Methodologies for integrating energy flexible buildings in the future smart grid

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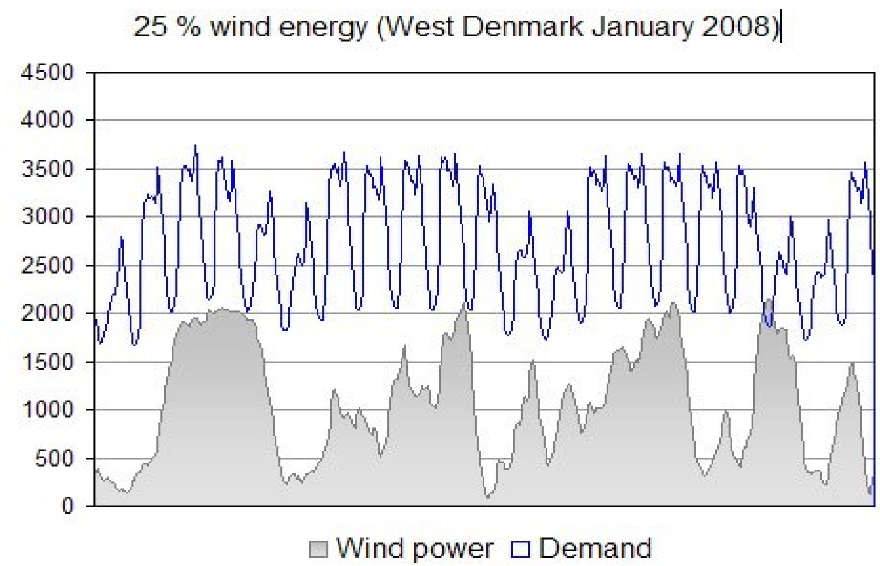
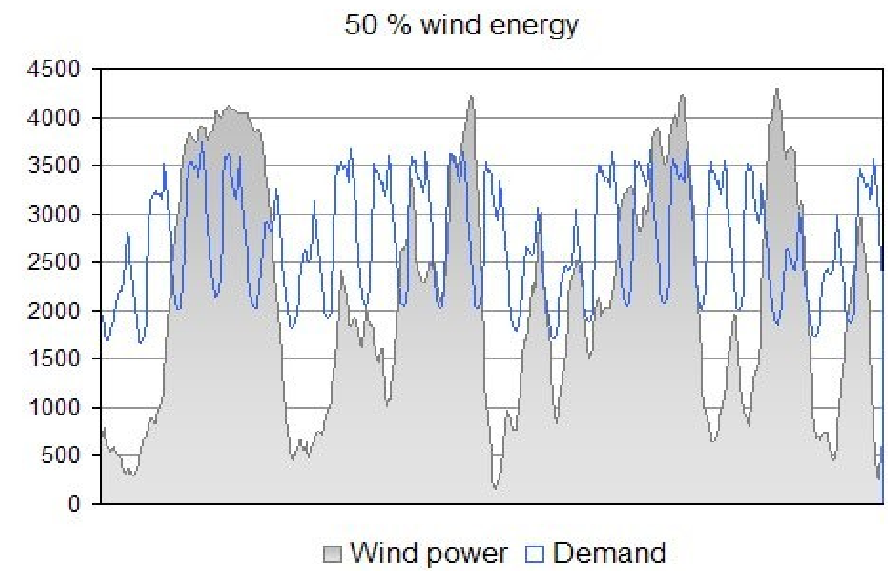
The Danish Wind Power Case

.... balancing of the power system





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

In the first half of 2017 more than 44 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

Existing Markets - Challenges

- Dynamics
- Stochasticity
- Nonlinearities
- Many power related services (voltage, frequency, balancing, spinning reserve, congestion, ...)
- Speed / problem size
- Characterization of flexibility
- Requirements on user installations

Challenges (cont.)

Preparatory study on Smart Appliances

European Commission

Ecodesign Preparatory Study performed for the European Commission

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Home > Project summary

Project Summary

The Ecodesign Preparatory Study on Smart Appliances (Lot 33) has analysed the technical, economic, market and societal aspects with a view to a broad introduction of smart appliances and to develop adequate policy approaches supporting such uptake.

The study deals with Task 1 to 7 of the Methodology for Energy related products (MEErP) as follows:

- Scope, standards and legislation (Task 1, Chapter 1);
- Market analysis (Task 2, Chapter 2);
- User analysis (Task 3, Chapter 3);
- Technical analysis (Task 4, Chapter 4);
- Definition of Base Cases (Task 5, Chapter 5);
- Design options (Task 6, Chapter 6);
- Policy and Scenario analysis (Task 7, Chapter 7).

