Smart-Energy Operating-System;
A Framework for Implementing Flexible Energy Systems

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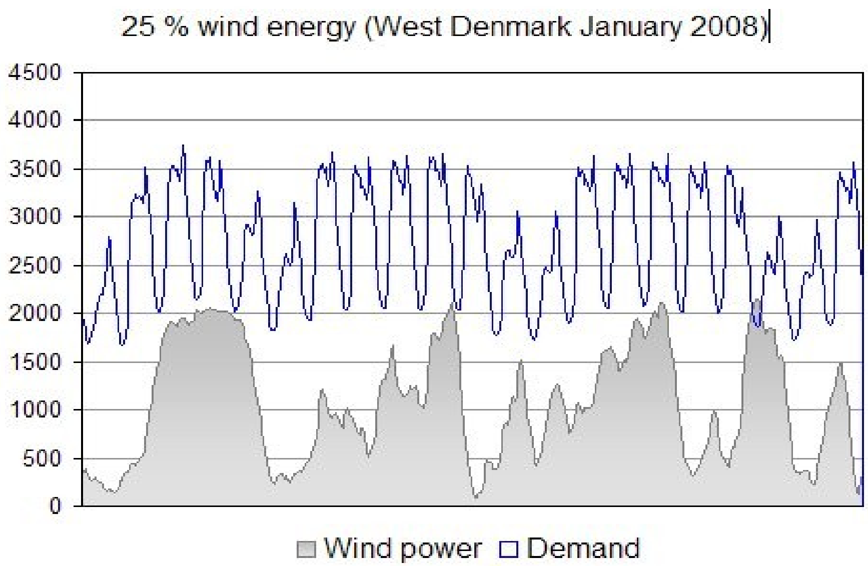
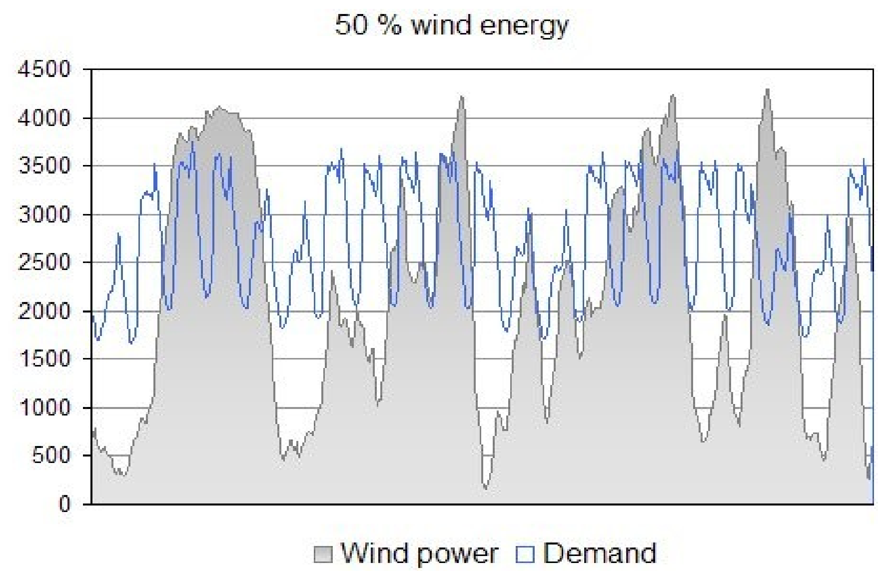
The Danish Wind Power Case

…. balancing of the power system





In 2008 wind power did cover the entire demand of electricity in 200 hours (West DK)

In 2015 more than 42 pct of electricity load was covered by wind power.

For several days the wind power production was more than 100 pct of the power load.

July 10th, 2015 more than 140 pct of the power load was covered by wind power

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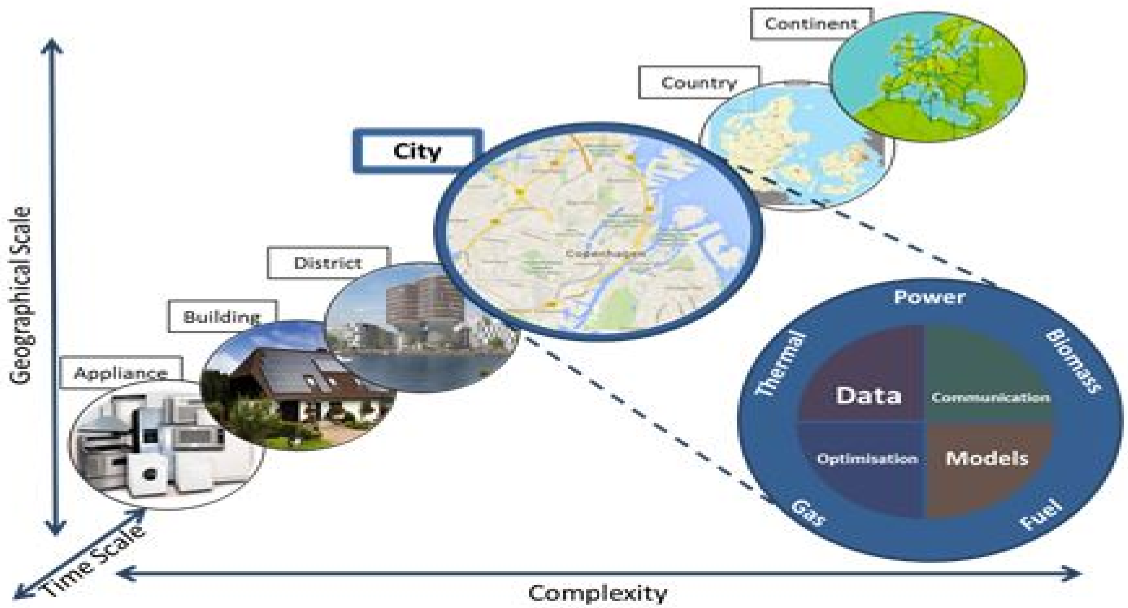
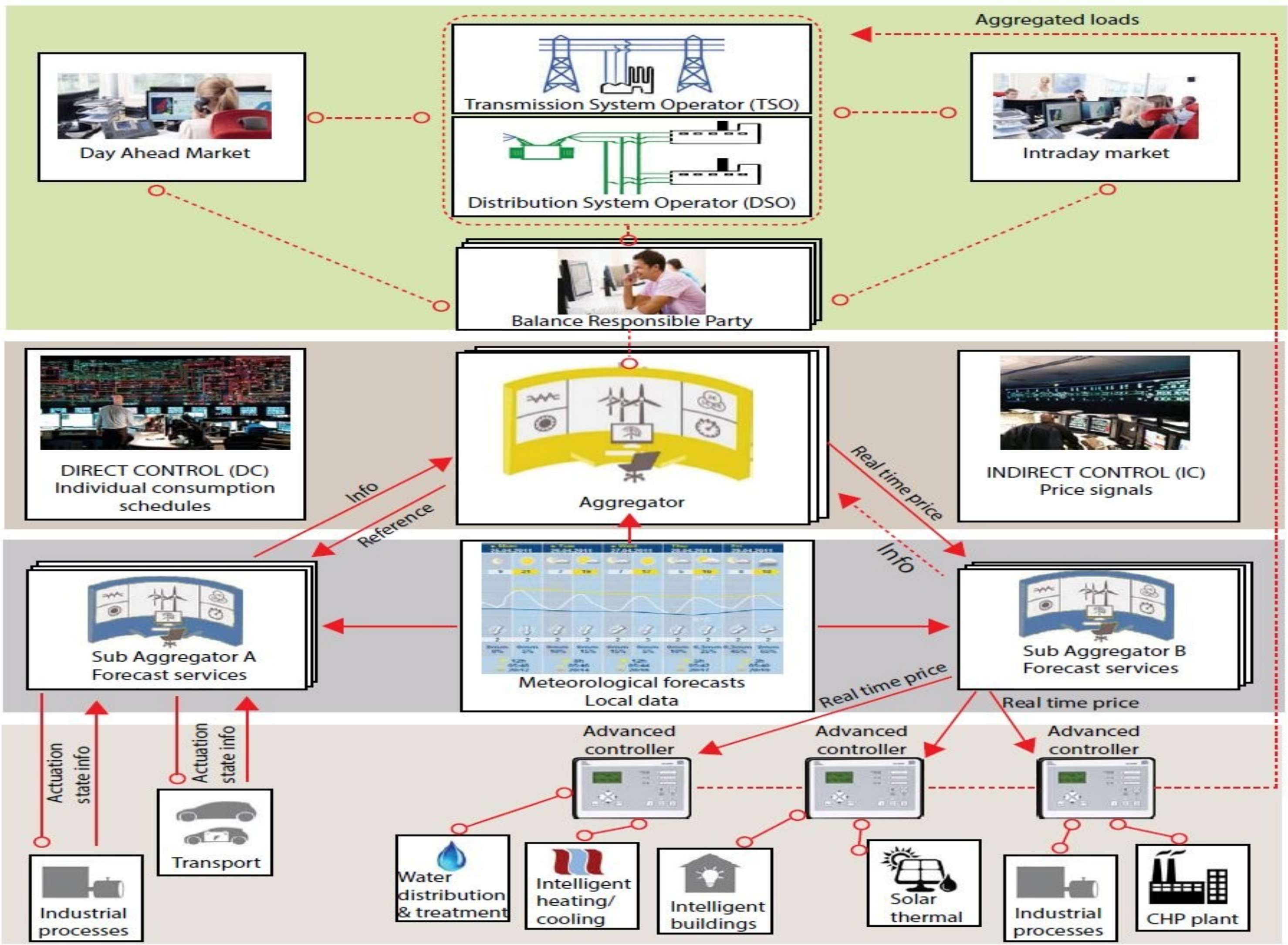
Flexible Solutions and CITIES

