E.ON Energy Research Center

# E.ON Energy Research Center
# RWTH Aachen University

## Research Projects with Optimization Applications

09.04.2014

Michael Diekerhof

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# Agenda

- Introduction E.ON Energy Research Center
- Related EU Projects to Optimziation
  - FINESCE
  - COOPERATE
  - MERLIN
  - Others
- Distributed coordination of residential heating units
  - Motivation
  - Central scheduler
  - Decentralized scheduler
  - Conclusion

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# E.ON Energy Research Center: Overview

E.ON Energy Research Center

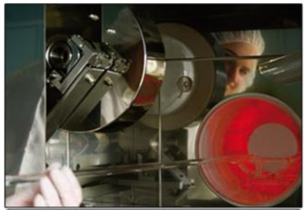
- June 2006: the largest research co-operation in Europe between a private company and a university was signed
- Five new professorships in the field of energy technology were defined across four faculties
- Research areas: energy savings, efficiency and sustainable power sources

**ACS** Institute for Automation of Complex Power Systems

**EBC** Institute for Energy Efficient Buildings and Indoor Climate

**FCN** Institute for Future Energy Consumer Needs and Behavior

**GGE** Institute for Applied Geophysics and Geothermal Energy



**PGS** Institute for Power Generation and Storage Systems

Electrical Engineering & Information Technology

Mechanical Engineering

Business and Economics

Georesources & Materials Engineering

# Research Fields at E.ON Energy Research Center

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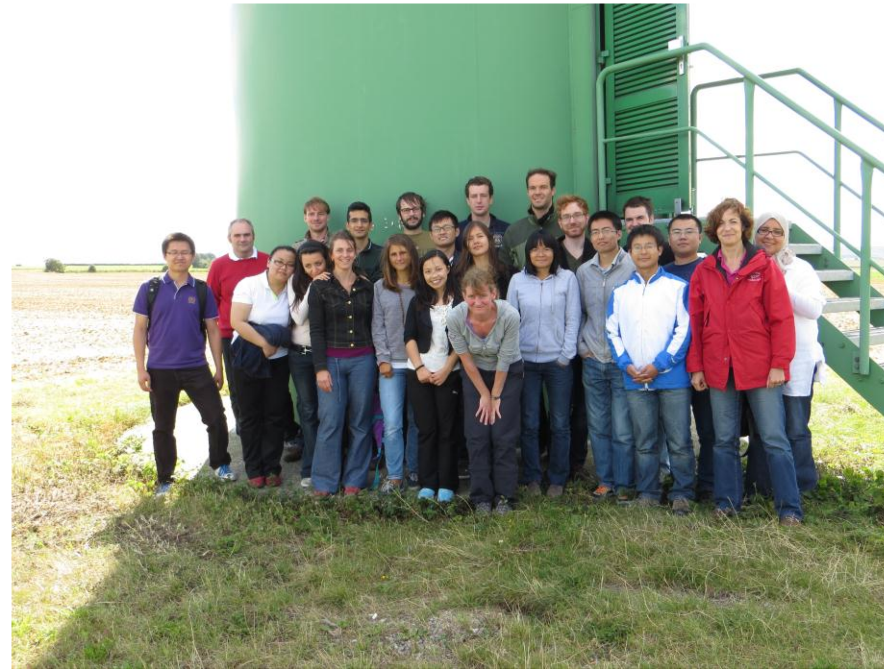
# Automation of Complex Power Systems (ACS)

- 1 apl Professor (Prof. Ponci)
- 1 Visiting Professor
- 1 Chief Engineer (Dipl.-Ing. Schäfer)
- 3 PostDocs
- 21 Junior Researchers (PhD assistants)
- 3 SW Developers + 2 Azubis
- About 20 MS Assistants/HiWi
- 2 Secretaries + 1 Azubi
- 1 open position



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# ACS Strategy

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*Research, develop and apply methodologies and technologies that enable the transition to the Next-Generation Energy System characterized by low CO2 emissions and customer-centric approach, via advanced intelligent solutions*

## This requires

- Formalizing the **Dynamics of Future Grids,** understanding the behavior in presence of Distributed Energy Generation and Renewables
- Analyzing the **grid as a complex system** in which different infrastructures interact, primarily power system and communication
- Developing innovative **simulation methods** with special focus on **real-time simulation** for advanced testing solutions
- Developing **new automation concepts** (monitoring and control) to operate in scenarios characterized by a large number of players
- Developing innovative ICT solutions for energy systems, with special focus on **Future Internet, Cloud Computing, Big Data**
- Develop new concepts of **services in support to grid operations,** focused on the **new role of the customer**

# ACS Research Areas

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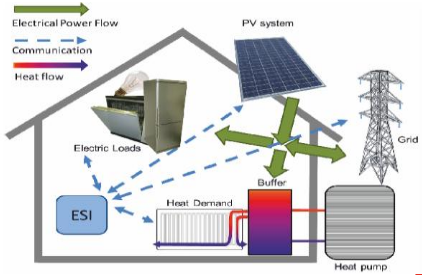



## Applications

Smart Cities
Future Energy Networks
Center for Wind Drives
Future Internet

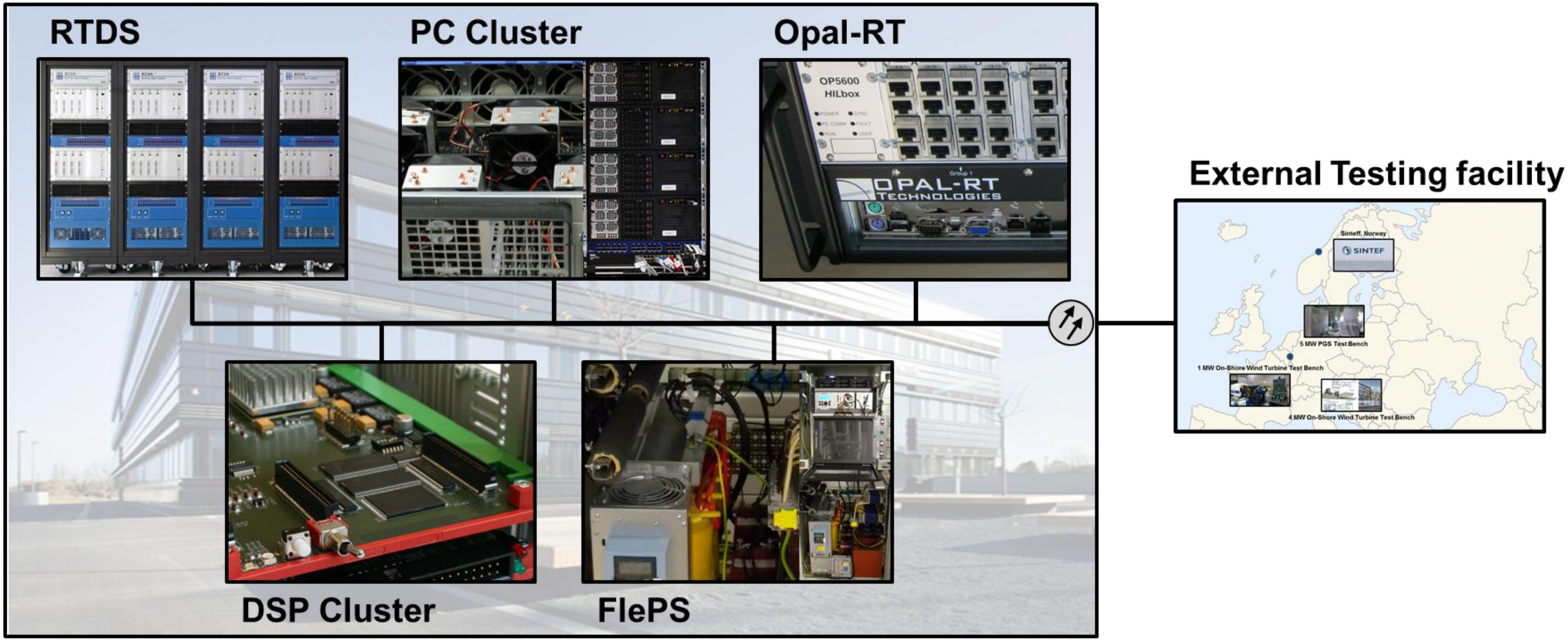
## Grid Operations

Fundamentals of Grid Dynamics
Network Stability
Hybrid DC/AC Networks
Grid Monitoring
Grid Automation
Integration of Renewables

## ICT 4 Energy

Data-driven Energy systems
Distributed Computing for
Complex System Simulation
Distributed Intelligence for
Energy Systems
Cloud applications for energy
Real-Time Systems

# Real Time Laboratory at ACS



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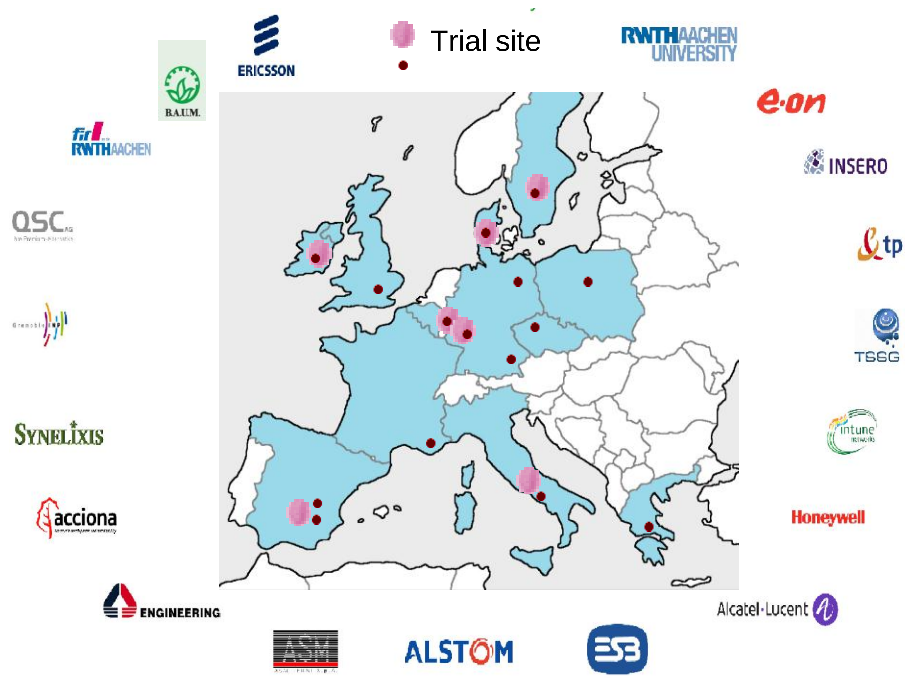
# FP 7 FINESCE