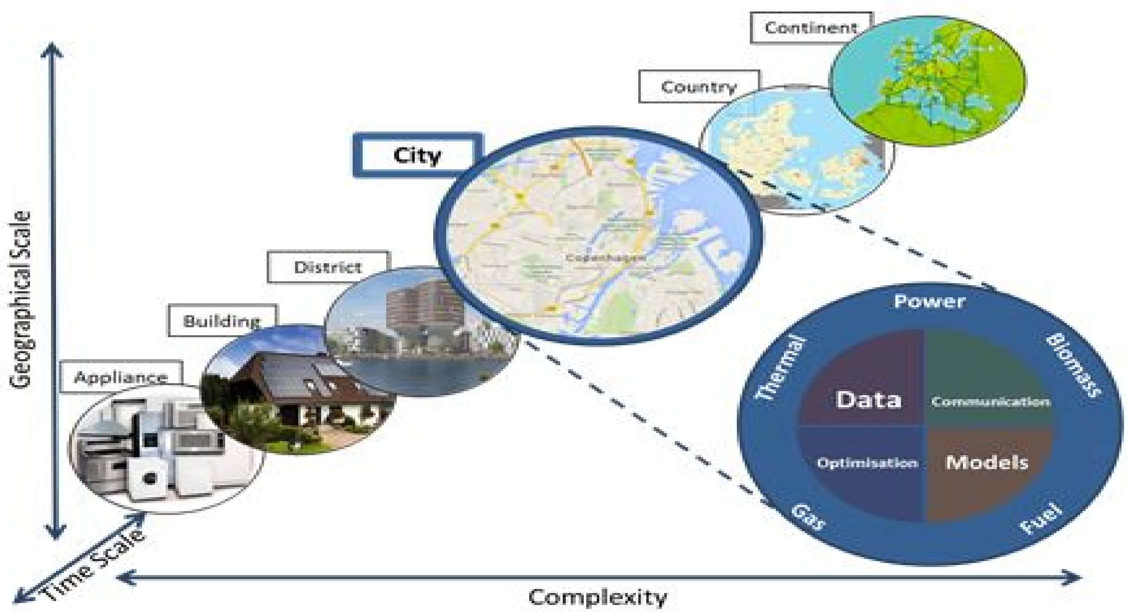
An executive summary of the project results can be downloaded here.

Throughout the study, new relevant aspects have come up which will be covered in a second phase of the Preparatory Study:

- Chargers for electric cars: technical potential and other relevant issues in the context of demand response.
- The modelling done in the framework of MEErP Task 6 and 7 will be updated with PRIMES data that recently became available, and with the EEA-countries.
- The development and assessment of policy options that were identified in the study will be further elaborated and deepened.

Temporal and Spatial Scales

The ***Smart-Energy Operating-System (SE-OS)*** is used to develop, implement and test of solutions (layers: data, models, optimization, control, communication) for ***operating flexible electrical energy systems (incl. buildings)*** at **all scales**.



