A Distributed Multi-agent Control System for Power Consumption in Buildings

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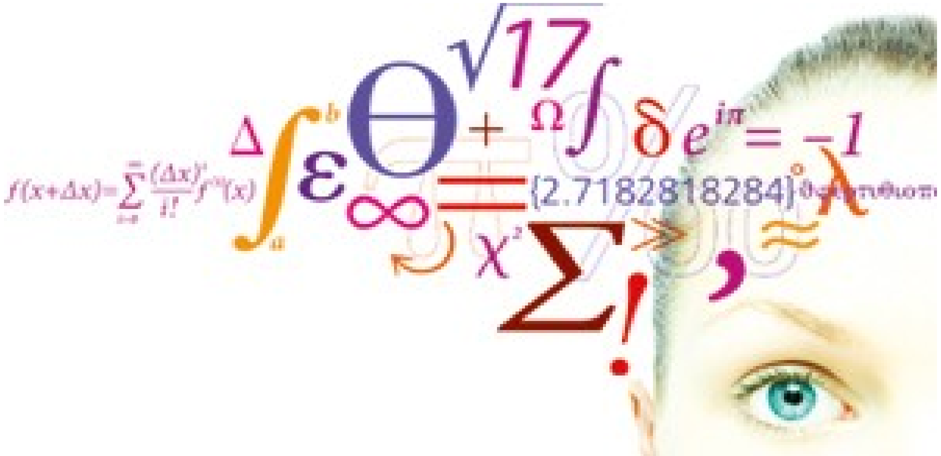
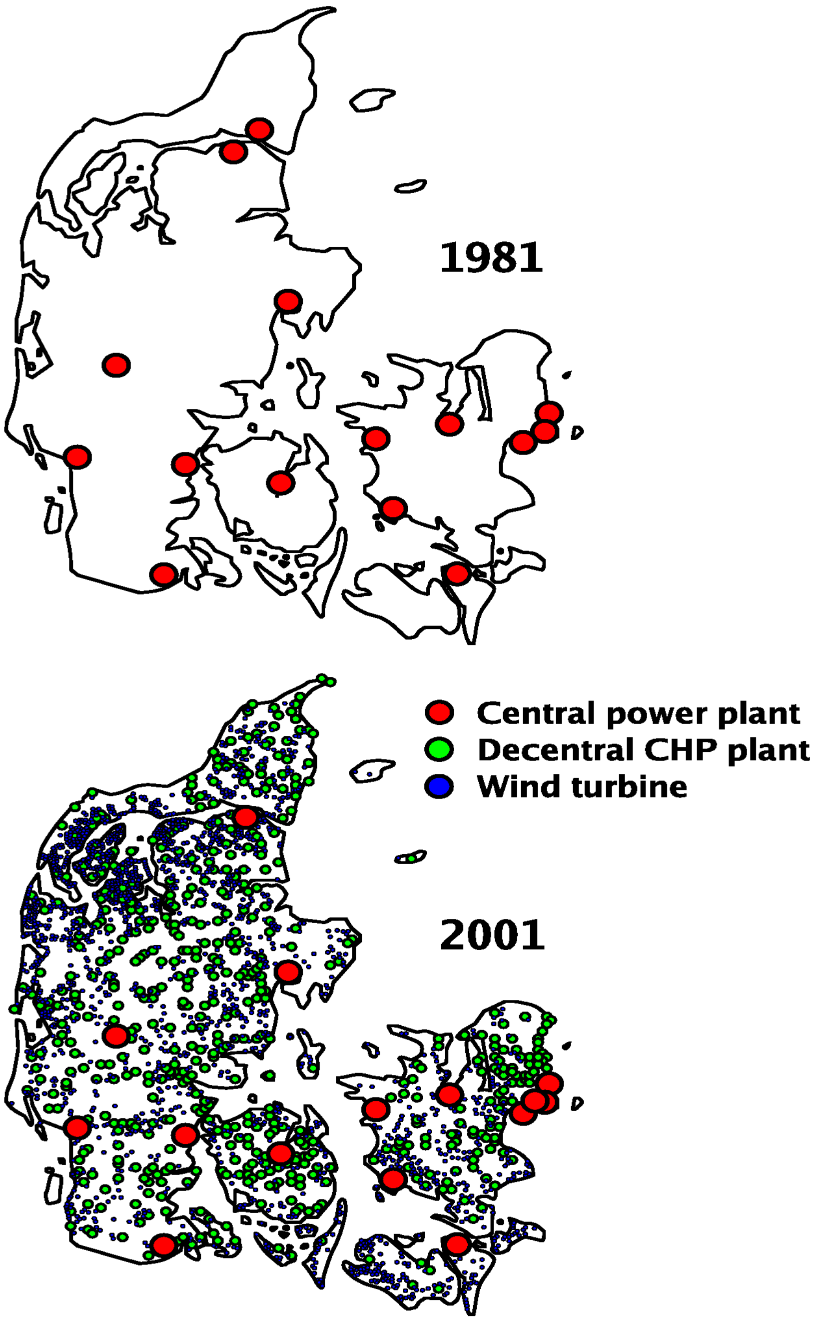
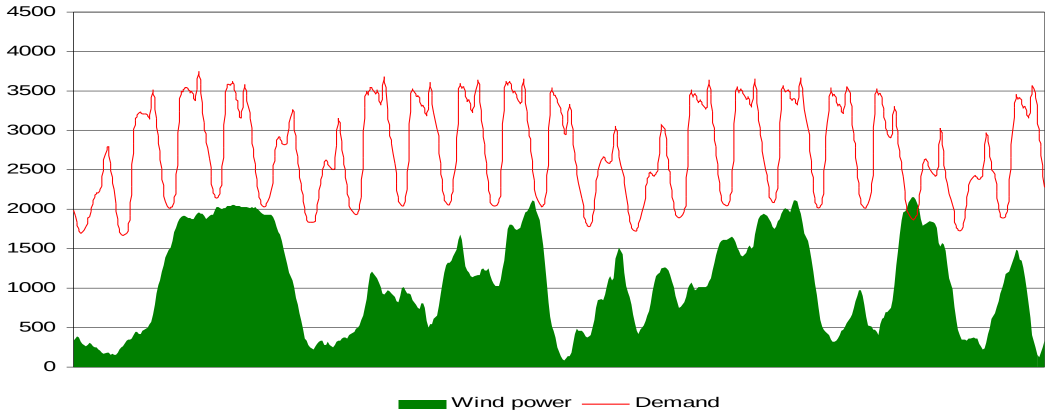