- Phase 2 project for FINSENY focused on field test development
- Large EU Project with a budget over 15MEuro
- ACS main lab for preliminary test before implementation
- Prof. Monti, Technical Manager of the overall project
- 7 Different Field Tests across Europe



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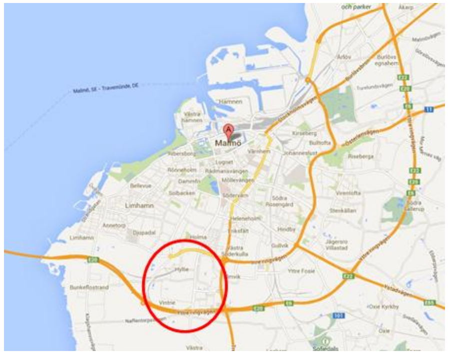
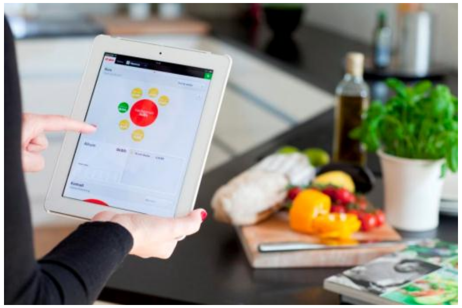
## WP1: FI providing the sustainable smart city energy

Scope:

- The scope of the WP1 trial is to execute Demand Side Management and Demand Side Response tests with external buildings in the Hyllie district, Malmö, Sweden, based on an integrated approach of energy carriers



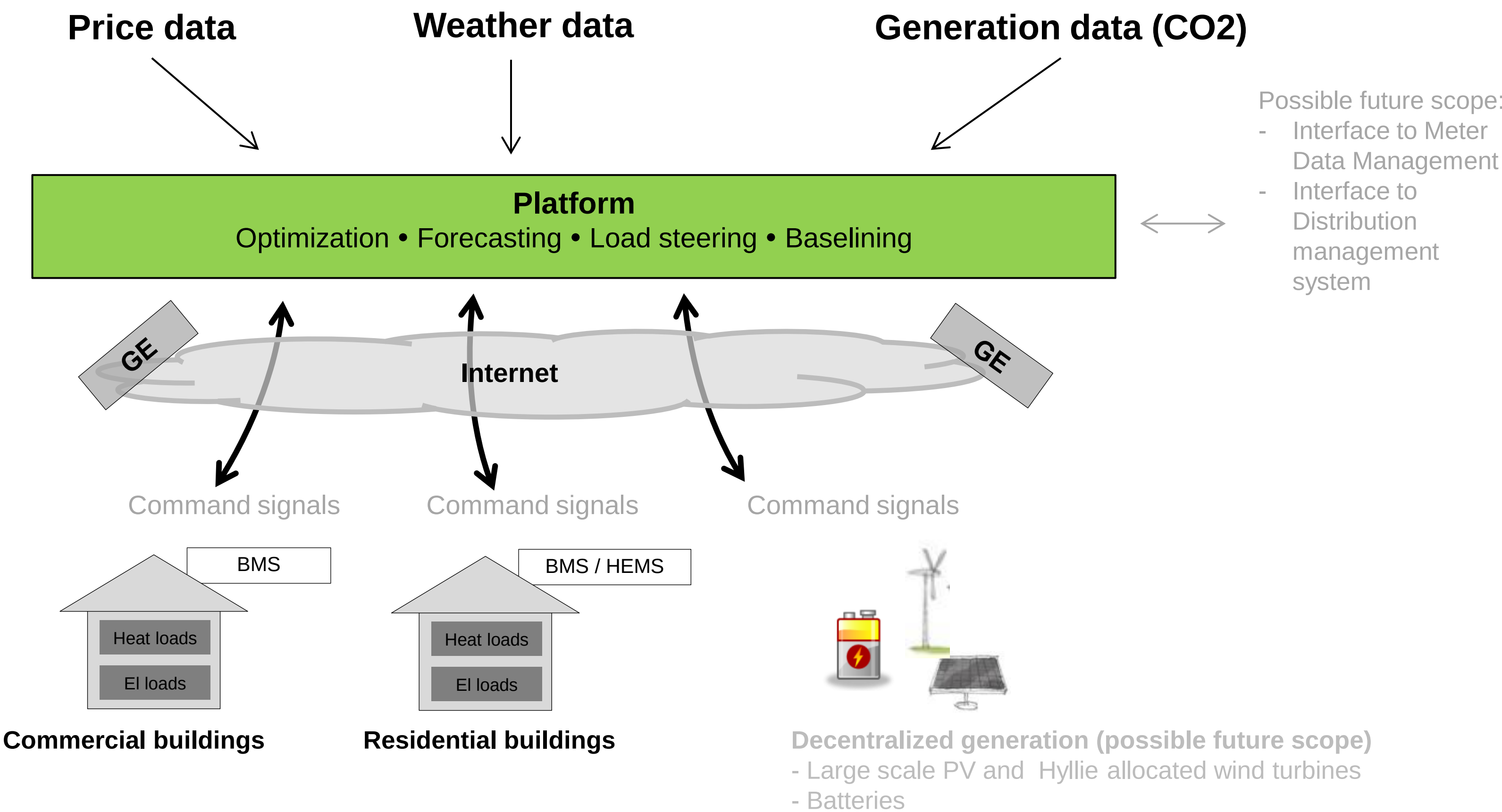
Hyllie, Malmö



Use Cases:

- Cost optimization (electricity/heat) by price signals
- Optimization of demand (electricity/heat) by energy mix signals
- Instantaneous reduction of energy consumption

# WP1: FI providing the sustainable smart city energy



## WP2: FI for End-users' Energy Ecosystems – Horsens, Denmark

- **Promote balancing of electricity production and consumption via demand controlling**
- Provide access to the trial site data in a FI platform
- Provide access to the FINESCE API with access to building control and building data
- Enable efficient grid utilization via demand controlling
- Promote demand controlling either via user interaction or automation
- **Evaluate large scale effects of algorithms using simulation**

# FP7 FINESCE

## WP5: FI in Electricity in Action

- Stream I: eCar batteries as interruptible loads to balance the power grid
- Stream II: Substation communication for power management

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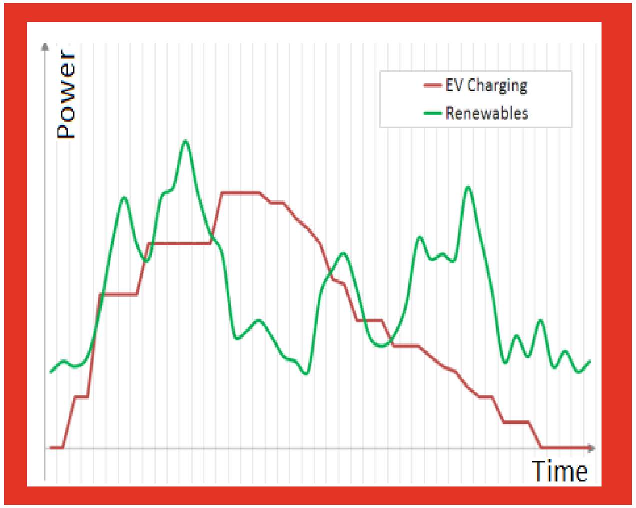
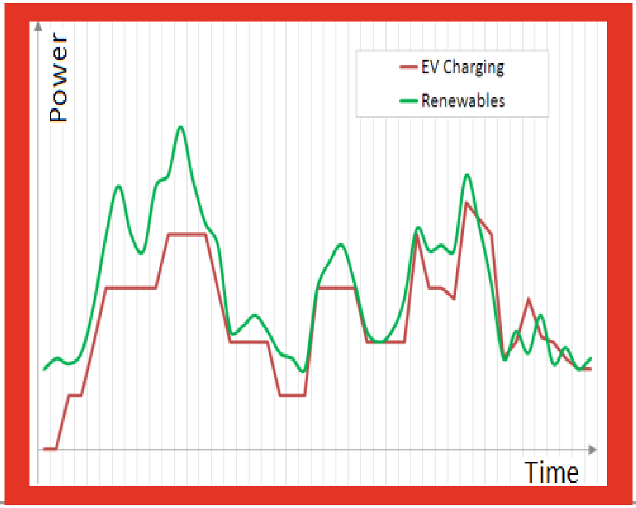
## WP5: FI in Electricity in Action

- Integrate Electric Vehicles (EVs) into electrical grid with the aim of tracking renewable energy generation
- Develop and test EV charging management systems using
  - WiMAX and LTE solutions
  - Future Internet (FI) technologies
- Determine best communications technology to use

EV charging independent of renewable generation




EV Charging tracking renewable generation



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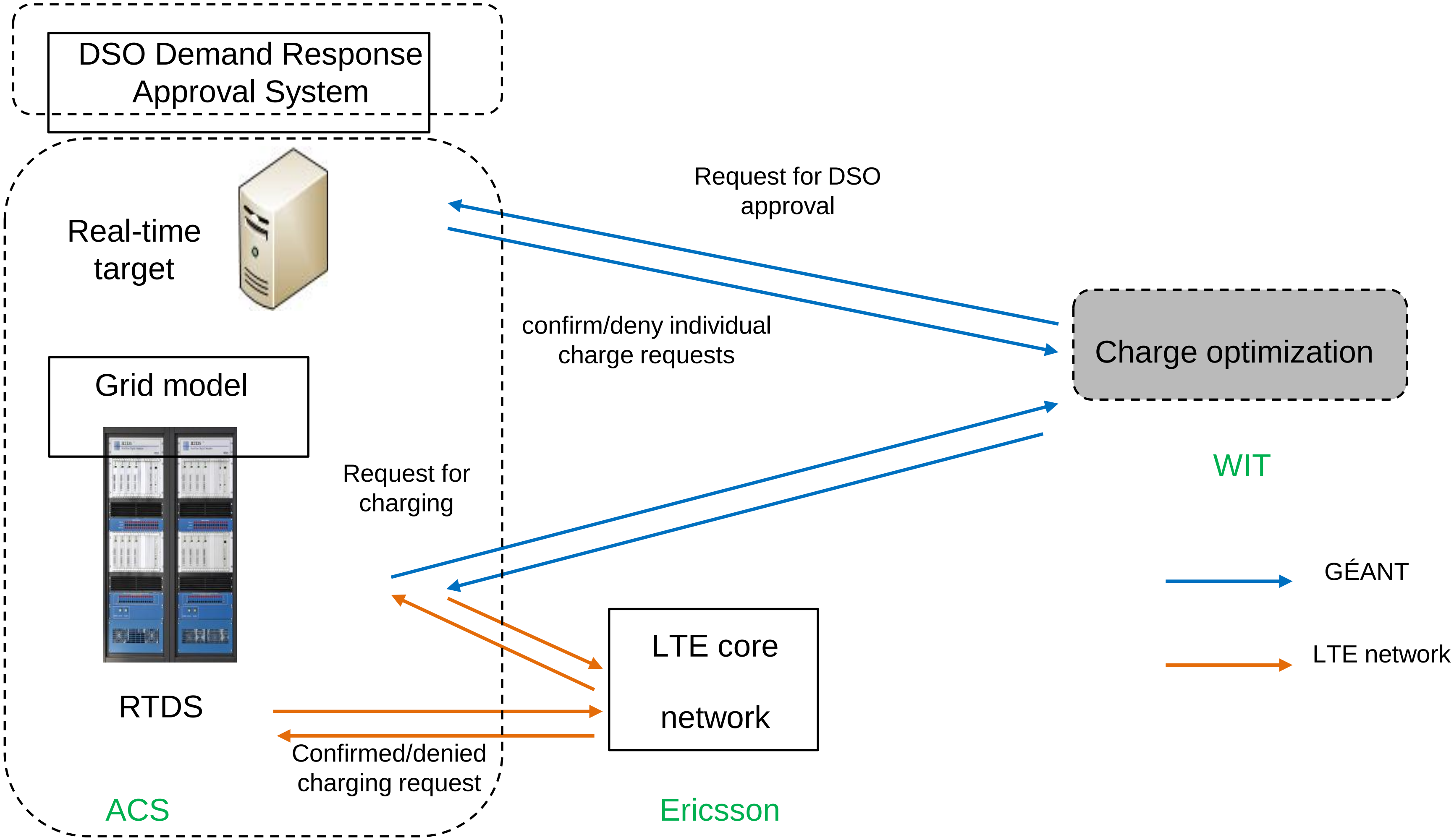
# WP5: FI in Electricity in Action ACS Main Set-up