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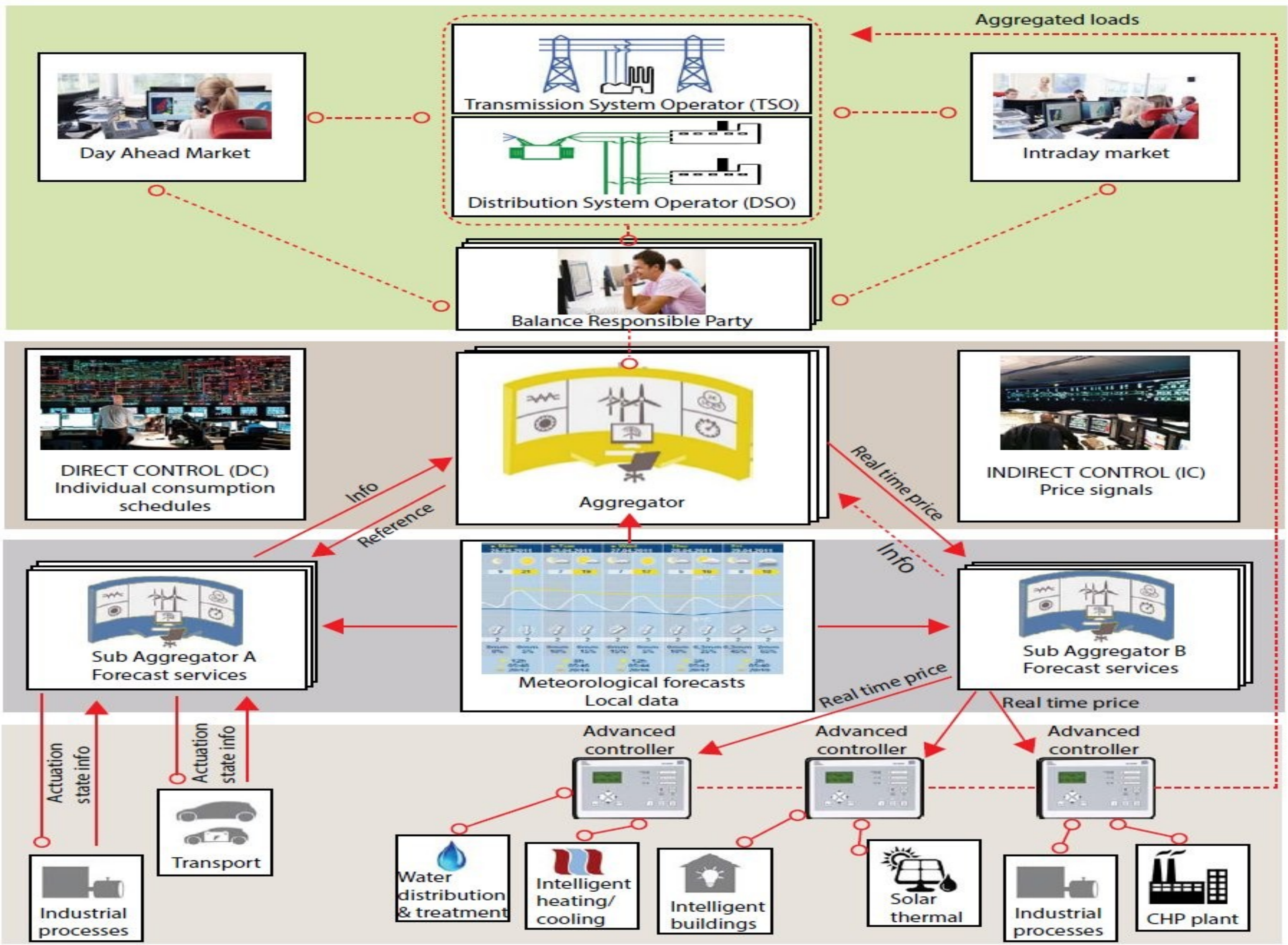
Smart-Energy OS



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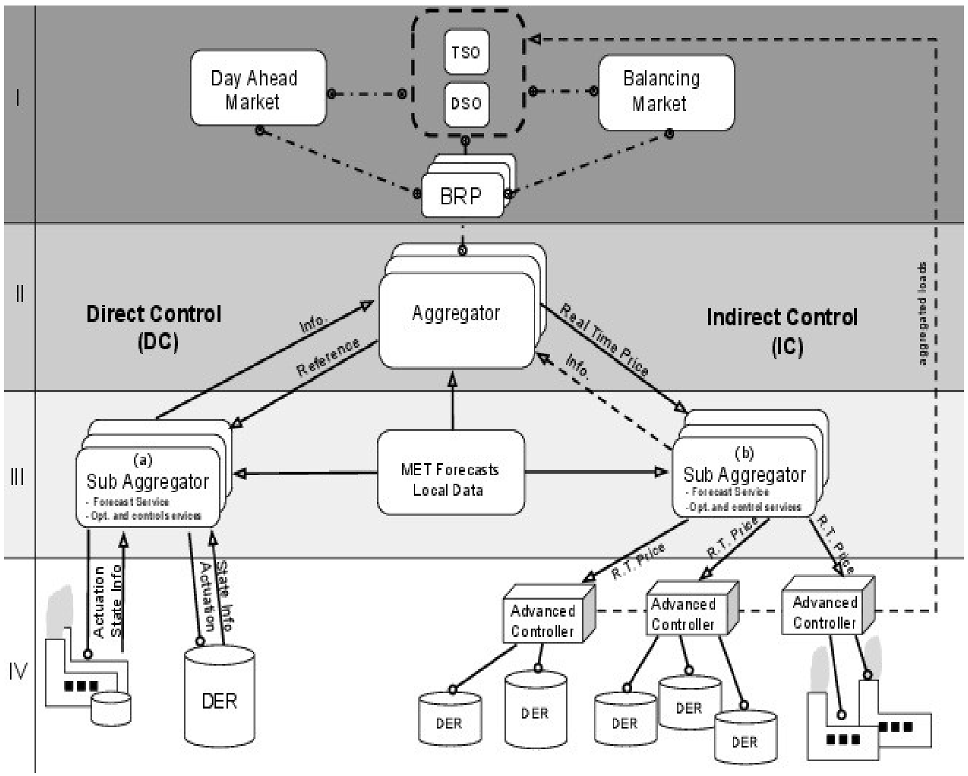
Control and Optimization