The Danish challenge

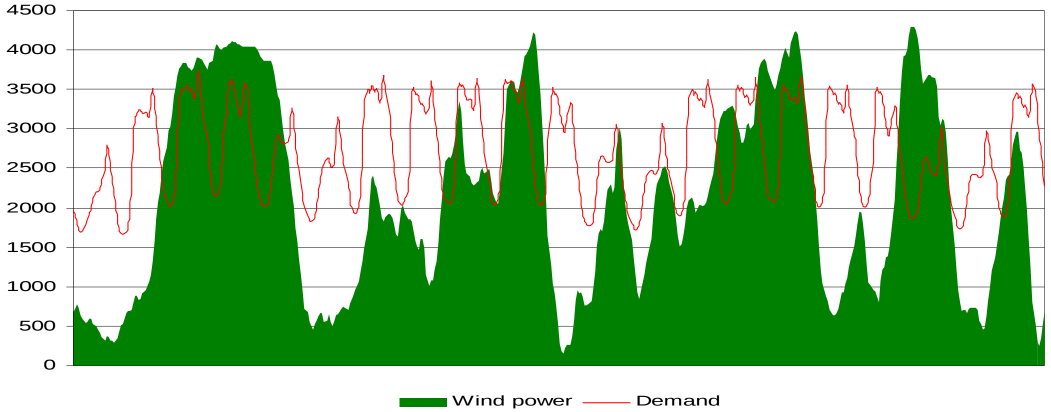
- Electricity supply ca. 1980: 15 coal-fired power plants
- Political desire to exploit renewables and to increase energy efficiency → subsidies and other incentives
- Electricity supply ca. 2000: about 500 distributed CHP plants and about 5000 wind turbines
- Wind power penetration ca. 29% (2011)
- Government target: 50% wind power in 2020



Towards 50% wind power



DK West, January 2008



DK West wind x2

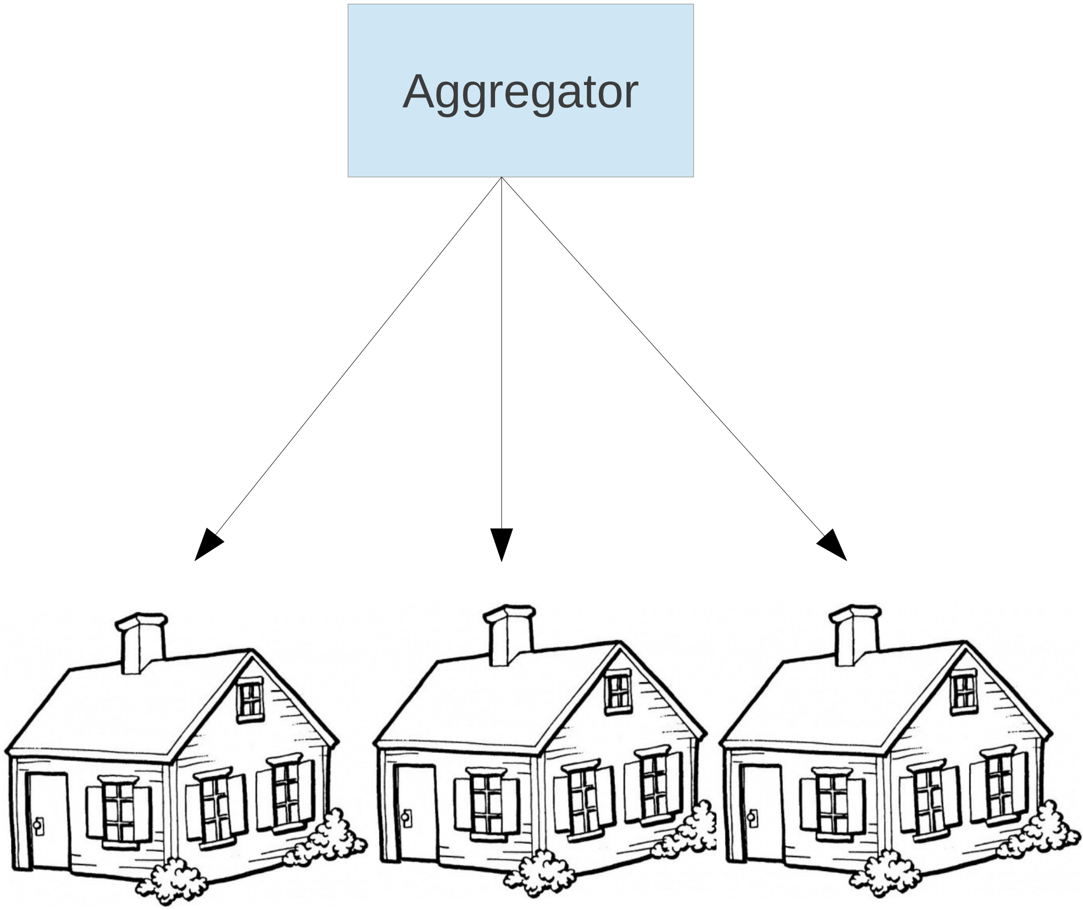
- Already at 29% wind penetration, wind production exceeded total consumption on some occasions
- In an energy system with 50% wind and 10% PV, overflow will be massive.
- In a business-as-usual scenario, wind production would have to be curtailed for more than 1000 hours per year.

Controllable demand

- Since production is less controllable, consumption need to follow production
- Yearly consumption of Danish houses accounts to around 31% of overall consumption
- It is still unknown how much flexibility a house can offer, there are several danish projects researching controllable demand:
  - e-Flex
  - EcoGrid
  - iPower
  - INCAP

Issues

- Communication to the grid Aggregator (for example hosted by Balance Responsible Party) needed
- Home automation needed to receive signals and control the demand
- Infrastructure to manage devices of different:
  - Type
  - Purpose
  - Vendor
  - Controllability
  - flexibility



Device types

- Controllable
  - Flexible
  - Programmed
- Uncontrollable
  - Spontaneous use
  - Base load

Home control strategy

- Existing home automation focus on the energy saving
- With increasing uncontrollable renewable production houses cannot constantly save, they are allowed to overuse energy at some times and reduce consumption when there is little production
- This work explores the flexibility of a house at its limit, deal with disturbances and controls an unknown set of different devices

A Distributed Multi-agent Control System for Power Consumption in Buildings

- Encapsulate functionality within devices
- Self-organization
- Extendability
- Forward-compatibility
- Reconfigurability
- Adaptation

- System need to perform several independent tasks
- Actors with different goals need to communicate and cooperate
- Redundancy
- Modularity

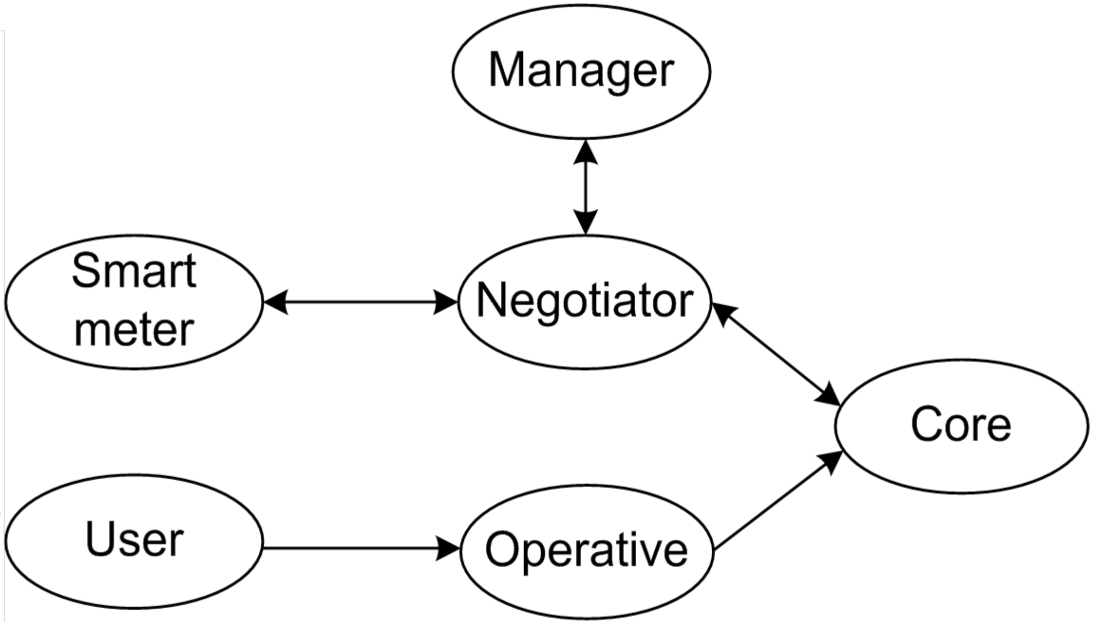
Agent architecture

Manager is an agent that is responsible for managing negotiations between different devices in the building.