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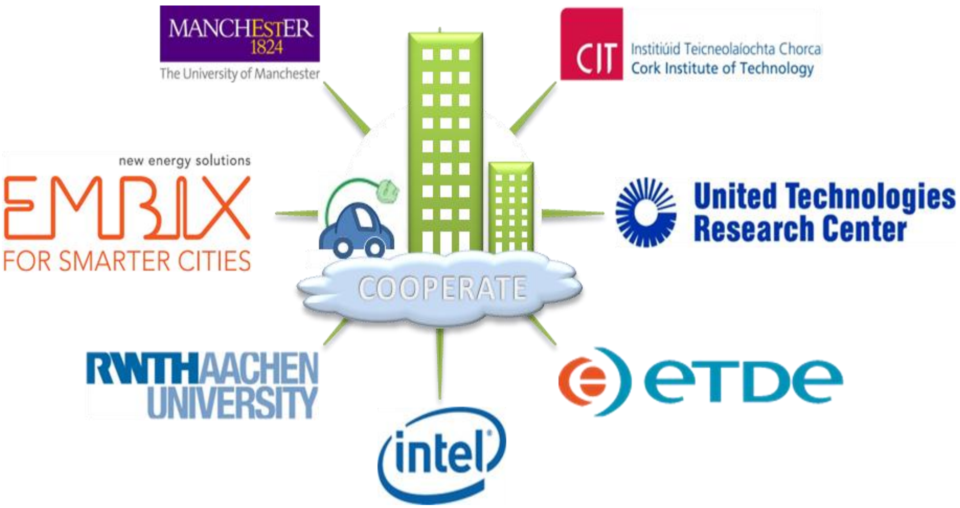
# FP7 – COOPERATE

- Control and Optimization for Energy Positive Neighbourhoods
- COOPERATE will develop an open, scalable cloud-based service platform for neighbourhoods
- Final target is the creation of a Positive Energy Neighborhood
- New services, not only in the energy arena will be implemented
- Two validation sites: the Bouygues Challenger campus in Paris and the CIT Bishopstown campus close to Cork.

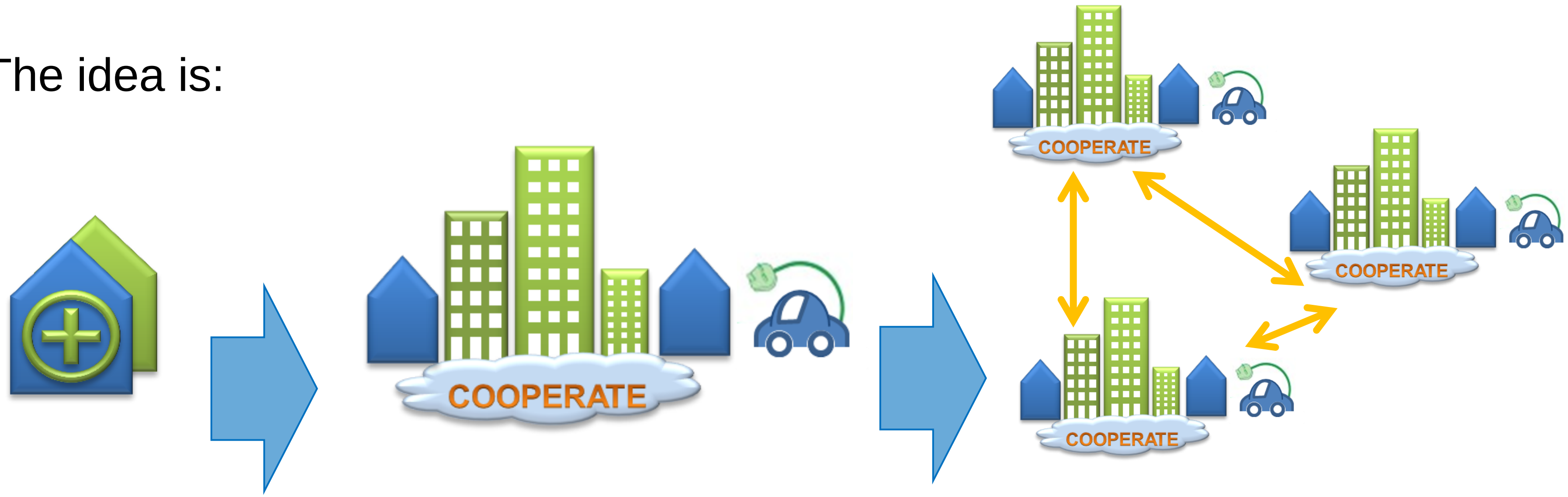


# FP7 COOPERATE – Vision of the project

An **energy positive neighbourhood** is a neighbourhood which

- Maximises usage of local and renewable energy resources
- Contributes positively to the wider electricity grid
- Targets a minimal $CO_2$ footprint

The idea is:



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# FP7 MERLIN

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- Sustainable and intelligent **M**anagement of **E**nergy for smarter **R**ai**L**way systems in Europe: an **IN**tegrated optimisation approach

- Distributed intelligence for energy optimization in railway systems
- The railway system as a smart grid with movable and flexible loads
- Possibility of offering the flexibility as a service to the utility

# FP7 MERLIN
# Partially Decentralized Approach

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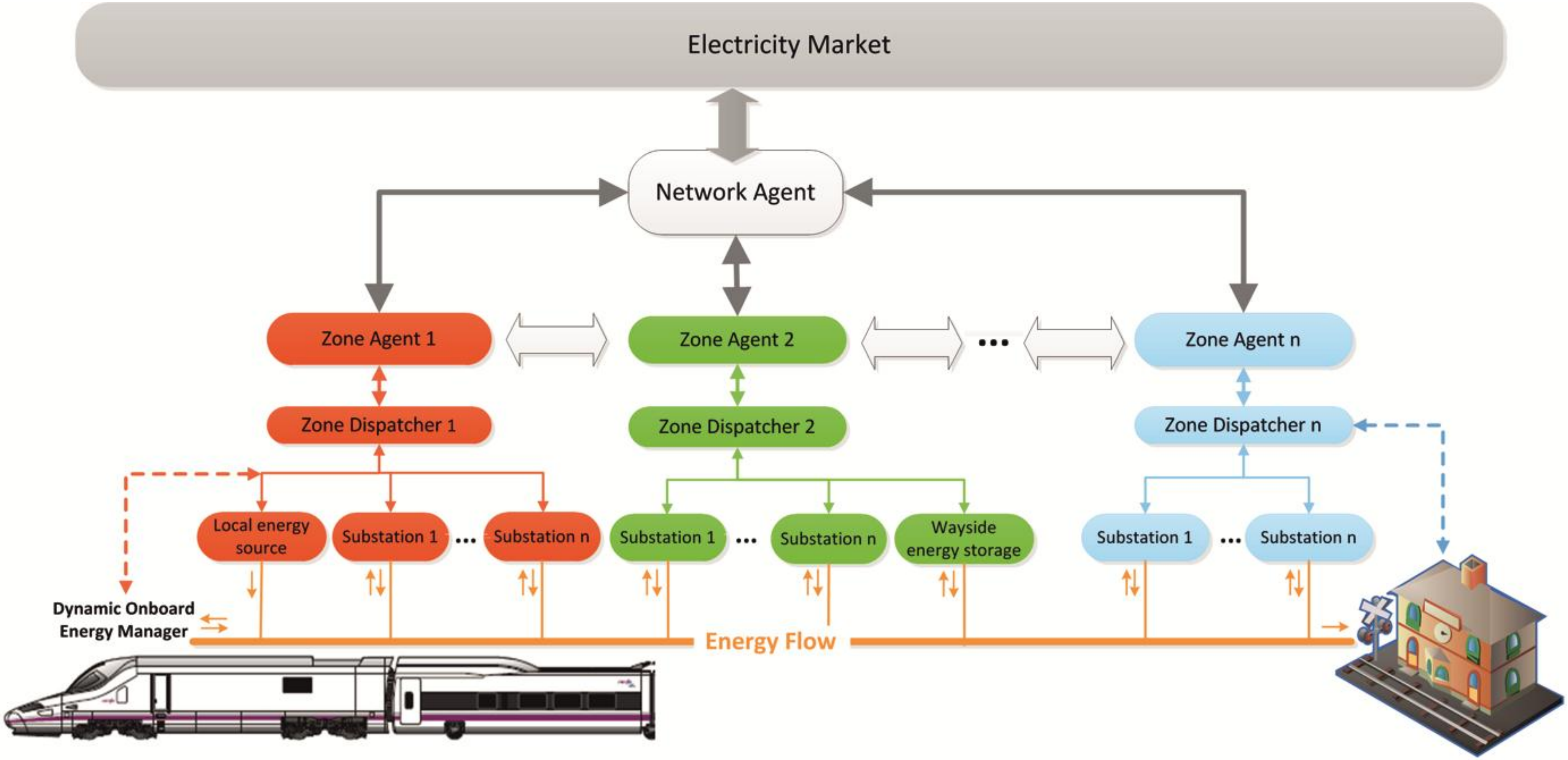




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# FP7 MERLIN
# Operational Modes