In 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'

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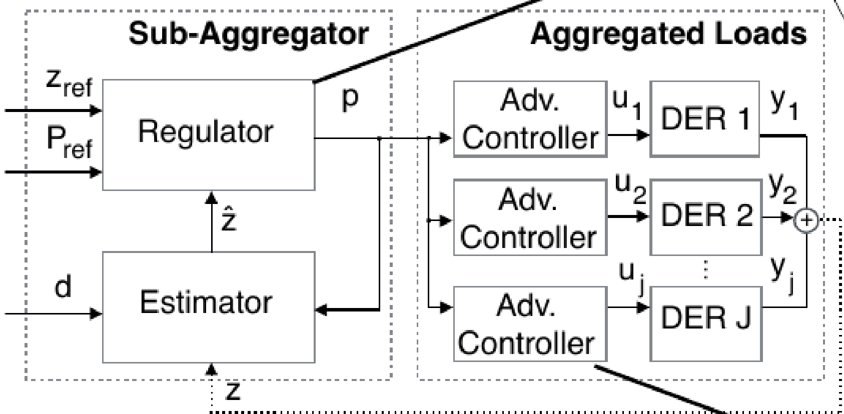
Proposed methodology
Control-based methodology

$$\min_{p} \quad \mathrm{E}\Big[\sum_{k=0}^{N} w_{j,k}||\hat{z}_k - z_{ref,k}|| + \mu||p_k - p_{ref,k}||\Big]$$

$$\text{s.t.} \quad \hat{z}_{k+1} = f(p_k)$$



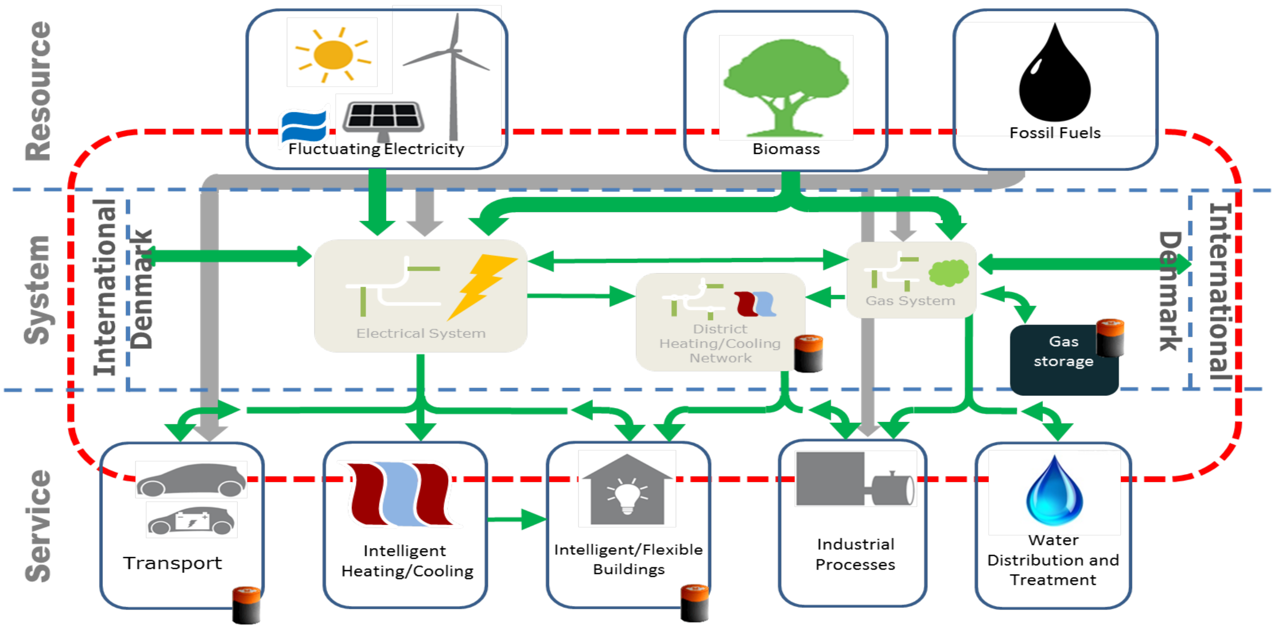
$$\min_{u} \quad \mathrm{E}\Big[\sum_{k=0}^{N}\sum_{j=1}^{J} \phi_j(x_{j,k}, u_{j,k}, p_k)\Big]$$

$$\begin{aligned} \text{s.t.} \quad x_{k+1} &= Ax_k + Bu_k + Ed_k, \\ y_k &= Cx_k, \\ y_k^{min} \leq y_k &\leq y_k^{max}, \\ u_k^{min} \leq u_k &\leq u_k^{max} \end{aligned}$$

We adopt a control-based approach where the **price** becomes the driver to **manipulate** the behaviour of a certain pool flexible prosumers.

