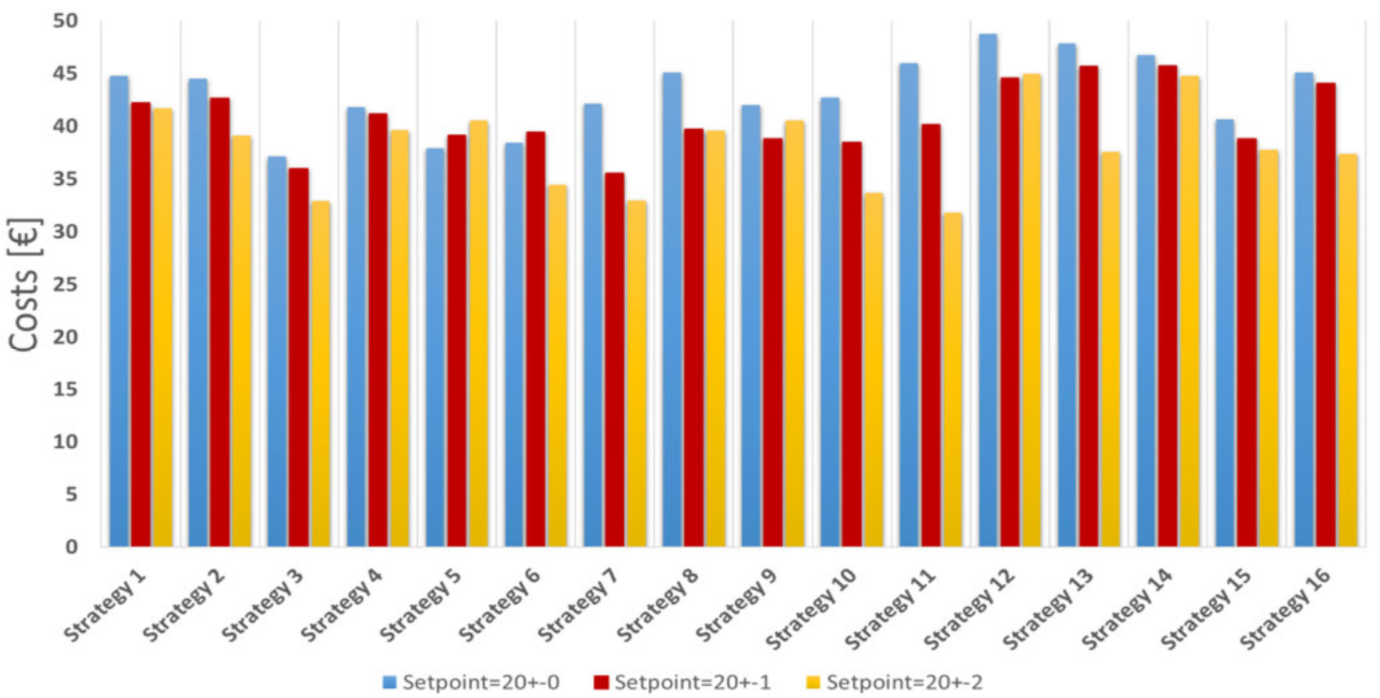
Day ahead pricing strategies



Day ahead pricing strategies

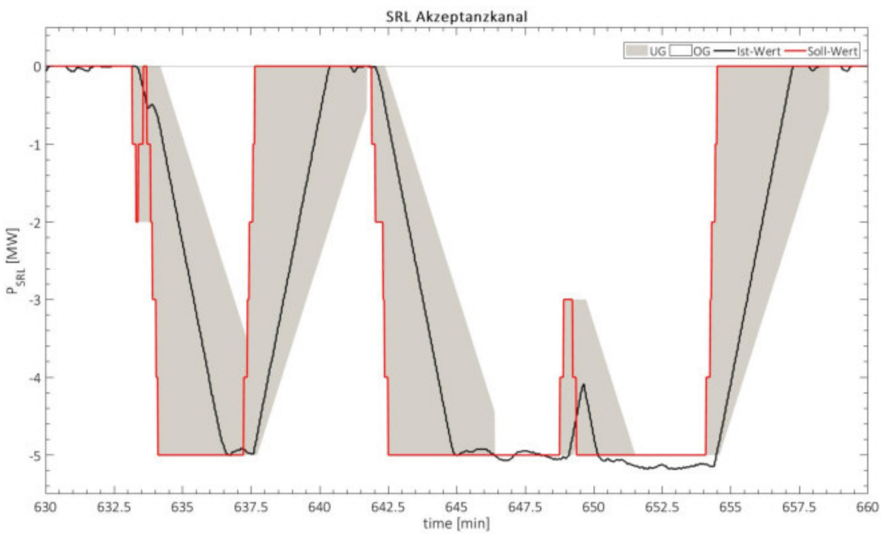


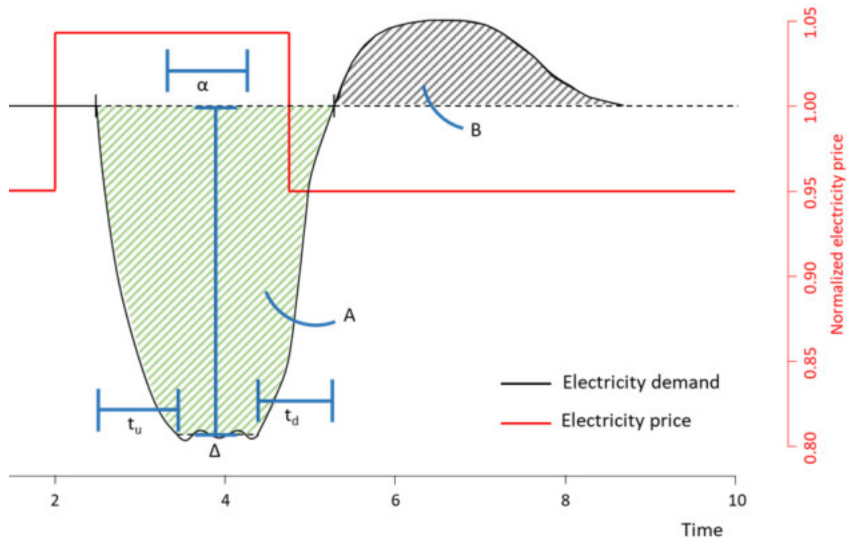
- Dynamic price thresholds instead of fixed price thresholds (to prevent low activations or overheating of the building)
- Cost savings up to 25% may be achieved by using optimal strategies, increasing the self-consumption ratio, having almost no influence on the thermal comfort and achieving significant peak reductions on the grid

Research Outlook: Creating New Experimental Data with 3 Pilots

Three Experimental Frameworks in S4B:

1. Load Profile Trace (static baseline)
2. Flexibility Profile Bid (dynamic baseline)
3. User Interaction (dynamic event/msg-based baseline)





visit Sim4Blocks website:

www.sim4blocks.eu

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