Negotiator is an agent responsible for starting and maintaining negotiation from the point of view of a single device.

Operative is an agent responsible for receiving and passing direct commands and signals to a device, that triggers no negotiation.

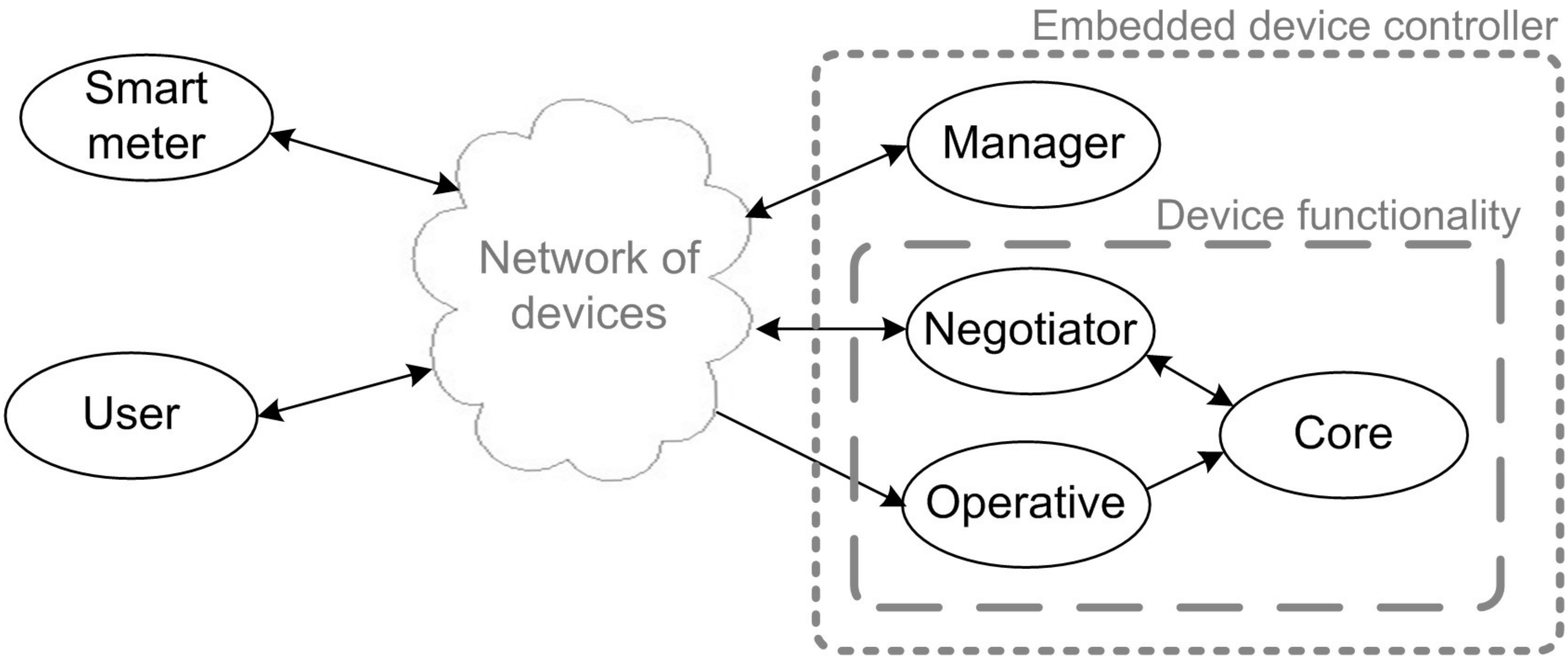
Core is an agent responsible for controlling a device directly and its behavior depends on a device type and implemented control algorithms.



Smart meter is an agent responsible for passing power setpoint to all the devices in the house and matching it with actual power consumption.

User can control all devices in the space, overriding automatic settings.

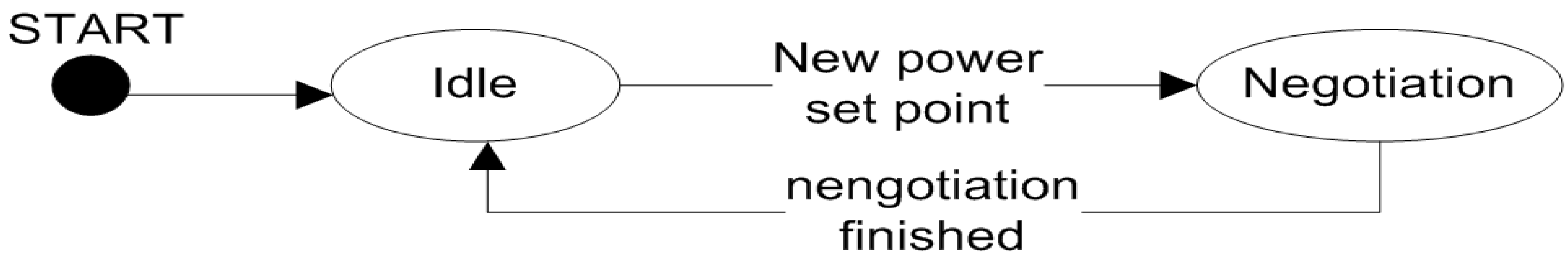
Embedded device controller



Every device consist of two parts:

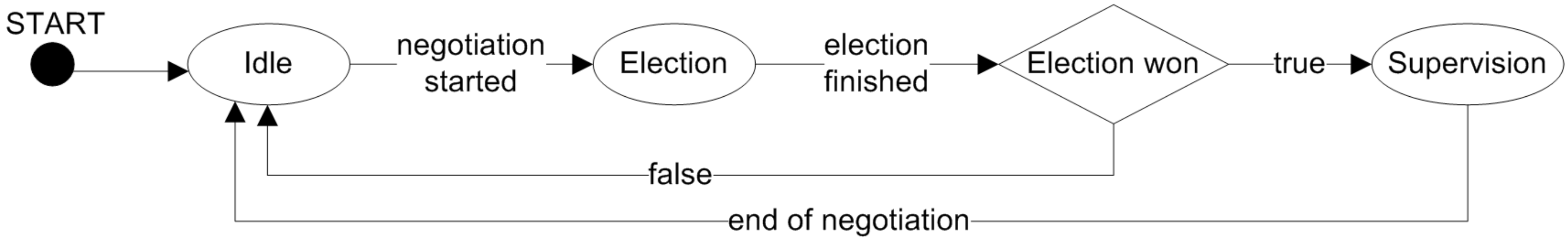
- Manager
- Device functionality (Negotiator, Operative and Core)

Negotiation



- New negotiation is started by individual devices and triggered by a new setpoint from a Smart Meter agent
- Negotiation request is sent to Manager agents

Management



- Manager waits in the idle state for a request
- When a negotiation request arrives election process is started
- If the particular manager wins the election, it starts supervision over set of devices

Election process: quality factor

Manager calculates personal quality factor, consisting of:

- **fairness function**, proportional to the number of negotiations (both active and finished) managed by the local manager, relative to the total number of negotiations,
- **occupancy function**, discrete function determining if the manager mi is already busy supervising another negotiation,
- **random number** between 0 and 100.