Grey-box models for energy systems

Intelligent systems integration using **data and ICT solutions** are based on **grey-box models for real-time operation of flexible energy systems**



Energy Flexibility Characteristics

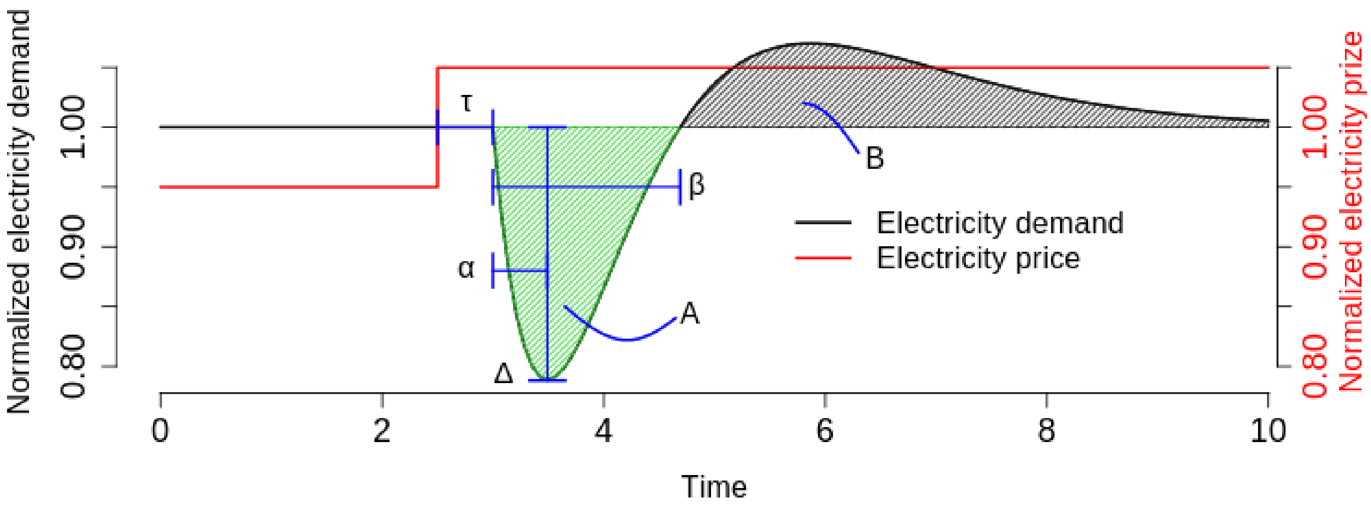
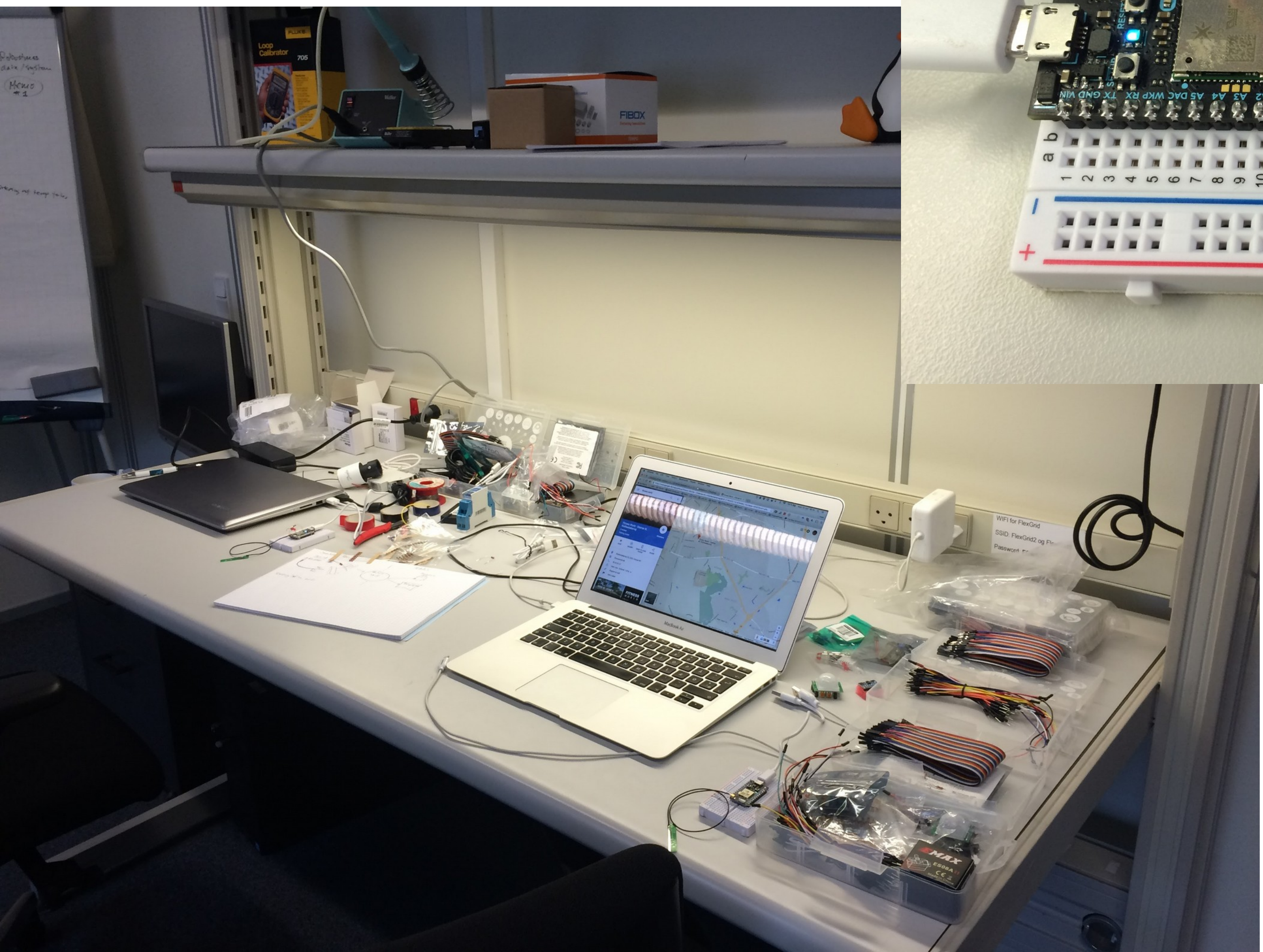
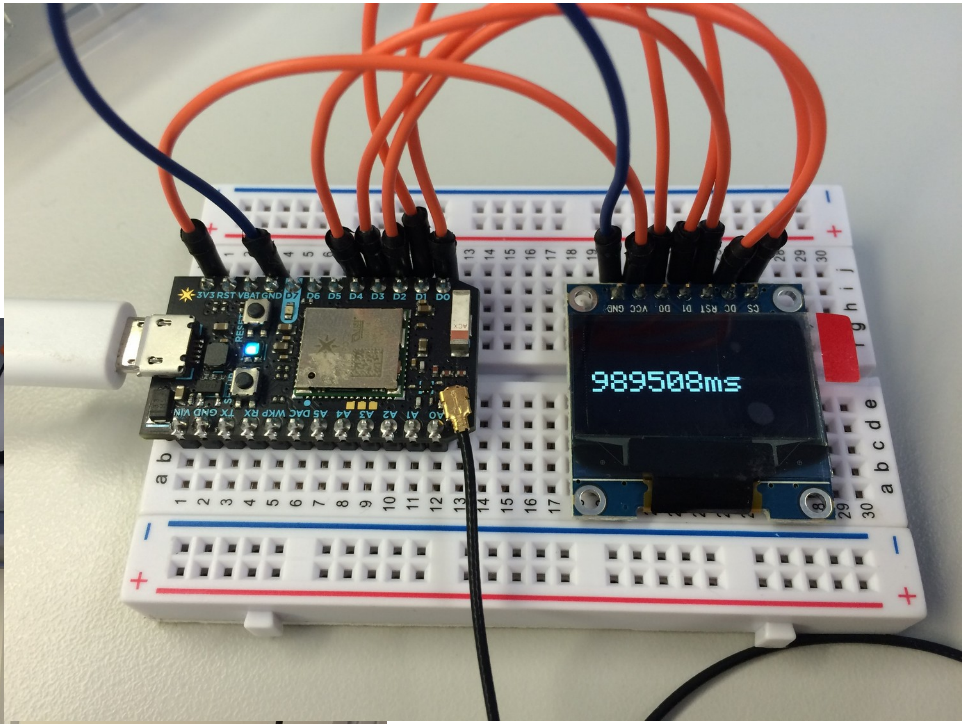