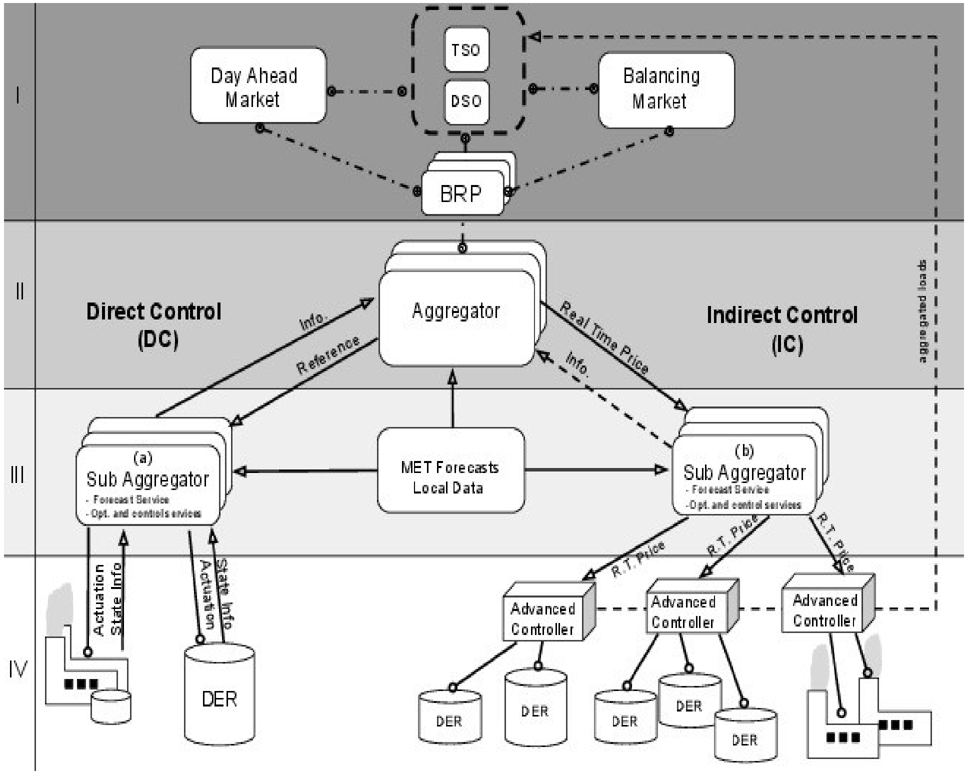
The ***Center for IT-Intelligent Energy Systems (CITIES)*** is aiming at establishing methodologies and solutions for design and operation of integrated electrical, thermal, fuel pathways at all scales.



Smart-Energy OS



Control and Optimization



In New Wiley Book: Control of Electric Loads in Future Electric Energy Systems, 2015

Day Ahead:

Stoch. Programming based on eg. Scenarios

Cost: Related to the market (one or two levels)

Direct Control:

Actuator: **Power**

Two-way communication

Models for DERs are needed

Constraints for the DERs (calls for state est.)

Contracts are complicated

Indirect Control:

Actuator: **Price**

Cost: E-MPC at **low (DER) level**, One-way communication

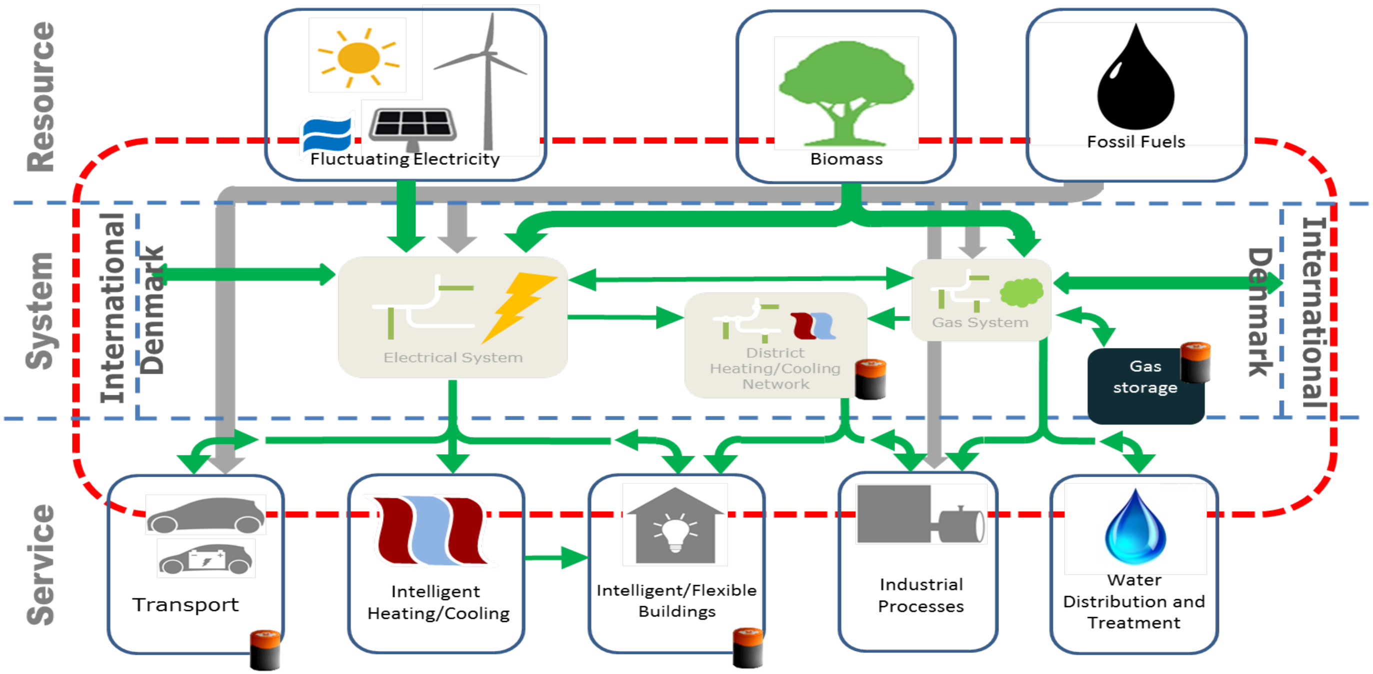
Models for DERs are not needed

Simple 'contracts'