If two or more managers have the same quality factor, renegotiation is performed.

Supervision process

- Chosen manager informs devices form controlled group that it is the manager
- Devices send their urgency factor and requested power consumption
- Managed decides which devices can operate:
  - Highest urgency
  - Within the overall power consumption limits

Supervision process: urgency factor

Urgency factor is calculated in the Core agent and consists of:

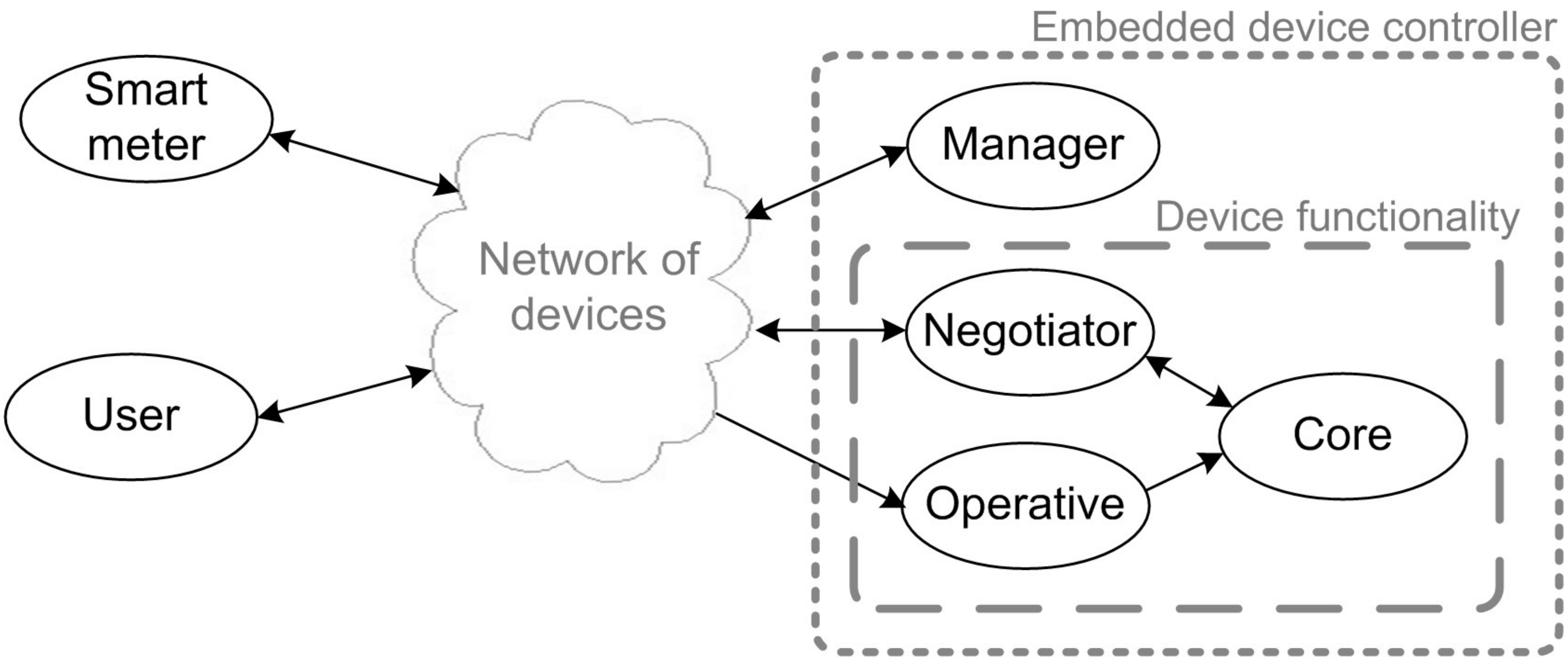
- **fairness function**. This discrete function determines if the device di is in operation. If the device is being used, its urgency to operate decreases, allowing other devices to be activated.
- **difference** between actual and desired comfort in the environment influenced by a device. Depending on the device, comfort may be expressed in terms of temperature, lighting conditions, humidity or other measurable comfort indicators.
- **room occupancy**. This discrete function reflects if presence sensors indicate that space is used. If no sensor is present, it is assumed that the space is not occupied.
- **random number** between 0 and 100.

Normal operation

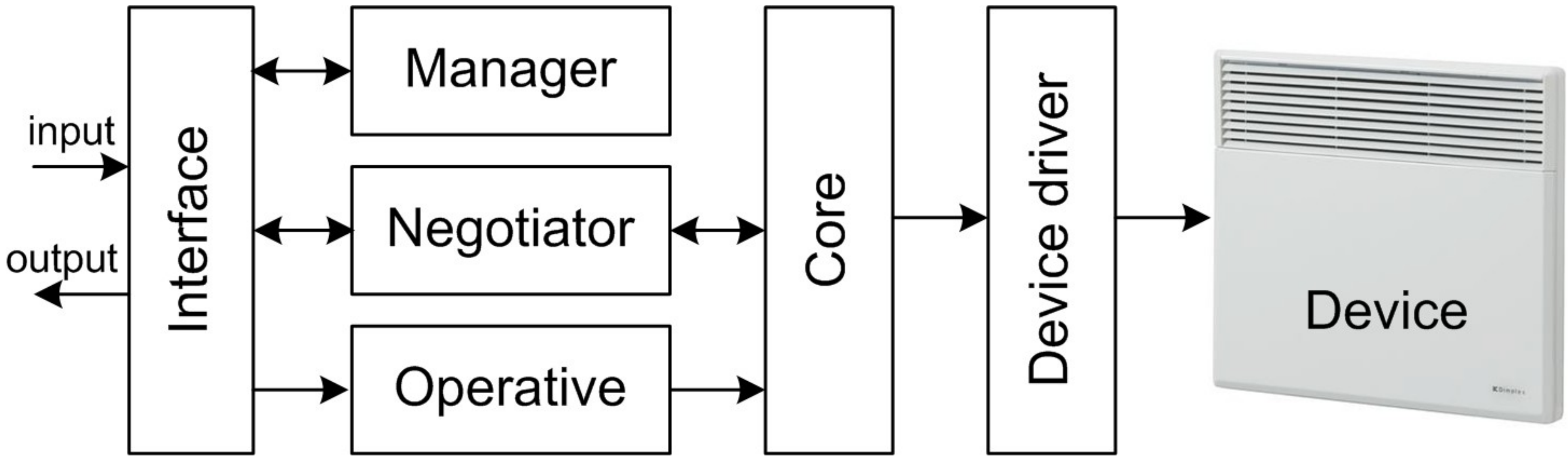
- Device is obliged to respect Managers decision
- Device is allowed to operate until there is a new request
- Devices operation ca be taken over by the user, this device becomes locked and does not participate in further negotiations.