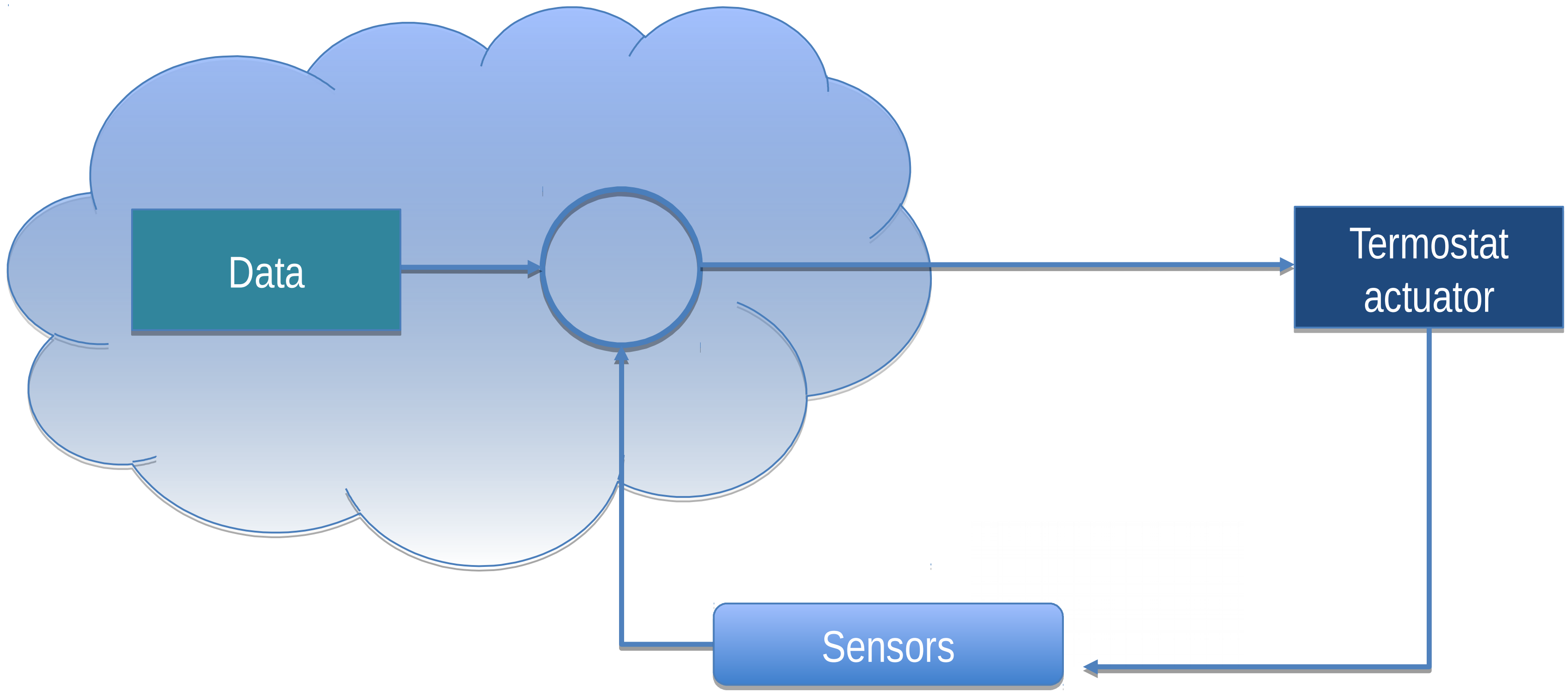
Figure 4: Six characteristics of the demand response to a step increase in electricity price. τ: The delay from adjusting the electricity prize and seeing an effect on the electricity demand, equal to approximately 0.5 here. Δ: The maximum change in demand following the price change, in this case close to 0.2. α: The time it takes from the change in demand starts until it reaches the lowest level, approximately equal to 0.5 here. β: The total time of decreased electricity demand, roughly equal to 2 here. A: The total amount of decreased energy demand, given by the green-shaded area. B: The total amount of increased energy demand, given by the grey-shaded area.

Lab testing ….