DTU

Models for describing flexibility

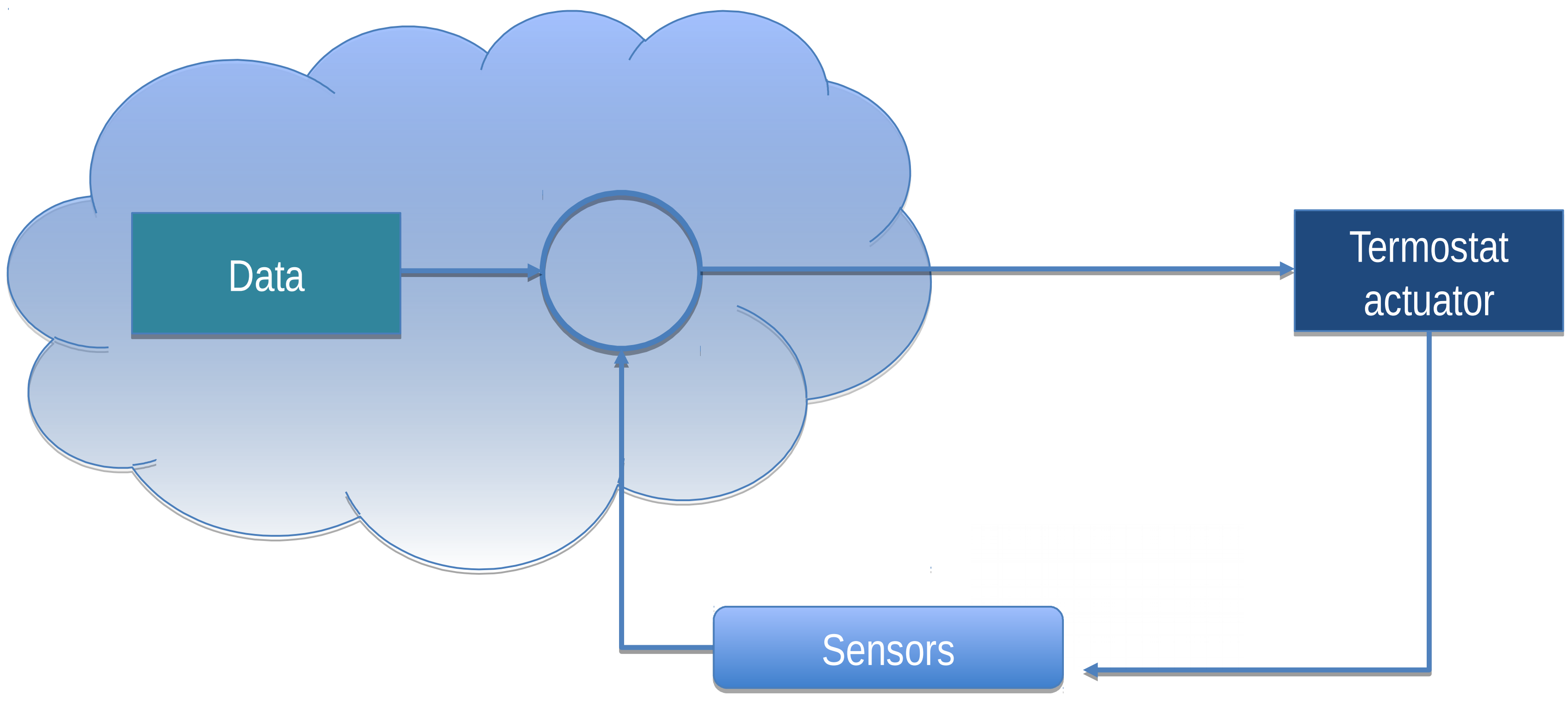
Data and statistical methods are used to establish **cyber-physical models for characterizing the flexibility**