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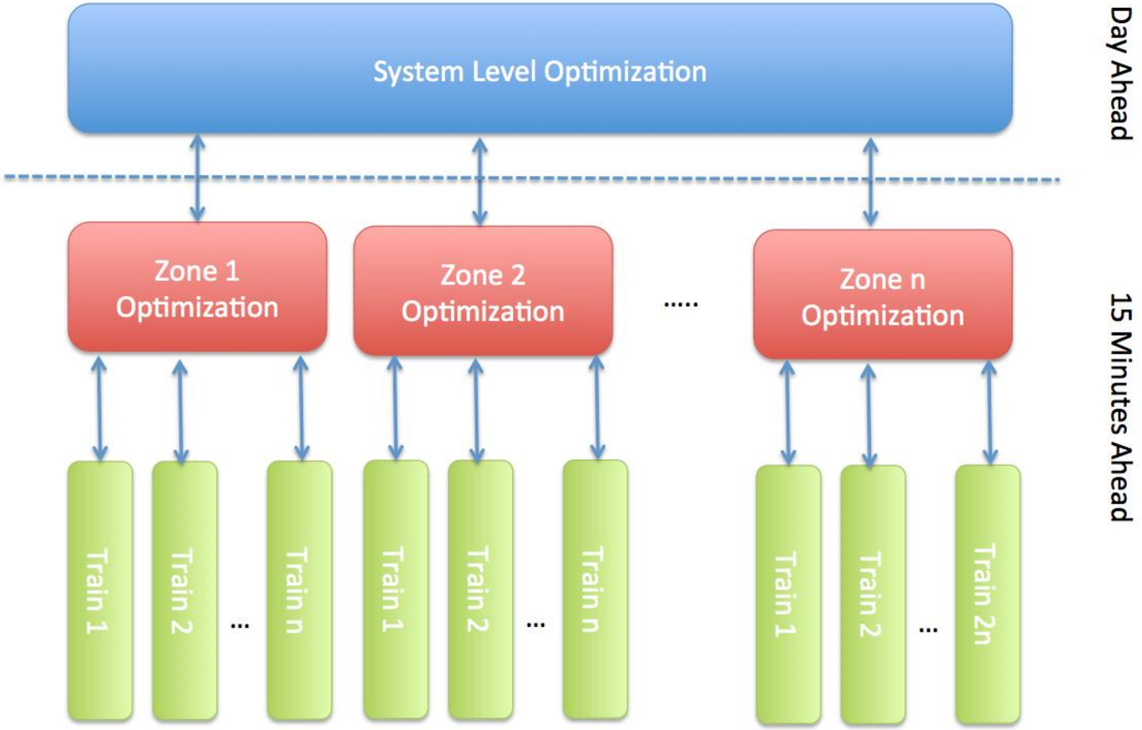
- Day-Ahead-Optimisation (DAO)
- 15-Minutes-Ahead-Optimization (MAO)
- Dynamic On-board Energy Management (DOEM)



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# Grid-interactive buildings

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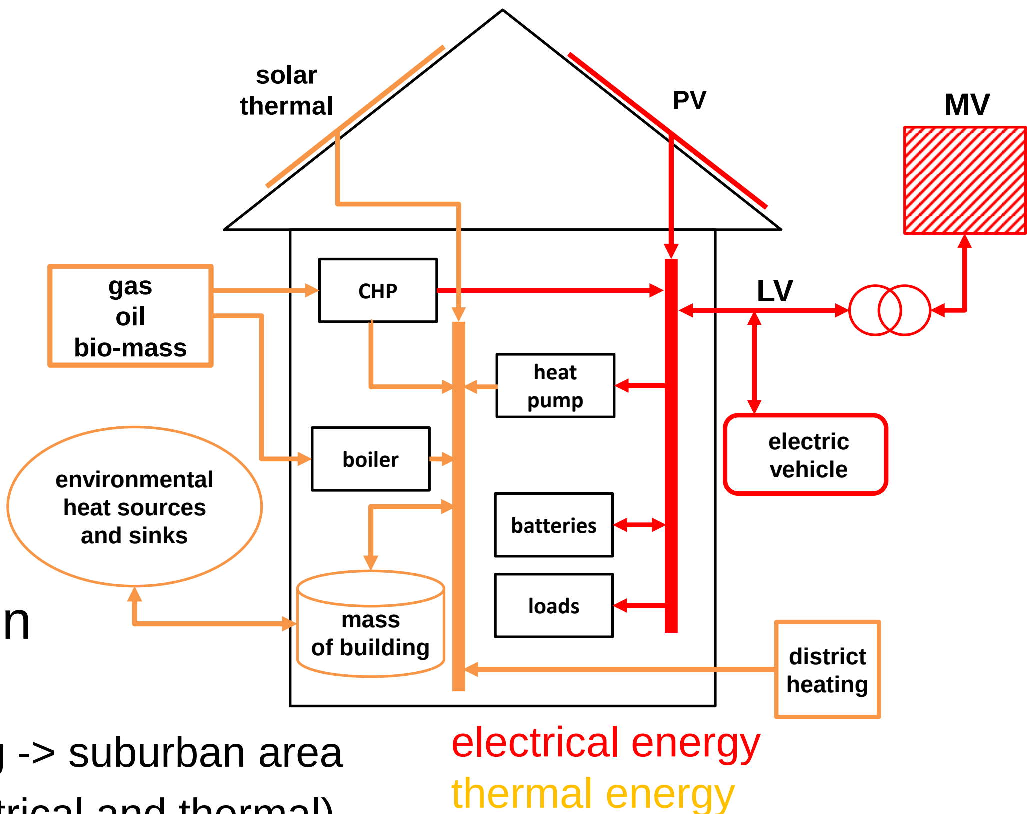
- Overall evaluation of
  - Building physics
  - Energy Management Systems
  - Energy economics concepts
- Assessment methodology
  - Multi-physics models
  - HiL-tests
- Control algorithms for Interaction of grid-interactive building
  - Individual components -> building -> suburban area
  - Building as source and sink (electrical and thermal)
  - Integration of renewable energies (e.g. PV)
  - Index for grid-compatibility → DSM ,Power Quality, fault handling

Fraunhofer ISE  Fraunhofer IBP

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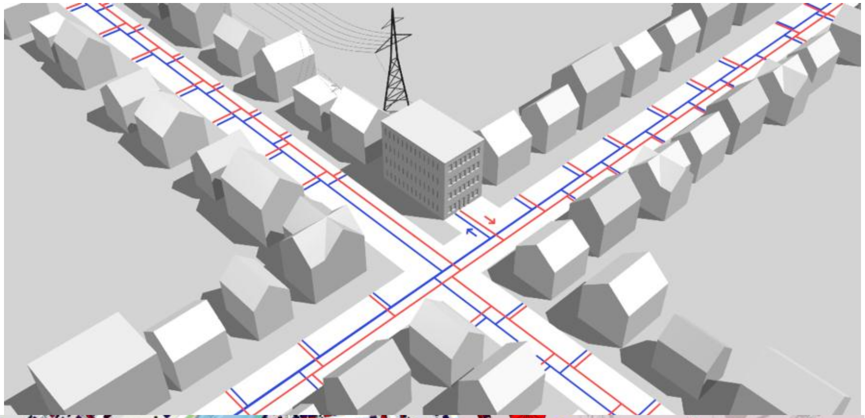
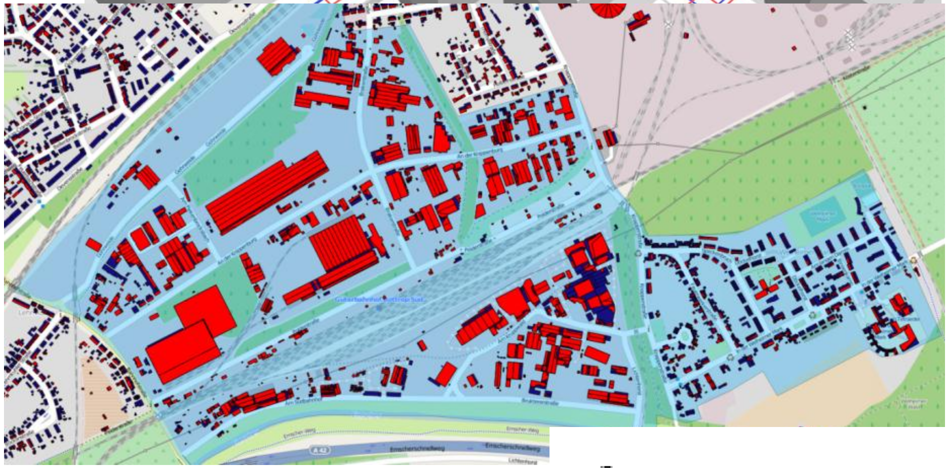
# InnovationCity Bottrop



- Development of new concepts for local control of low voltage grid
- Integration of different grids: electrical, gas, heating
- Detailed simulation of city-quarters to check the proposed solution
- Development of plans for large on-field deployment
- Optimization and scheduling of decentralized generation units





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# InnovationCity Bottrop
# Project Cycle