    Type: Controllable → Spontaneous use

Network implementation



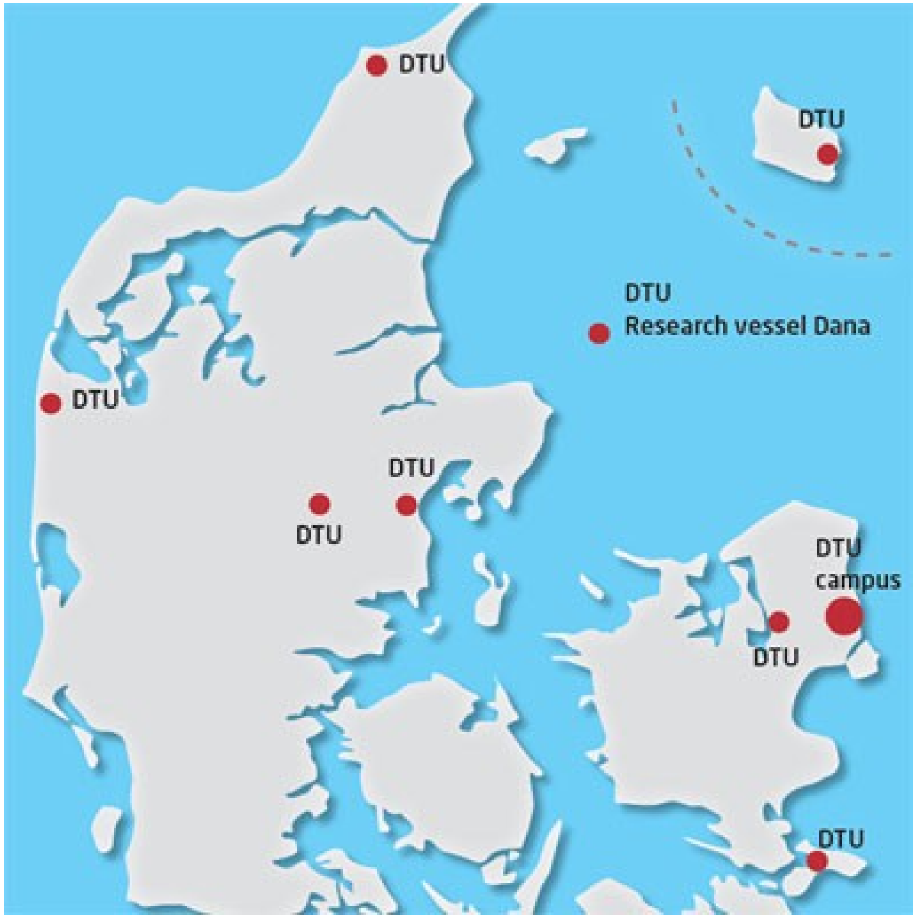
Device implementation



SYSLAB

SYSLAB is DTU Electrical Engineering, Risø campus laboratory for intelligent distributed power systems.

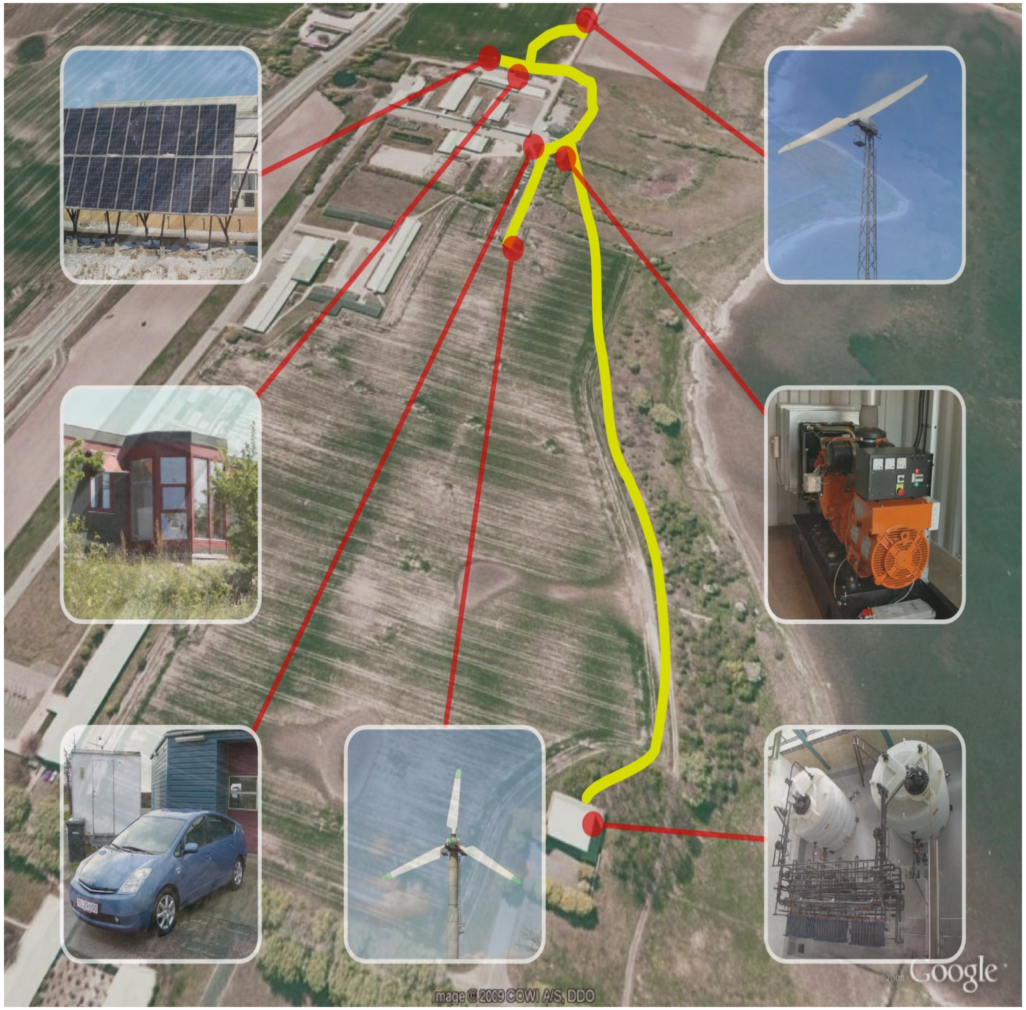
SYSLAB enables research and testing of control concepts and strategies for power systems with distributed control and integrating a number of decentralized production and consumption components including wind turbines and PV plant in a systems context.