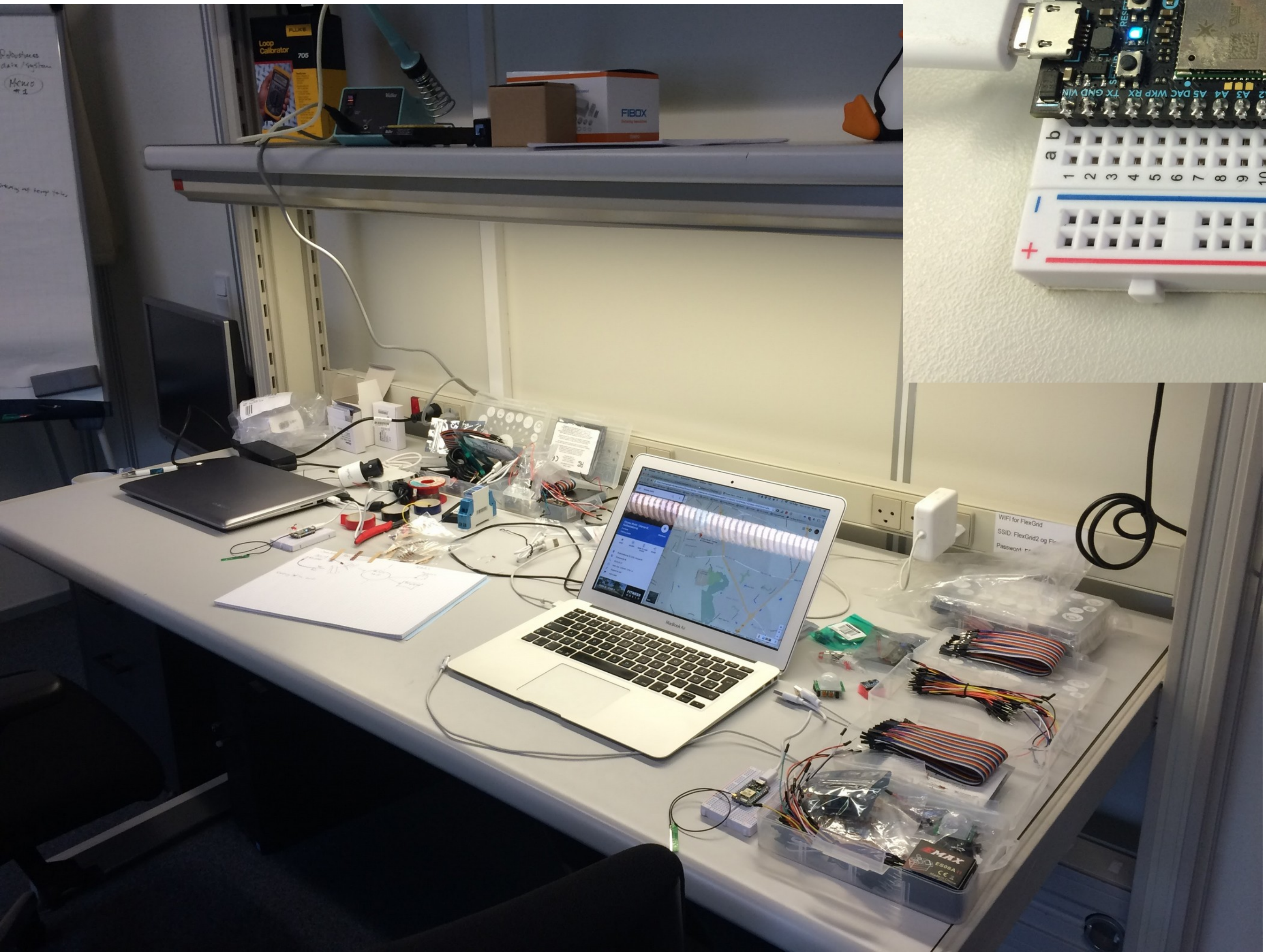
SE-OS Characteristics

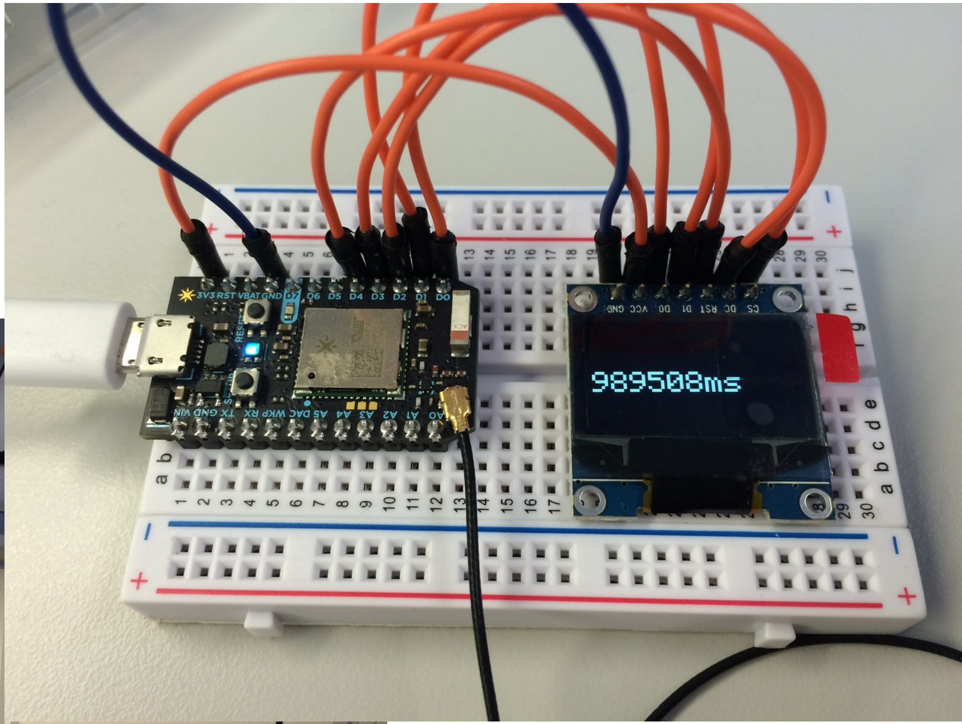
- Bidding – clearing – activation at higher levels
- Control principles (direct or indirect) at lower levels
- Cloud based solution for forecasting and control
- Facilitates energy systems integration (power, gas, thermal, ...)
- Allow for specialized aggregators
- Simple setup for the communication
- Simple (or no) contracts
- Rather simple to implement
- Harvest flexibility at all levels

SE-OS
Control loop design – **logical drawing**

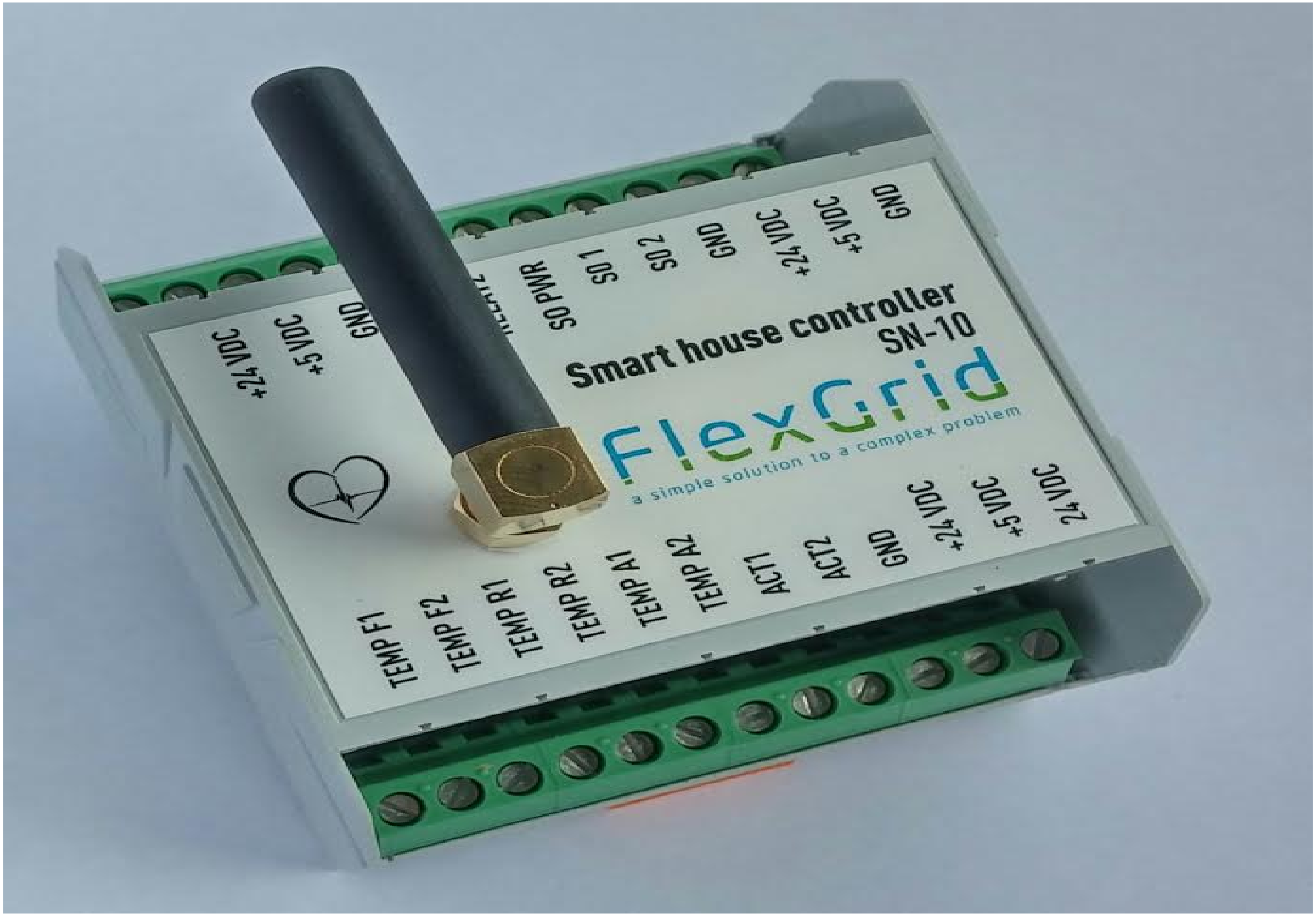


Lab testing ….