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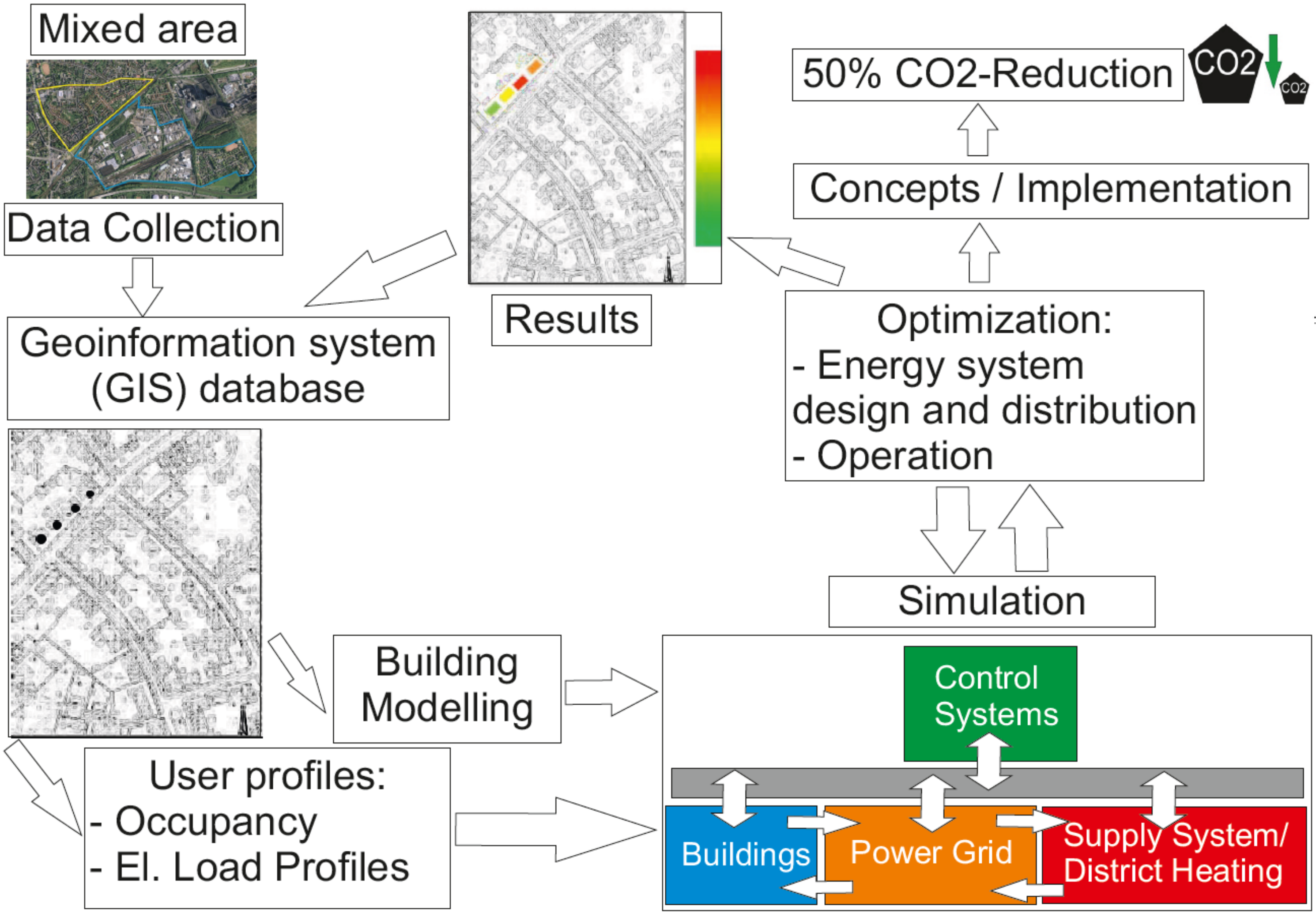


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# Motivation - Future energy system

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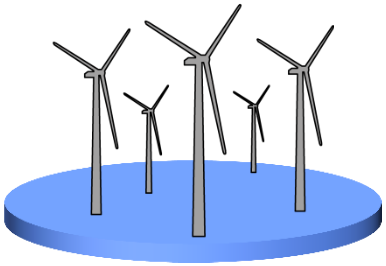
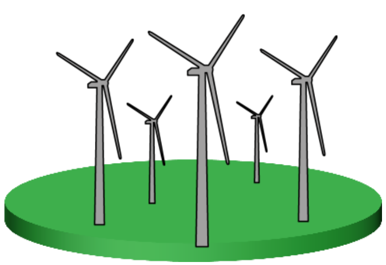
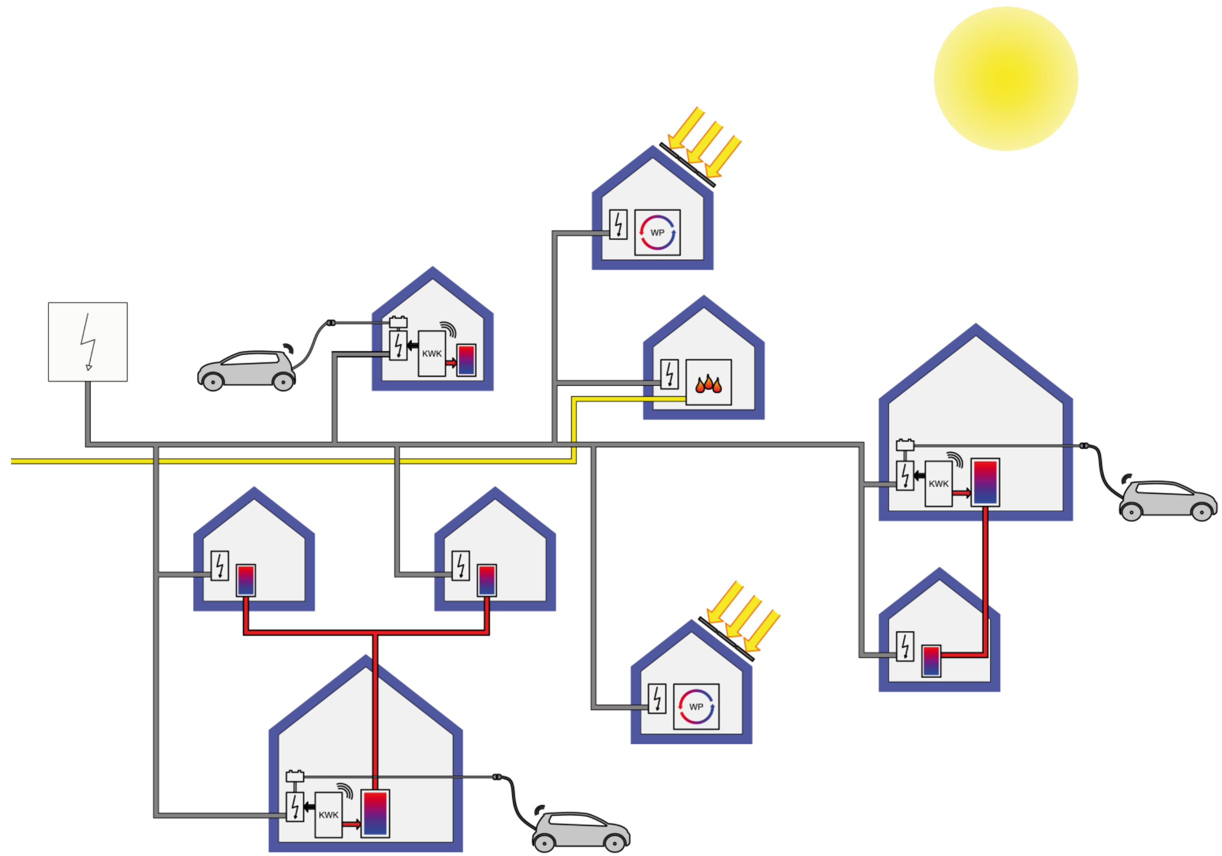