SYSLAB / Hardware platform

- 2 wind turbines (10+11kW)
- 3 PV array (7+10+10kW)
- Diesel genset (48kW)
- Office building (20kW)
- Dump load (75kW)
- 3 mobile loads (3x36kW)
- Flow battery (15kW)
- B2B converter (104kW)
- 3 NEVIC EV Charging post
- Machine set (30kW)
- Battery testing bays (300+50+50kVA)

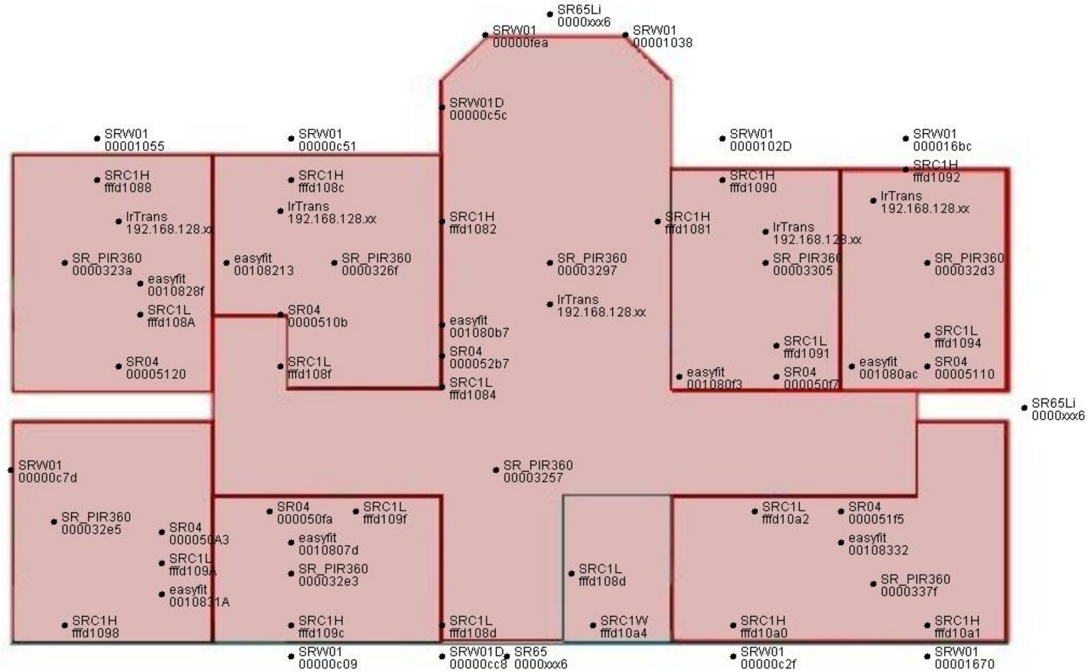
Small “real-world” power grid on Risø's premises

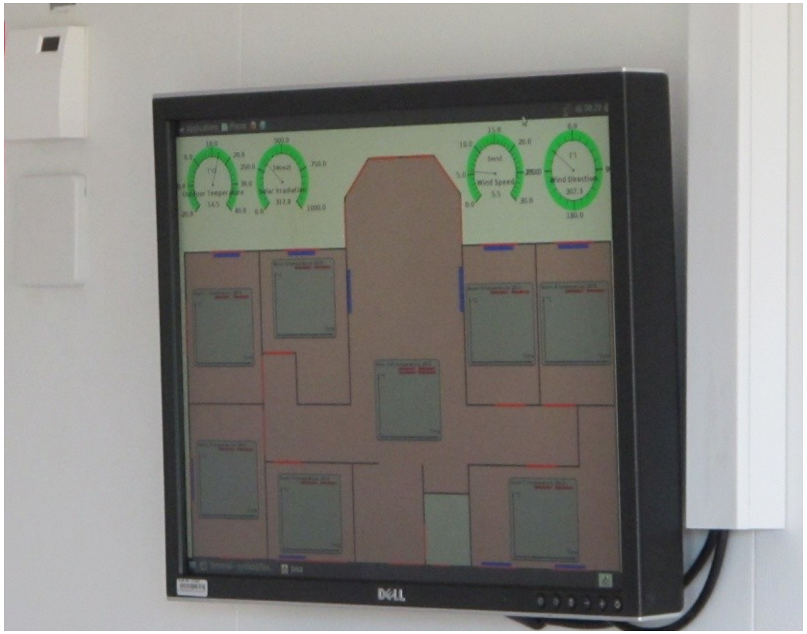


Power FlexHouse

Power FlexHouse

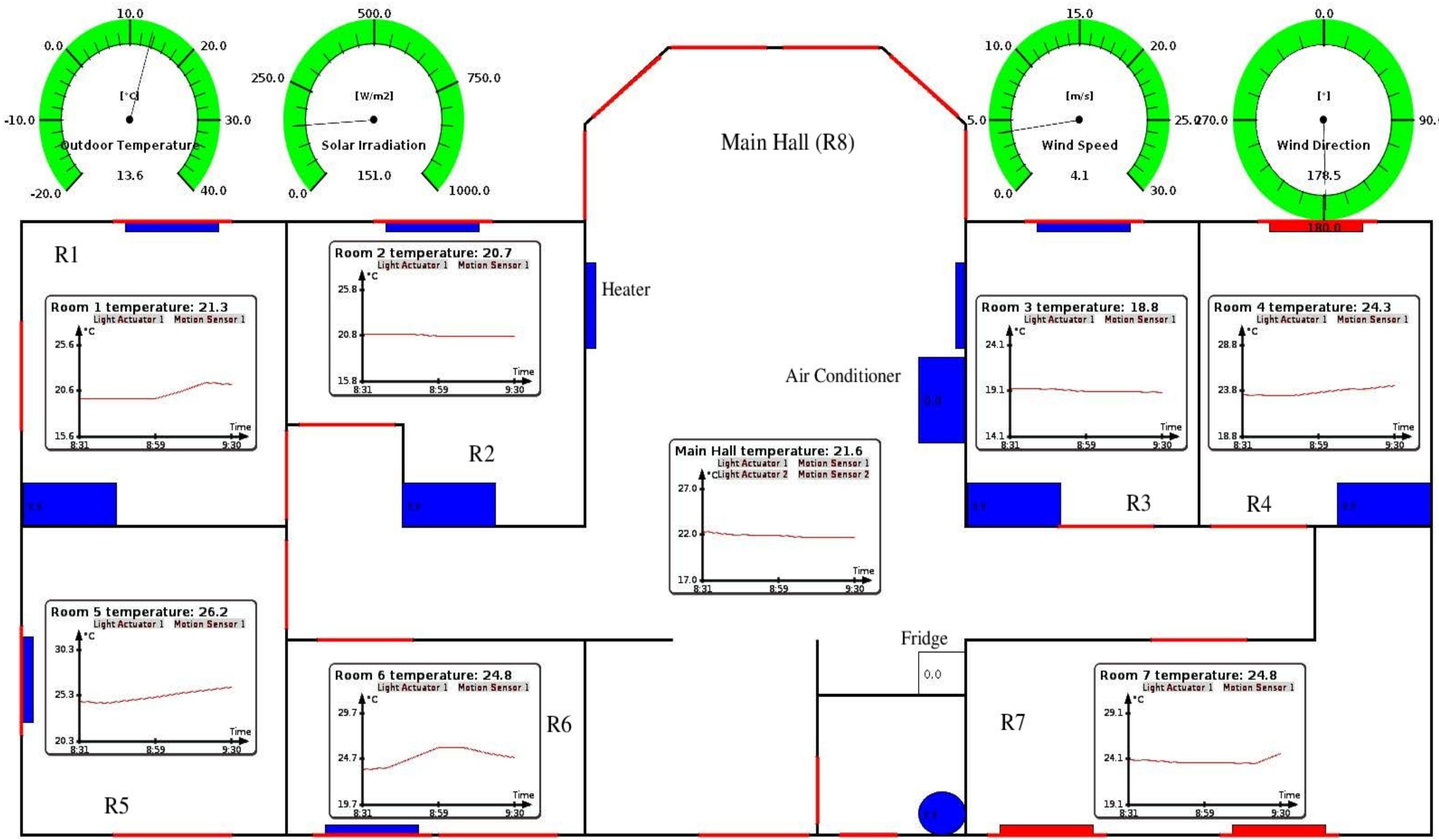
- Software and hardware platform for implementation of controllers for flexible consumption
- About 50 sensors in eight rooms: temperature, motion, ...
- Actuators for heating, cooling, lighting, fridge, hot water boiler
- Study control strategies for flexible loads, sensor requirements, modelling