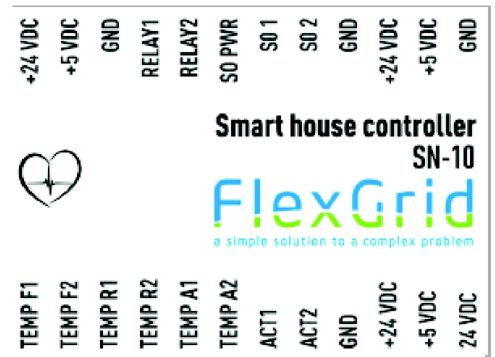
SN-10 Controller Prototype

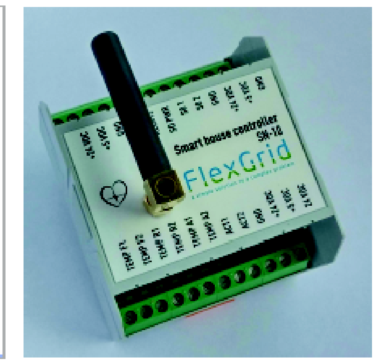


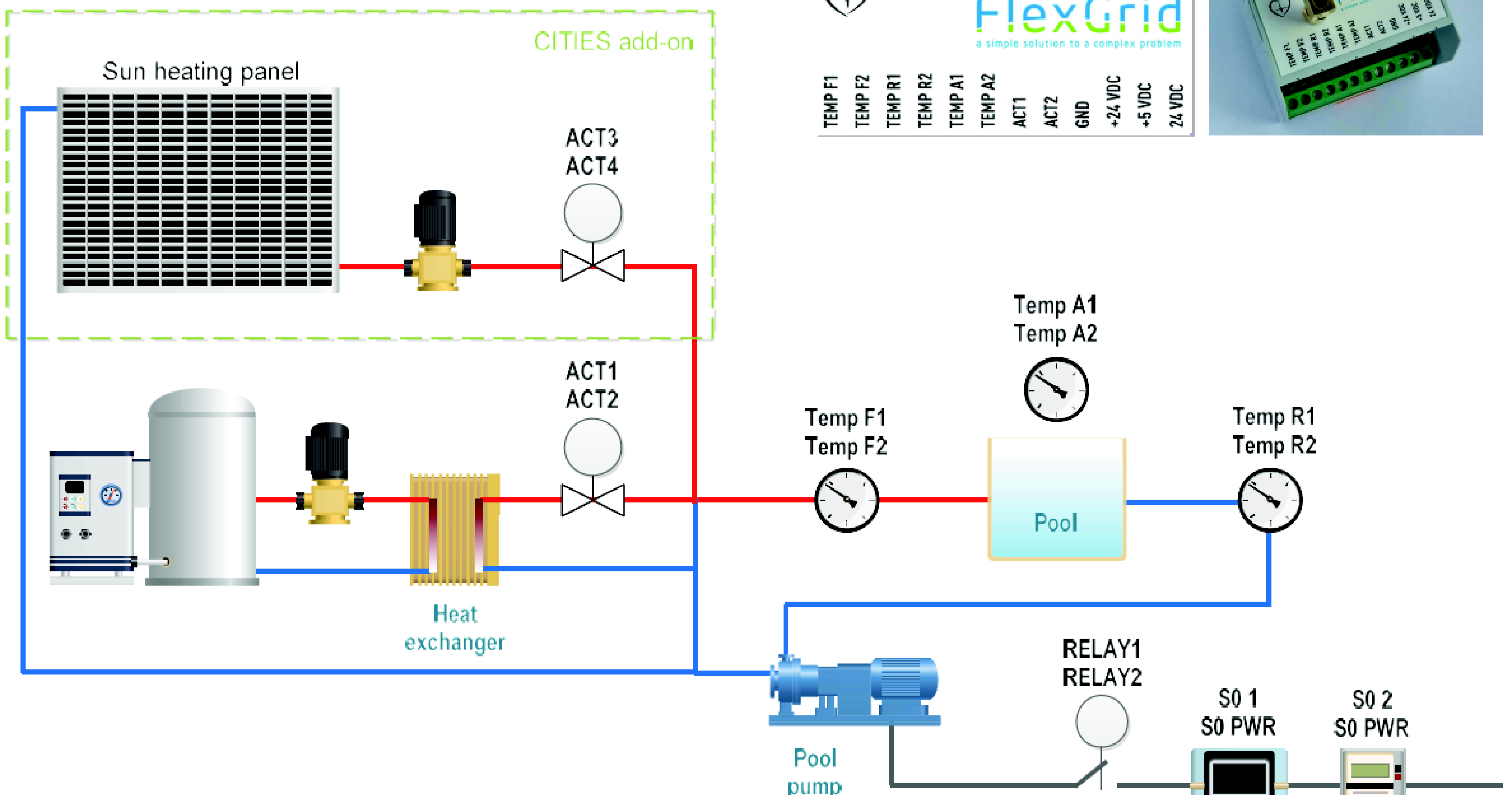
Smart Control of Summerhouses

PilotB SN-10 signal overview

revision 1.0 (CITIES add-on)



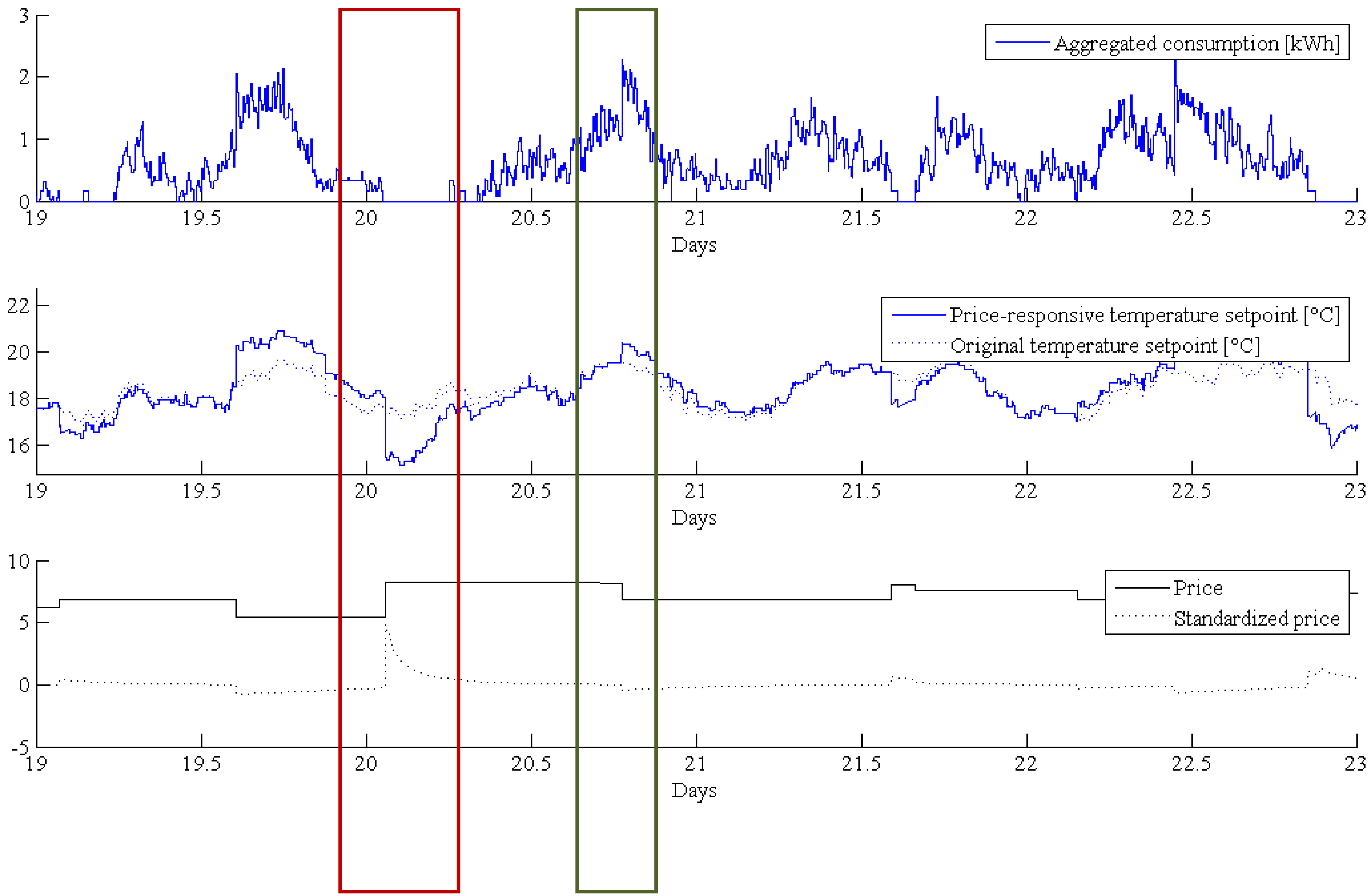




Indirect Control

Control of Heating Systems

Aggregation (over 20 houses)