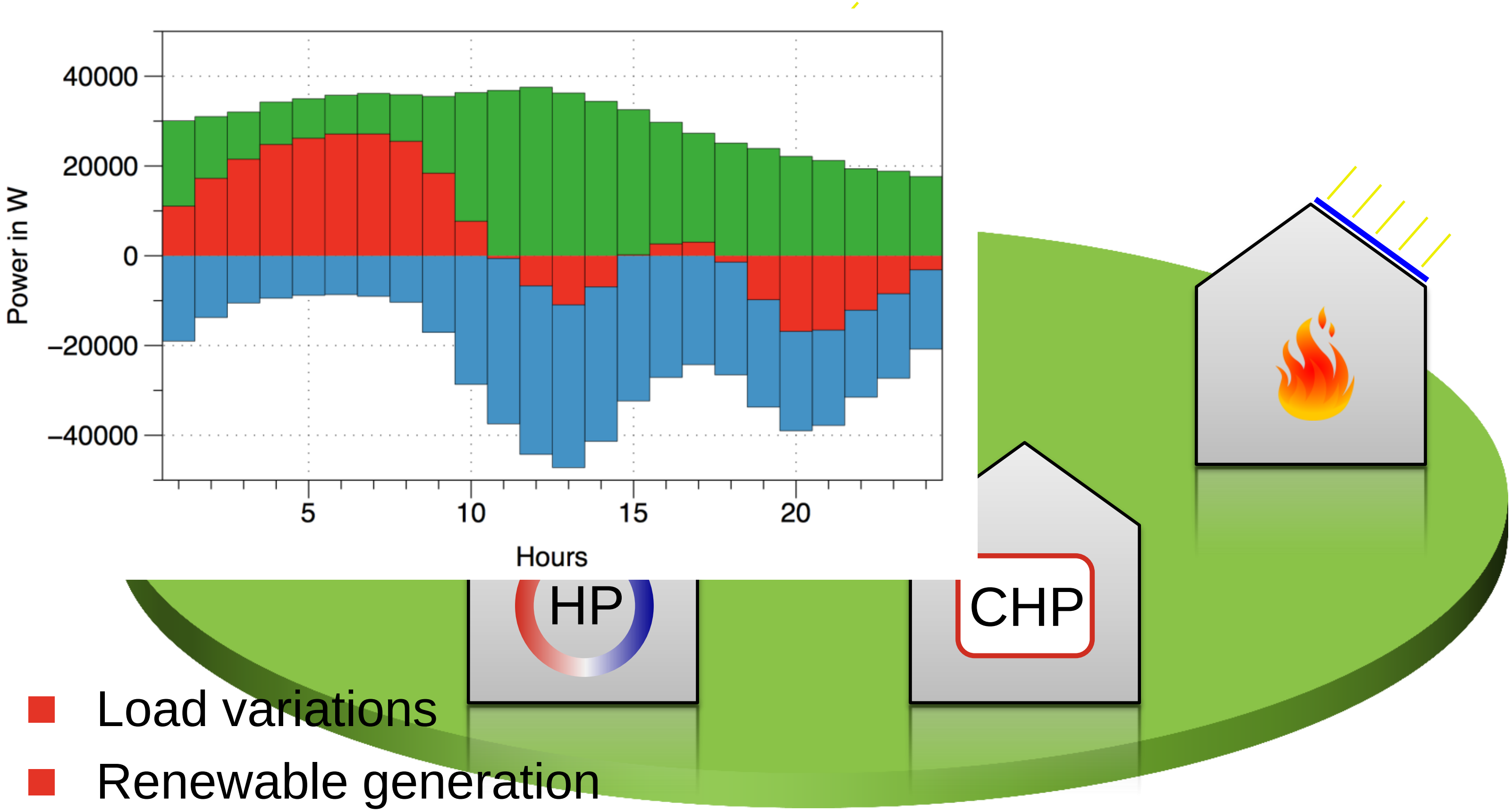
Off shore



On shore



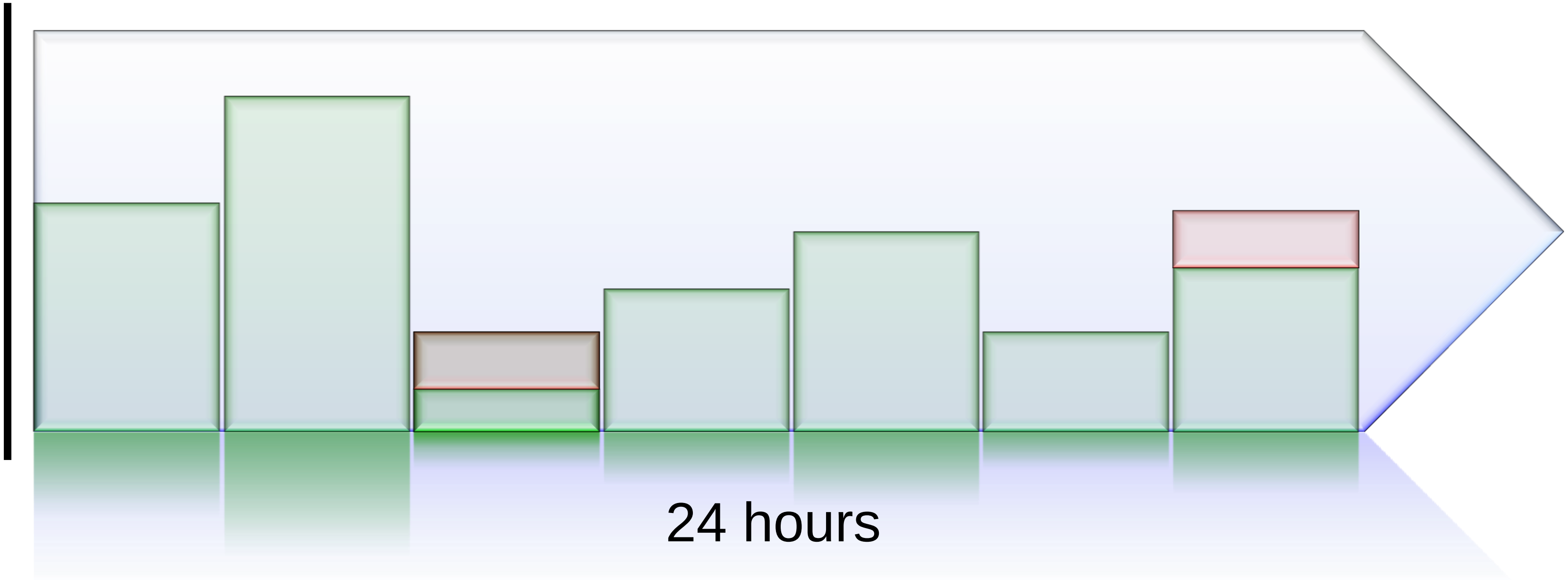
# Introduction




- Load variations
- Renewable generation

# Energy Management System
# Two Operation Modes

- Day ahead scheduling of the operation of shiftable heating systems
  - According to thermal demand
  - According to availability of RES
- Short term balancing during the day due to deviations
  - Forecast errors
  - User influence



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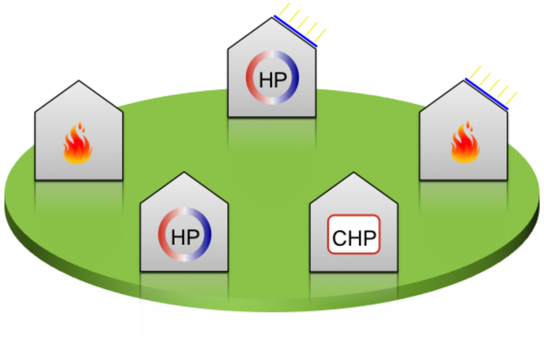
# Centralized approach

- Central approach (Benchmark)
  - Mixed Integer Program (MIP) solved for several houses
  - Constraints:

$$\sum_{t=1}^{T}\sum_{n=1}^{N}\left(Pth_{Heater_n} \cdot modlvl_{Heater_{n,t}} - Pth_{Storage_{n,t}} - Pth_{Demand_{n,t}}\right) = 0$$

$$0 \leq Eth_{storage_{n,t}} \leq STORCAP_n$$




  - Objective function:
    - Mismatch = $\sum_{t=1}^{T}\left((Renewable\ Generation)_t - \sum_{n=1}^{N} Pel_{Demand_{n,t}}\right)$
    - Fluctuations = $\sum_{t=1}^{T}((Mismatch\ - LSL)_t)$
    - Remainder = $\sum_{t=1}^{T}\left((Fluctuations)_t - \sum_{n=1}^{N} Pel_{HEATER_{n,t}}\right)$

$$\min \sum_{t=1}^{T} |Remainder_t|$$

# Results of centralized scheduling

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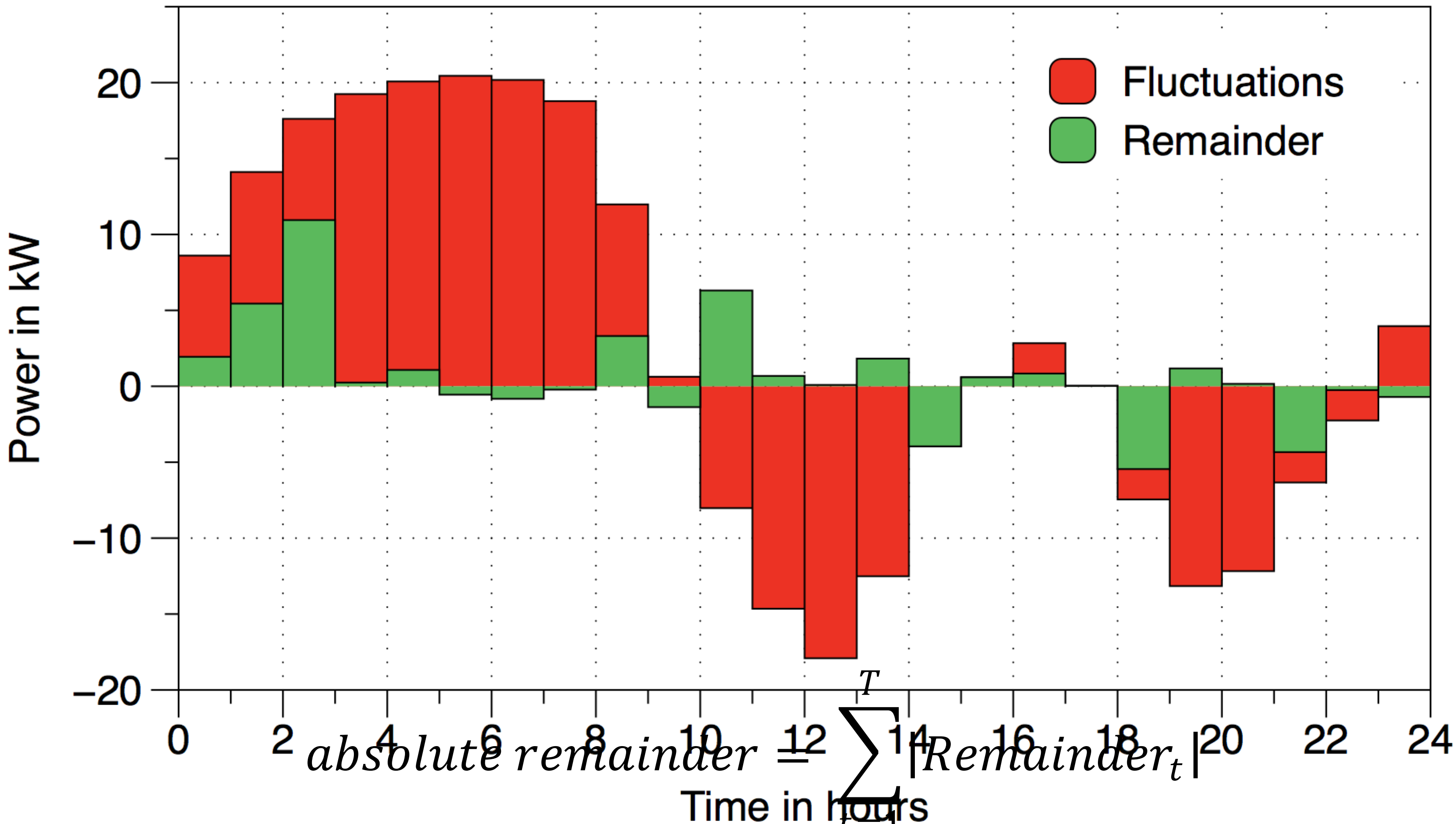


$$absolute\ remainder = \sum_{t=1}^{T} |Remainder_t|$$

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# Decentralized approach
# Local Optimization

- E.g. Minimimize On/Off Switching of heating units
  - Also others or possible (Min Co2, Price, …)

$$\text{Min} \sum_{t=1}^{T} |Switching_t|$$

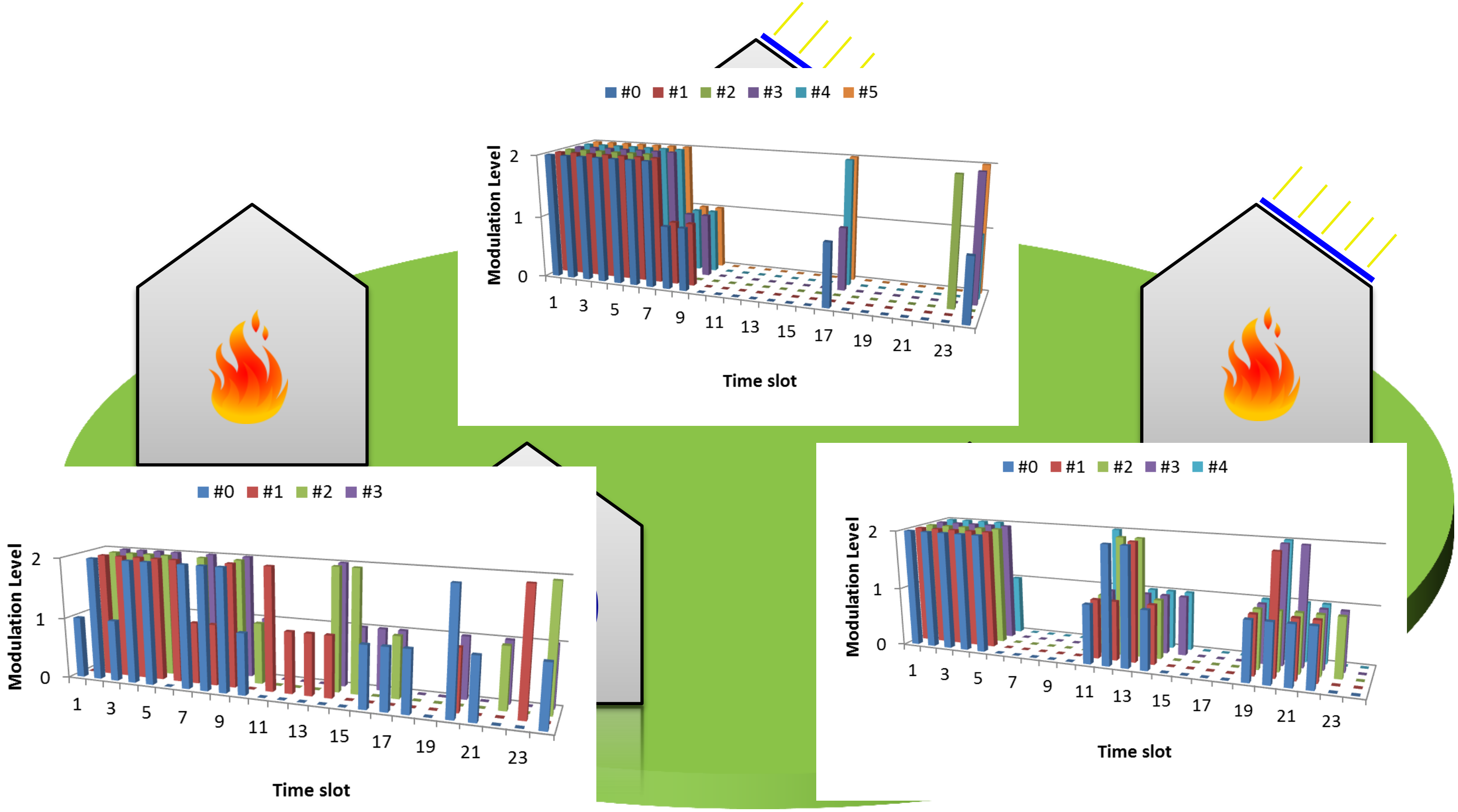
- Whereby Switching is defined as:

$$Switching_t - \begin{pmatrix} modlvlEH_t - modlvlEH_{t-1} + modlvlHP_t - modlvlHP_{t-1} \\ + modlvlCHP_t - modlvlCHP_{t-1} \end{pmatrix} = 0$$

$$\forall\, 1 \leq t \leq T$$

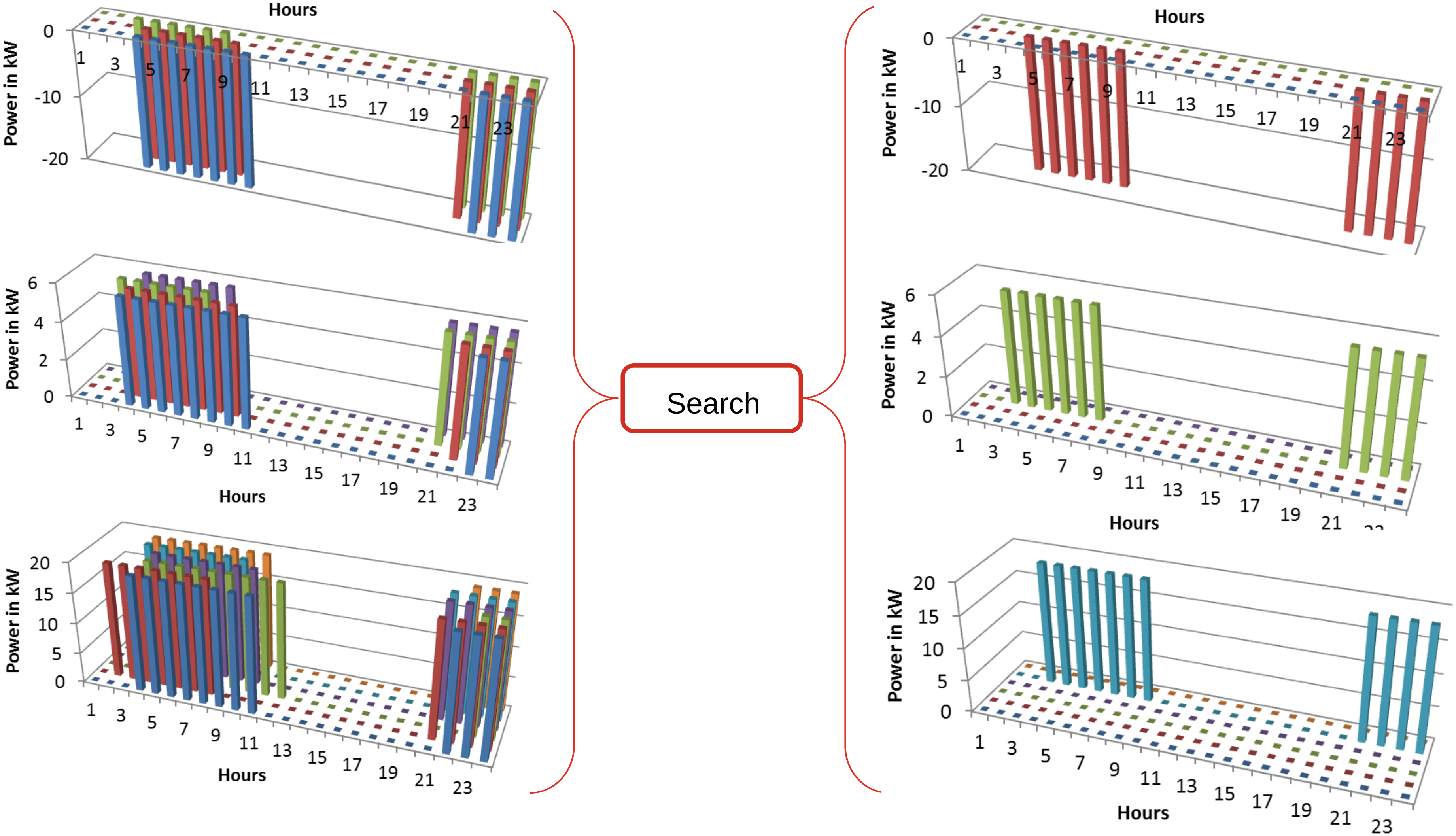
# Decentralized approach





# Decentralized approach





# Search



1

- Calculate „absolute remainder“ of all possible combinations

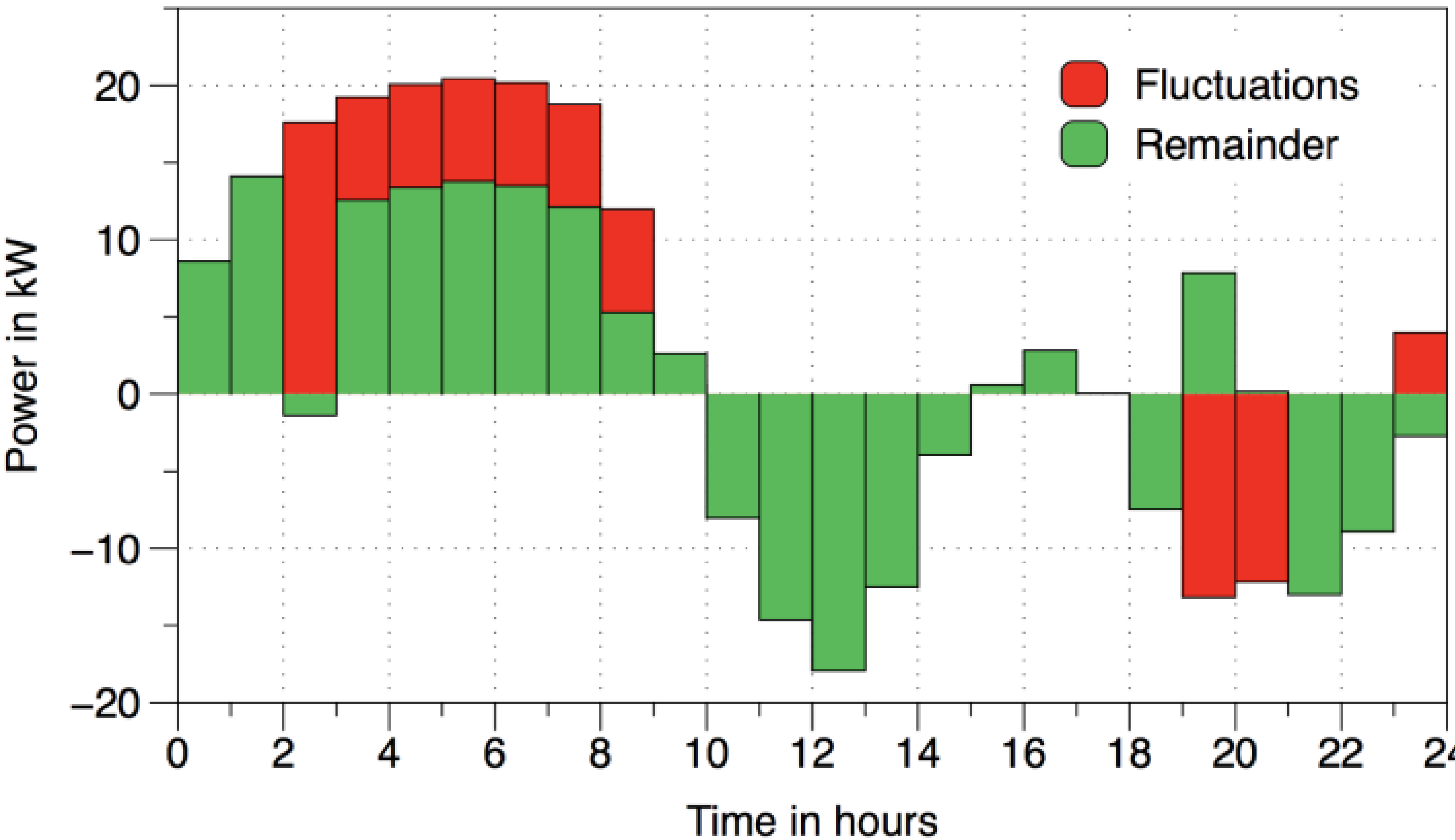
2

- Select combination with smallest „absolute remainder“

3

- Inform every building about the selected schedule

# Decentralized Approach - Results



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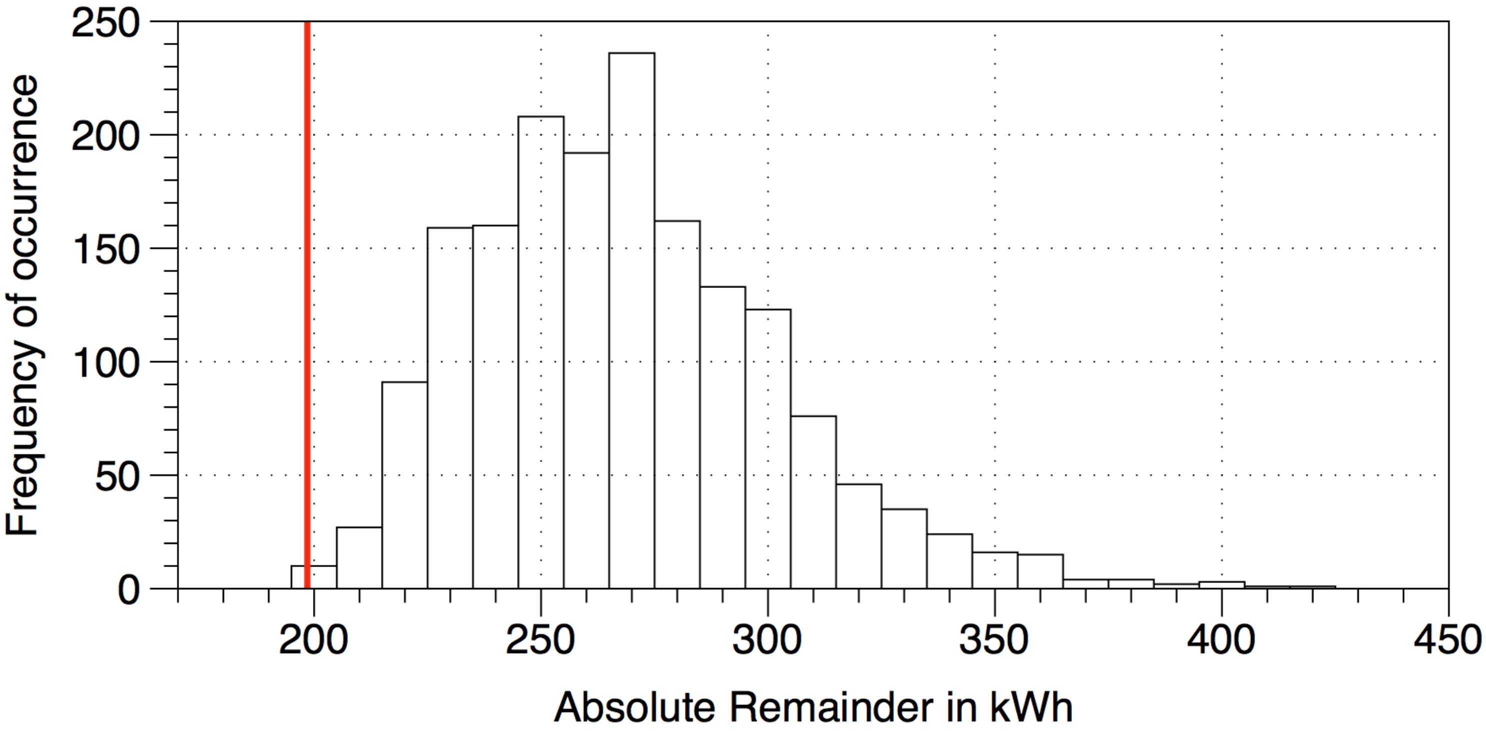

# Decentralized Approach - Results

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- Better result from the local point of view
  - Local objective function: reduce switching
  - Switching significantly reduced
- Performance from a global point of view goes down
  - Increased „absolute remainder“
  - Decreased global result due to reduced flexibility
- Solution
  - Relax the local objective