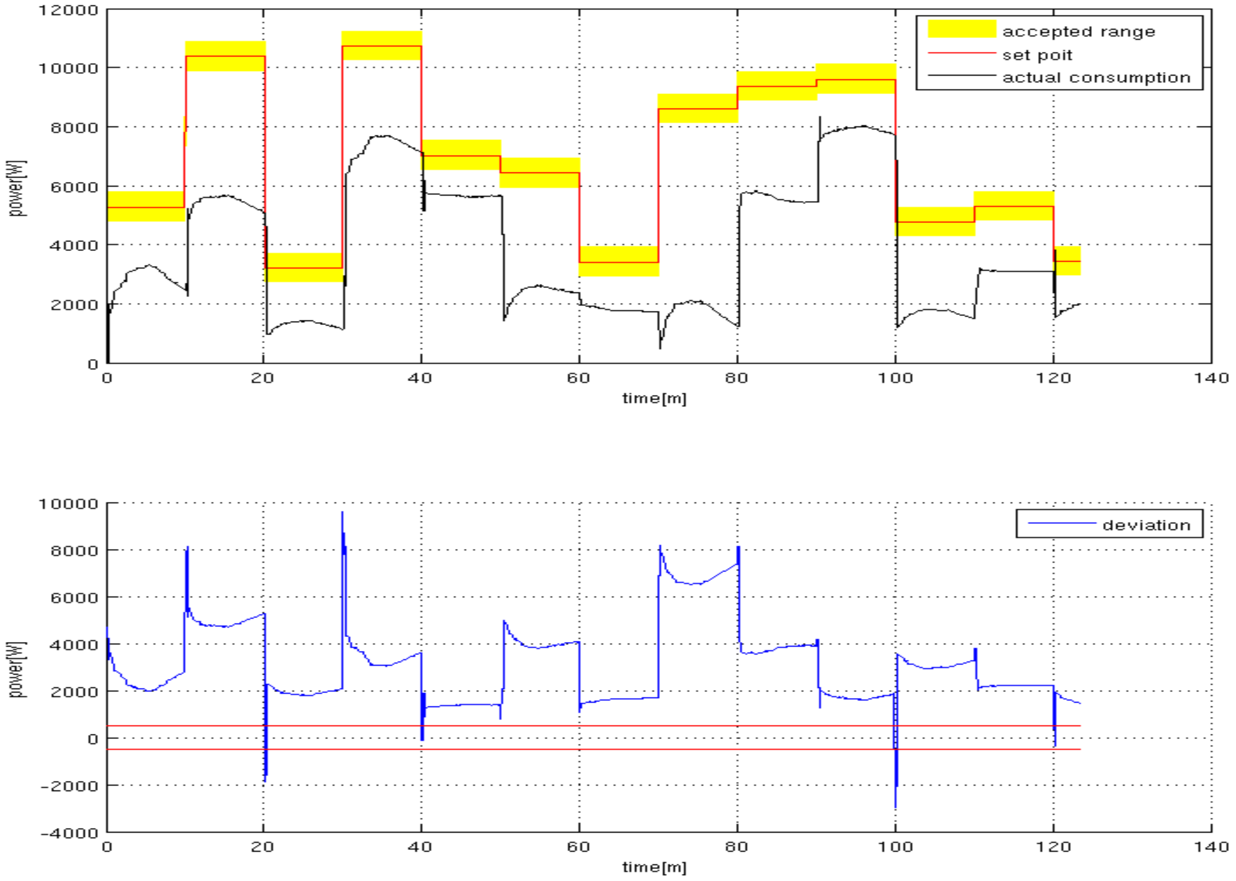
- System services provided by Demand Side Loads
  - Aggregation and Proof-of-concept implementation in SYSLAB
- Communication interface between load and system:
  - Which information to exchange,
  - How to communicate strategies,
  - Links to existing communication protocols