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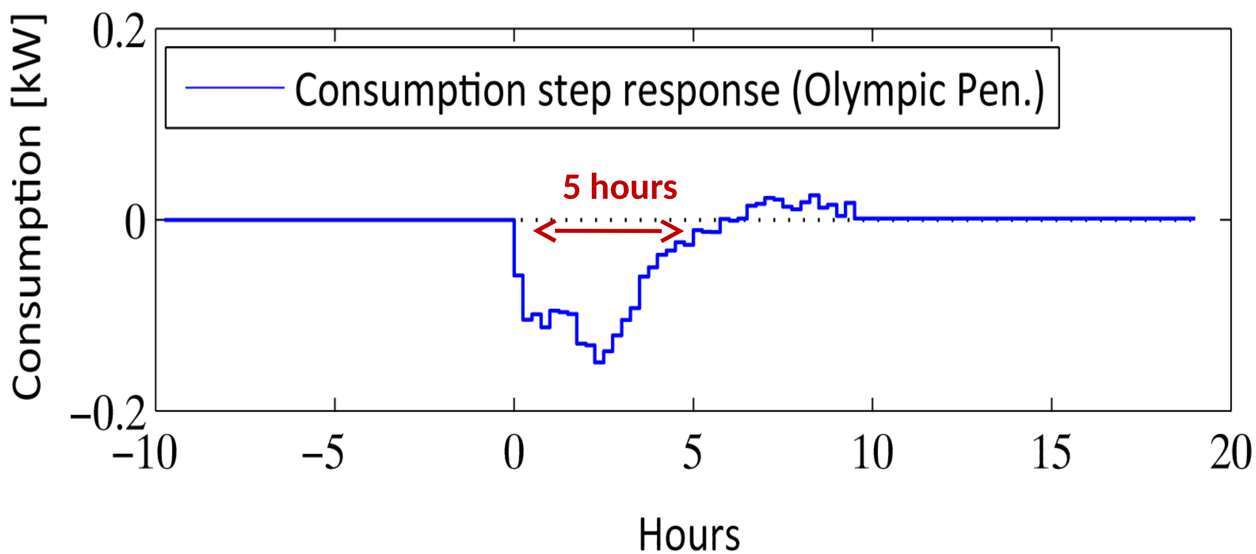
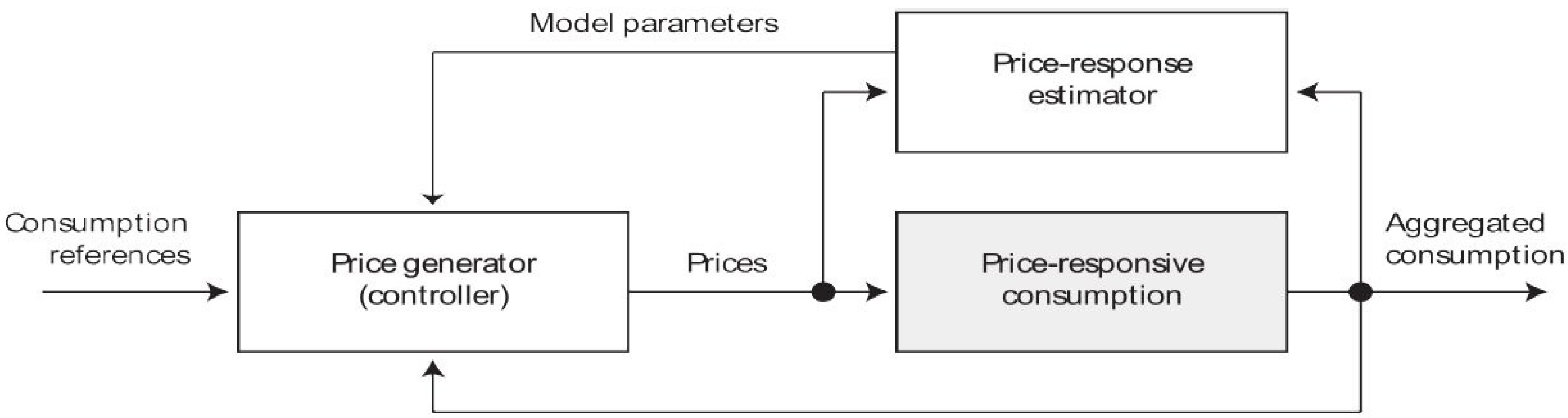
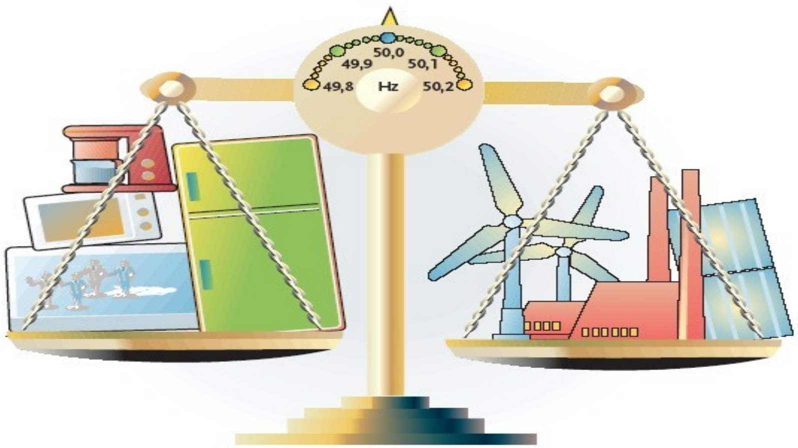
Flexibility described by Step Response Functions