  - Allow more possible schedules



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# Decentralized Approach - Results

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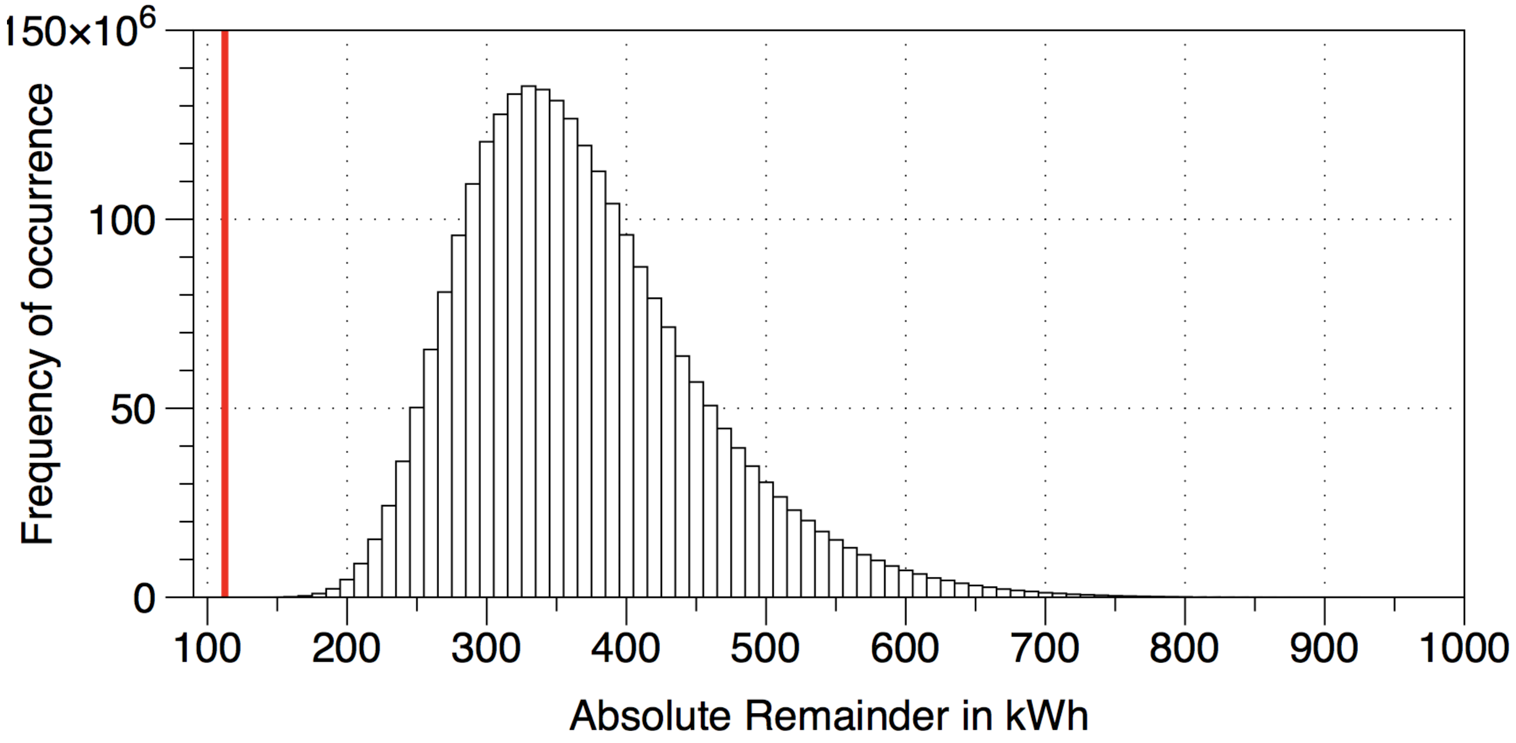

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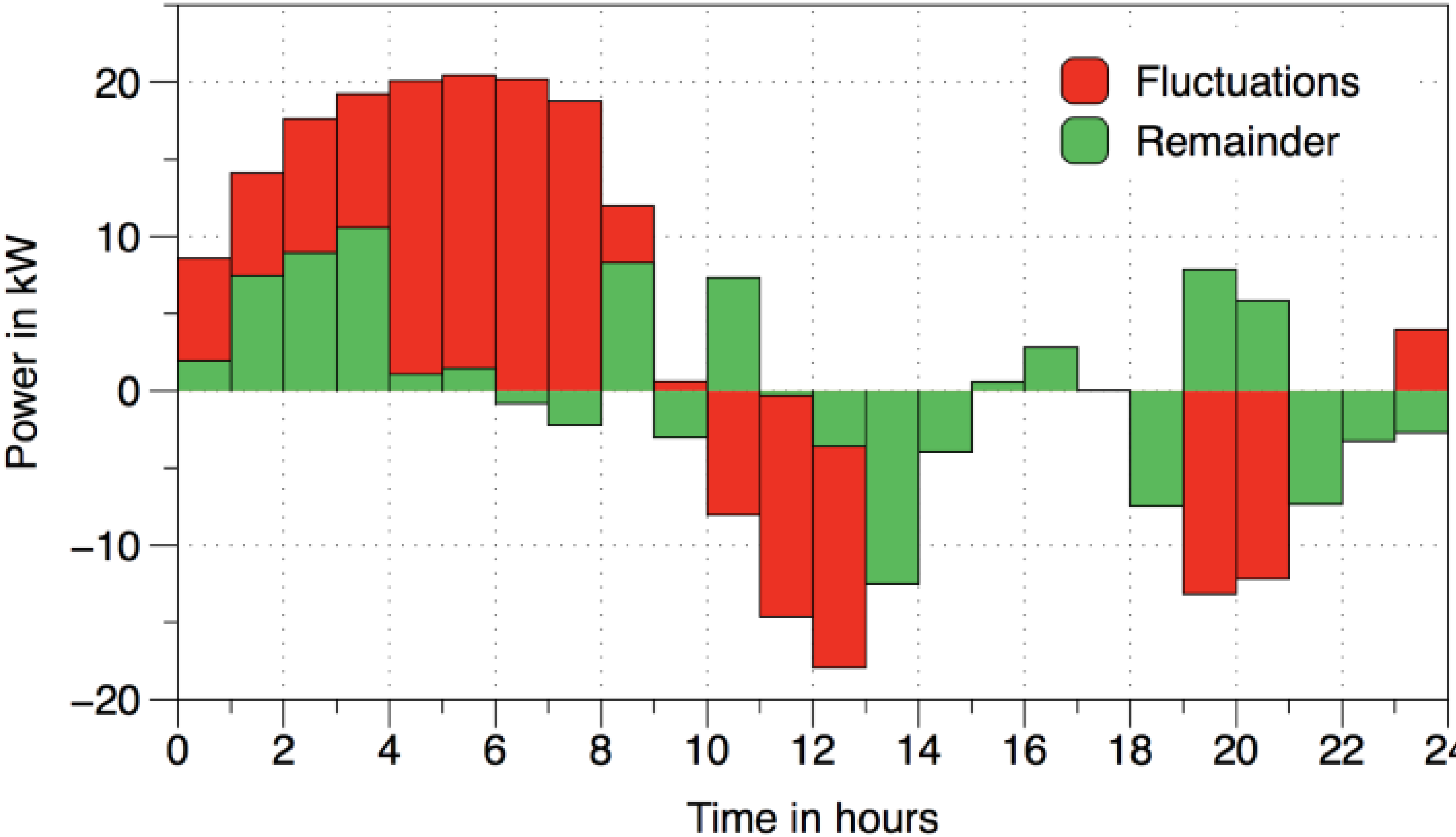

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# Conclusion and Outlook

- Every individual building can in first place do a local optimization
  - Every building can have a different objective function
  - Every building can decide how much flexibility it provides
- Flexibility of the individual building can be exploited on a higher level
  - Support integration of Renewables
- Advantages
  - A lot of detailed information don‘t have to be sent to a central unit
  - With a decentralized search, the approach would be completely decentralized
- Outlook
  - Implement more detailed objective functions for the individual buildings
  - Implement decentralized search

Thank you for your attention!