PowerFlexHouse



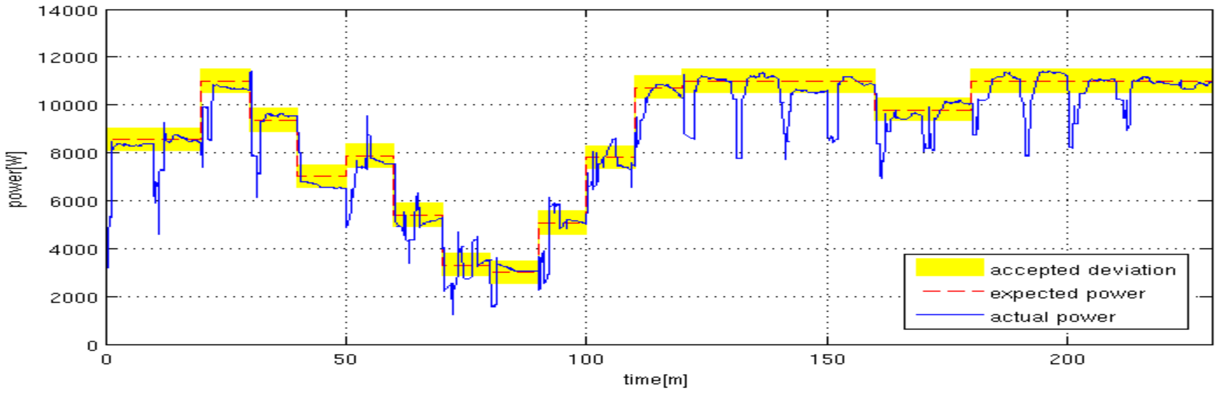
The initial experiment

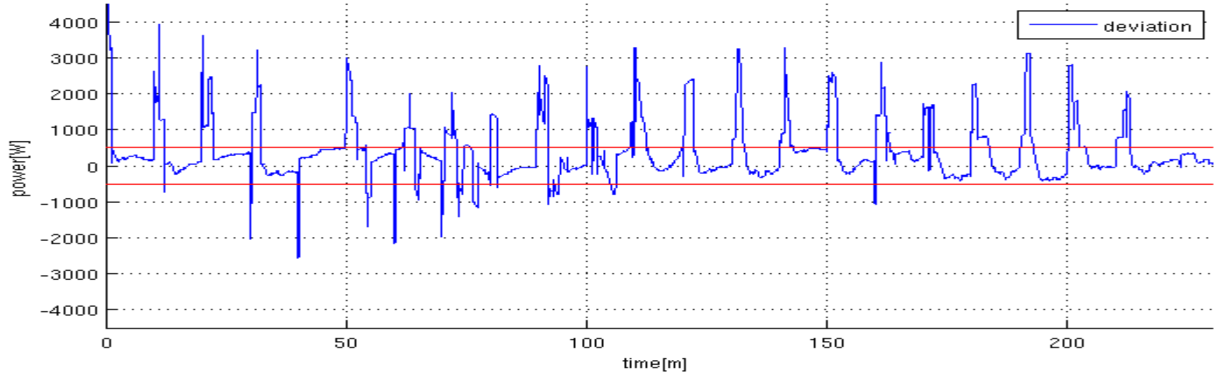
- Every 10 minutes smart meter sends a setpoint to all devices in the house and devices organize and reconfigure after a request
- Overall consumption does not match the requested setpoint
- STD deviation=**1479W**



Consumption adaptation

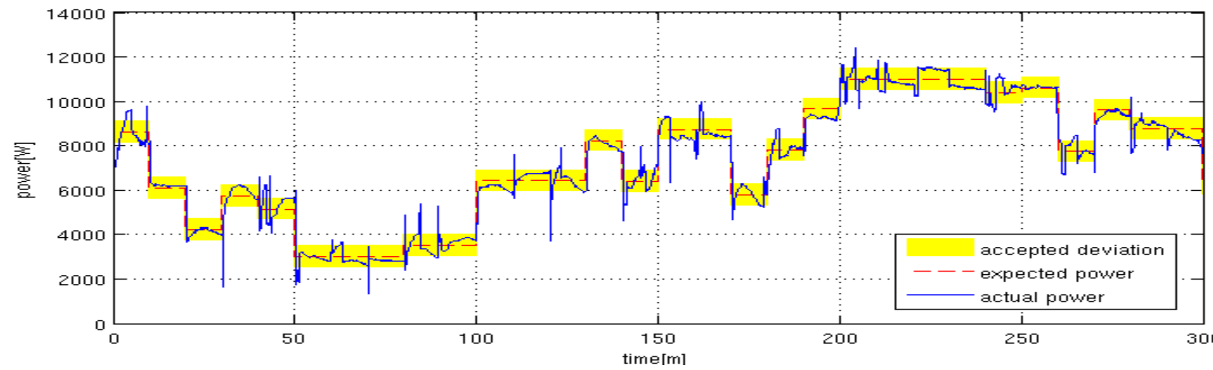
- Smart meter measures the house consumption and every 1 minute adapts its request
- Setpoit deviation is usually positive
- STD deviation=**1033W**

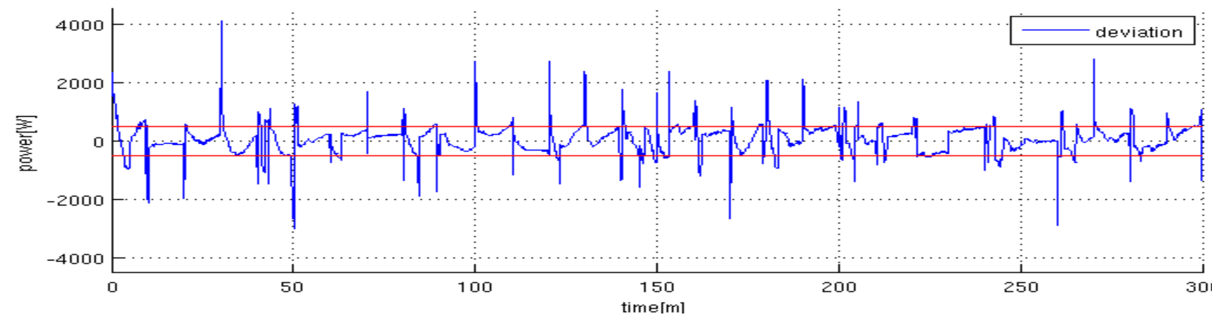




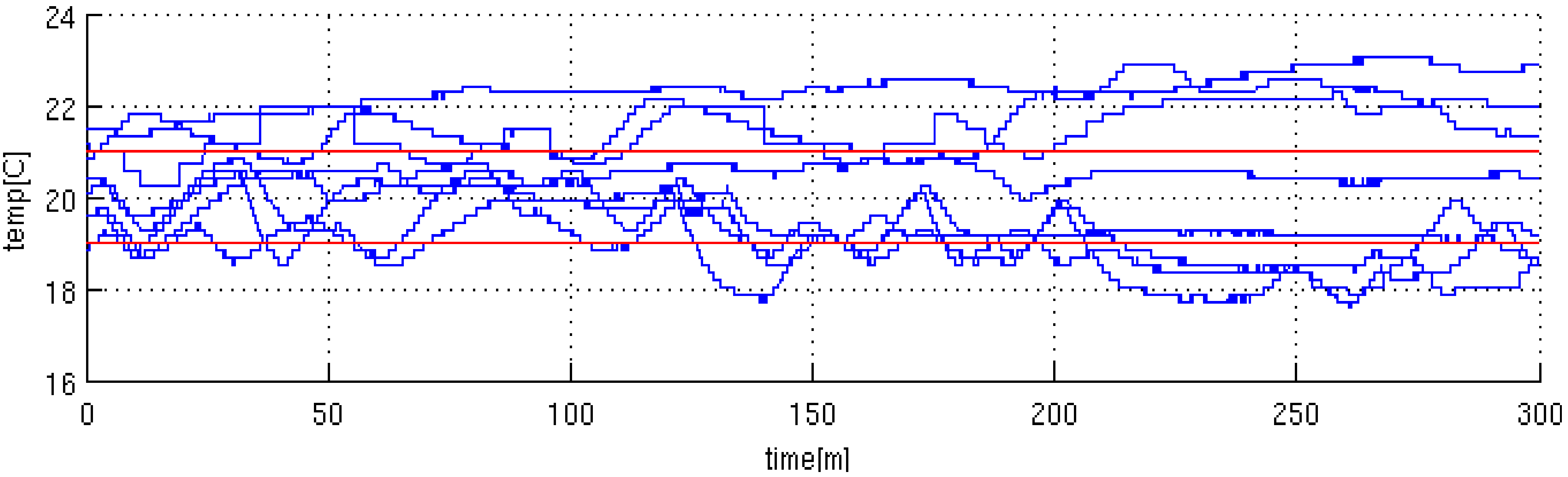
Reducing spikes in the power consumption

- Device consumption prediction refined
- Over several control cycles smart meter estimates its error
- STD deviation= **515W**





Temperature evolution



Future work

- Embedding device control in separate devices
- Reduction of spikes in the power consumption: more supervision from the Manager agent
- Smart meter is a single point of failure: local power measurements + stronger Manager agent supervision
- Renegotiation
- Timed device unlock

Thank you!

Questions?