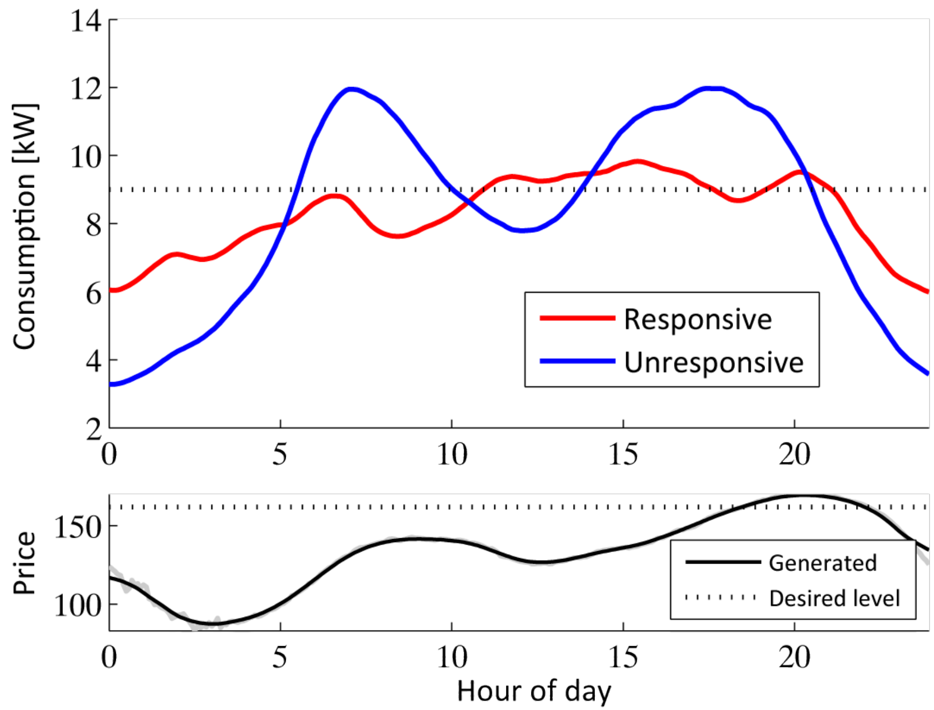
Control of Power Consumption





Control performance

Considerable **reduction in peak consumption**



Direct Control and Bids for Markets

Flexibility Related to Thermal Demand Response

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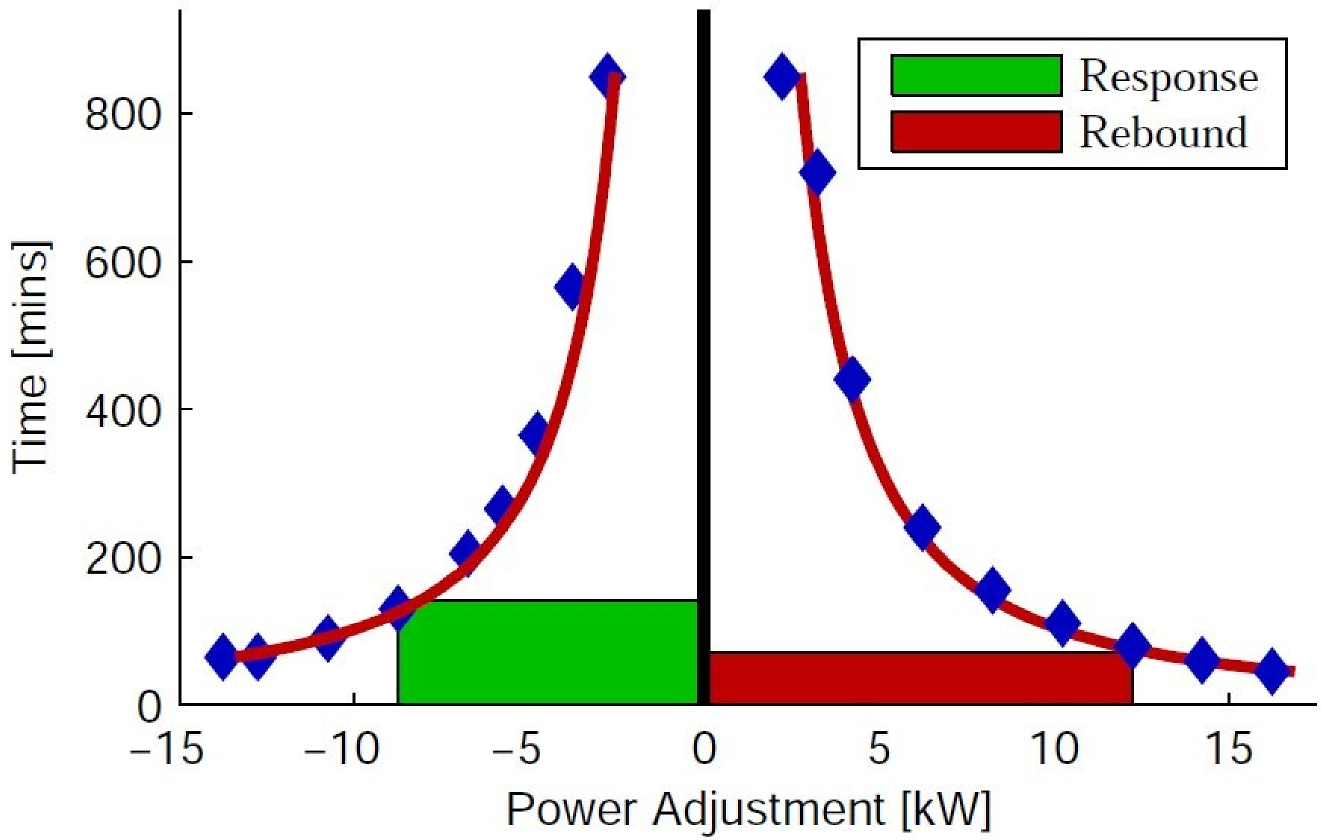
Flexibility Represented by Saturation Curves
(for market integration using block bids)



Characterization of Flexibility

- For indirect (price-based) control:
  - Step Response Functions
  - Flexibility depends on price
  - Area, Slope, Tmax, ….
- For direct control:
  - Saturation Curves
  - Describes also rebound effect

Case study

Control of Wastewater Treatment Plants

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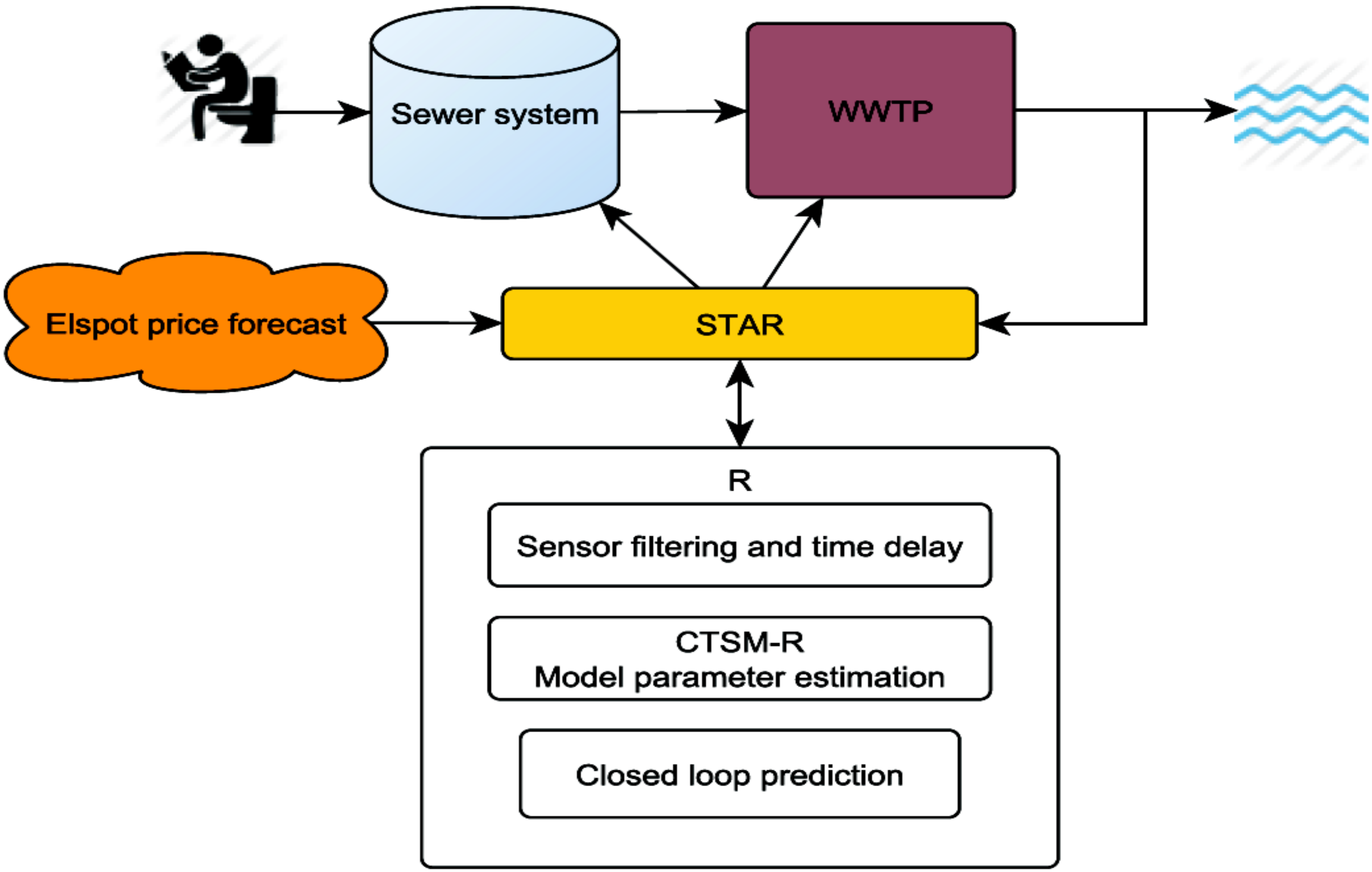
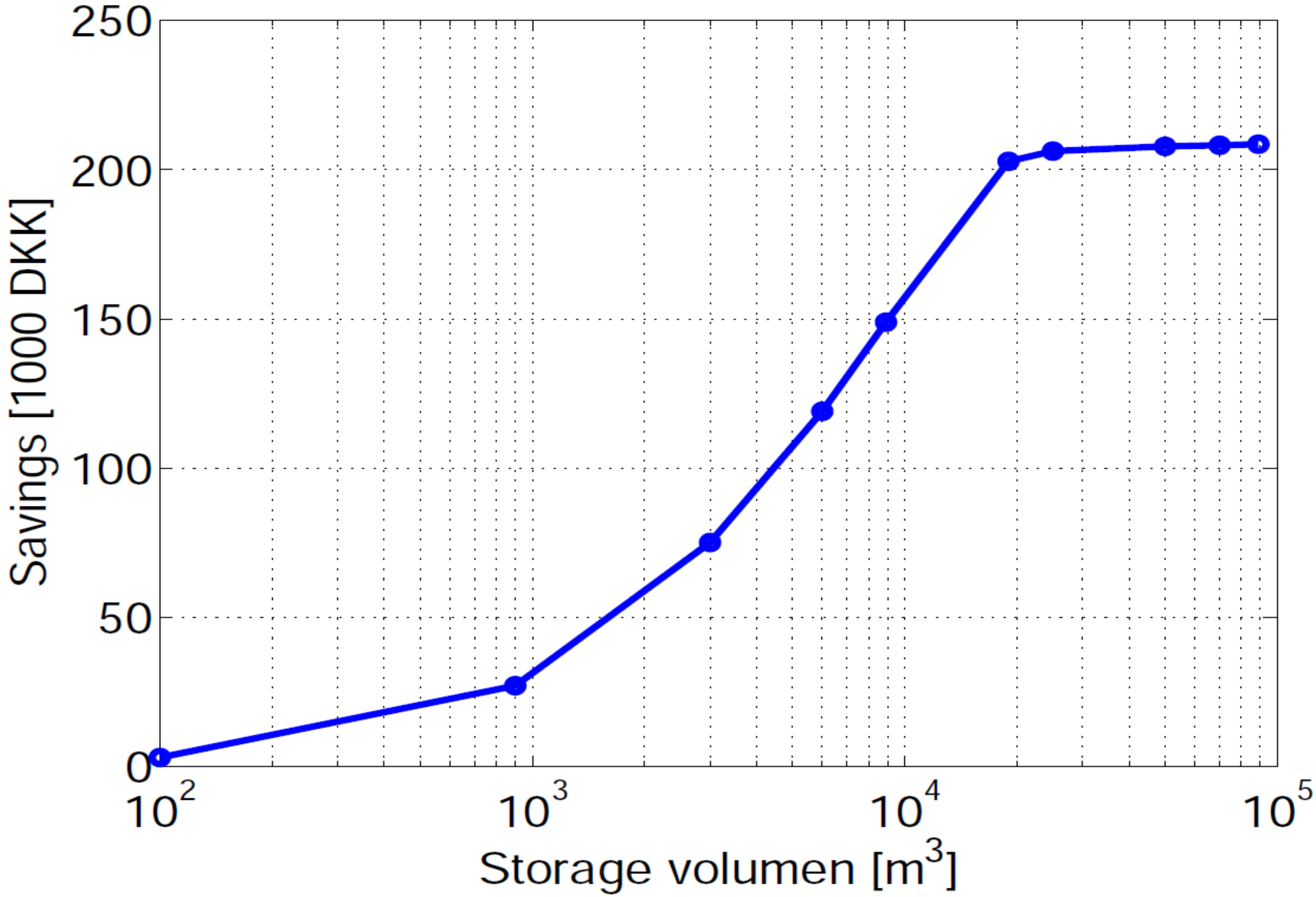
Kolding WWTP

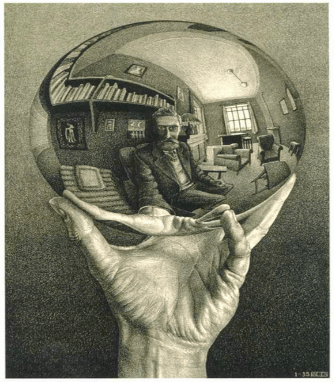
Flexibility in Wastewater Treatment



Sewer System Annual Elspot Savings

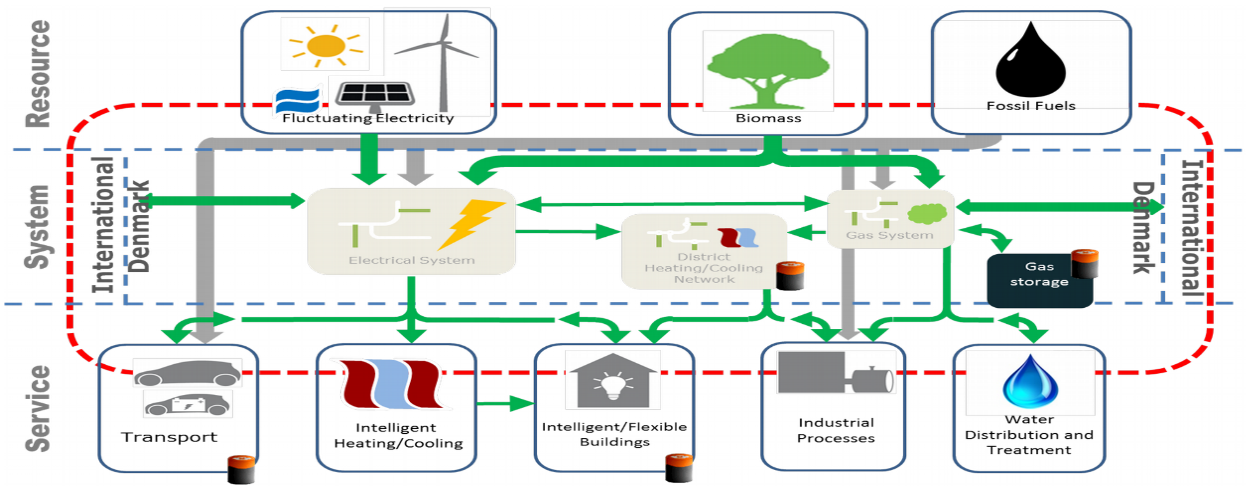


Flexible Power Systems
Some Demo Projects in CITIES



- Control of WWTP (ED, Krüger, ..)
- Heat pumps (Grundfos, EconGrid, ENFOR, ..)
- Supermarket cooling (Danfoss, TI, ..)
- Summerhouses (DC, ONE, SE, Energinet.dk, ..)
- Green Houses (NeoGrid, Danfoss, F.Fyn, ….)
- CHP (Dong Energy, F.Fyn, HOFOR, NEAS, …)
- Industrial production (DI, …)
- EV (charging) (Eurisco, ENFOR, …)
- ………….

(Virtual) Storage Solutions



- **Flexibility (or virtual storage) characteristics:**
  - Supermarket refrigeration can provide storage 0.5-2 hours ahead
  - Buildings thermal capacity can provide storage up to, say, 5-10 hours ahead
  - Buildings with local water storage can provide storage up to, say, 2-12 hours ahead
  - District heating/cooling systems can provide storage up to 1-3 days ahead
  - DH systems with thermal solar collectors can often provide seasonal storage solutions
  - Gas systems can provide seasonal/long term storage solutions

Summary

- A Smart-Energy OS for implementing flexible and integrated energy systems has been described
- Built on: Big Data Analytics, Cyber Physical systems, Stochastic opt./control, Forecasting, IoT, IoS, Cloud computing, ...
- **Modelling**: Toolbox – CTSM-R - for combined physical and statistical modelling (grey-box modelling)
- **Control:** Toolbox – MPC-R - for Model Predictive Control
- **Forecasting:** Framework (cloud based) for full probabilistic forecasting
- **Simulation:** Framework for simulating flexible power systems

Discussion

- IT-Intelligent Energy Systems Integration can provide virtual storage solutions (so maybe we should put less focus on electrical storage solutions)
- District heating (or cooling) systems can provide flexibility on the essential time scale (up to a few days)
- Gas systems can provide seasonal virtual storage solutions
- Smart Cities are just smart elements of a Smart Society
- We see a large potential in Demand Response. Automatic solutions, price based control, and end-user focus are important
- We see large problems with the tax and tariff structures in many countries (eg. Denmark).
- Markets and pricing principles need to be reconsidered; we see an advantage of having a physical link to the mechanism (eg. nodal pricing, capacity markets)