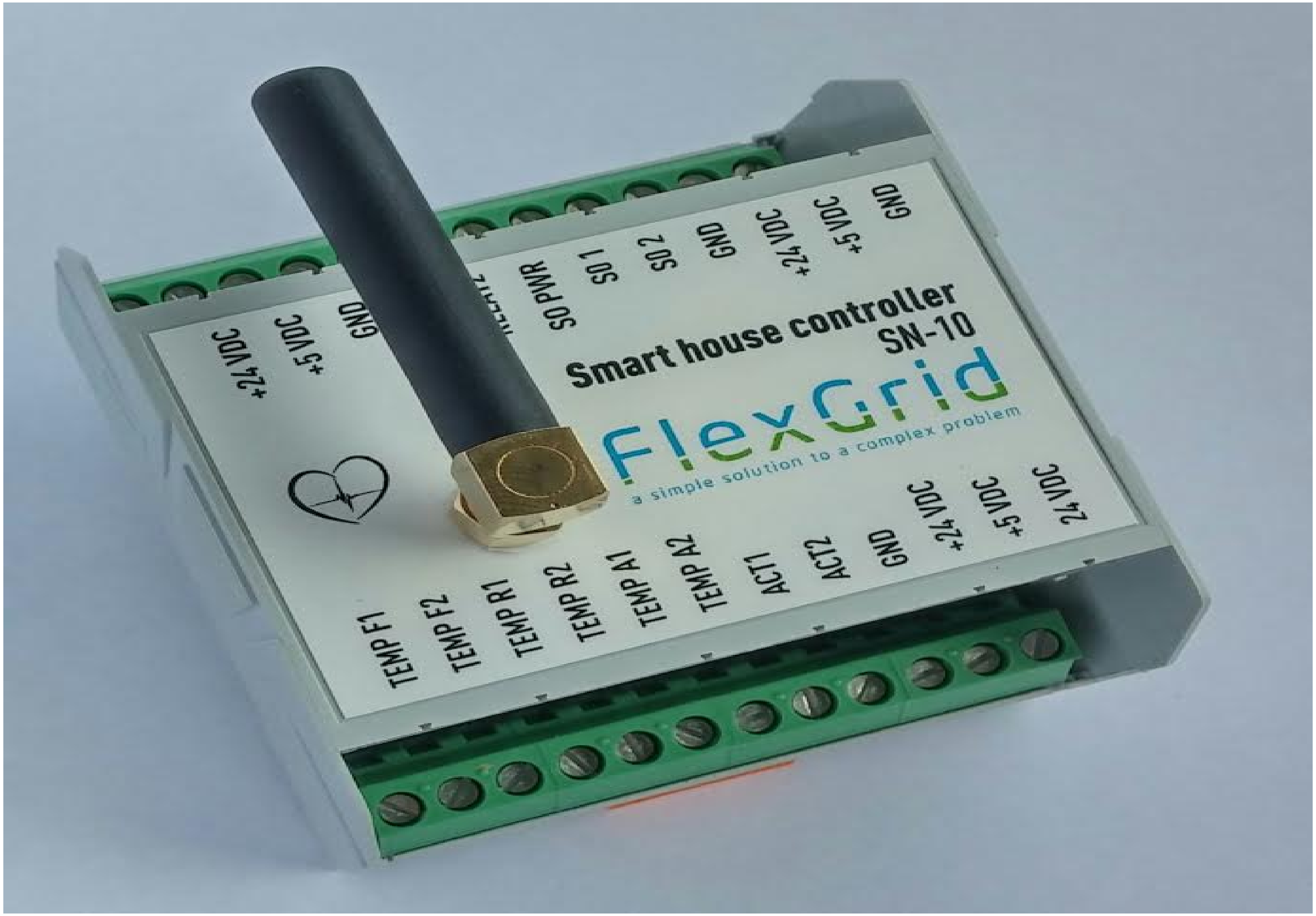




SE-OS
Control loop design – **logical drawing**

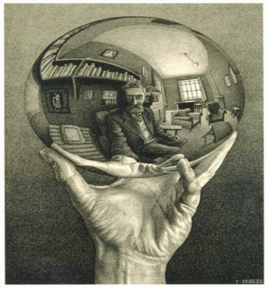


SN-10 Smart House Controller



SE-OS Characteristics

- 'Bidding – clearing – activation' at higher levels
- Nested sequence of systems – systems of systems
- Hierarchy of optimization (or control) problems
- Control principles at higher spatial/temporal resolutions
- Cloud or Fog (IoT, IoS) based solutions – eg. for forecasting and control
- Facilitates energy systems integration (power, gas, thermal, ...)
- Allow for new players (specialized aggregators)
- Simple setup for the communication and contracts
- Provides a solution for all ancillary services
- Harvest flexibility at all levels



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Case study No. 1

Control of Power Consumption using the Thermal Mass of Buildings (Peak shaving)

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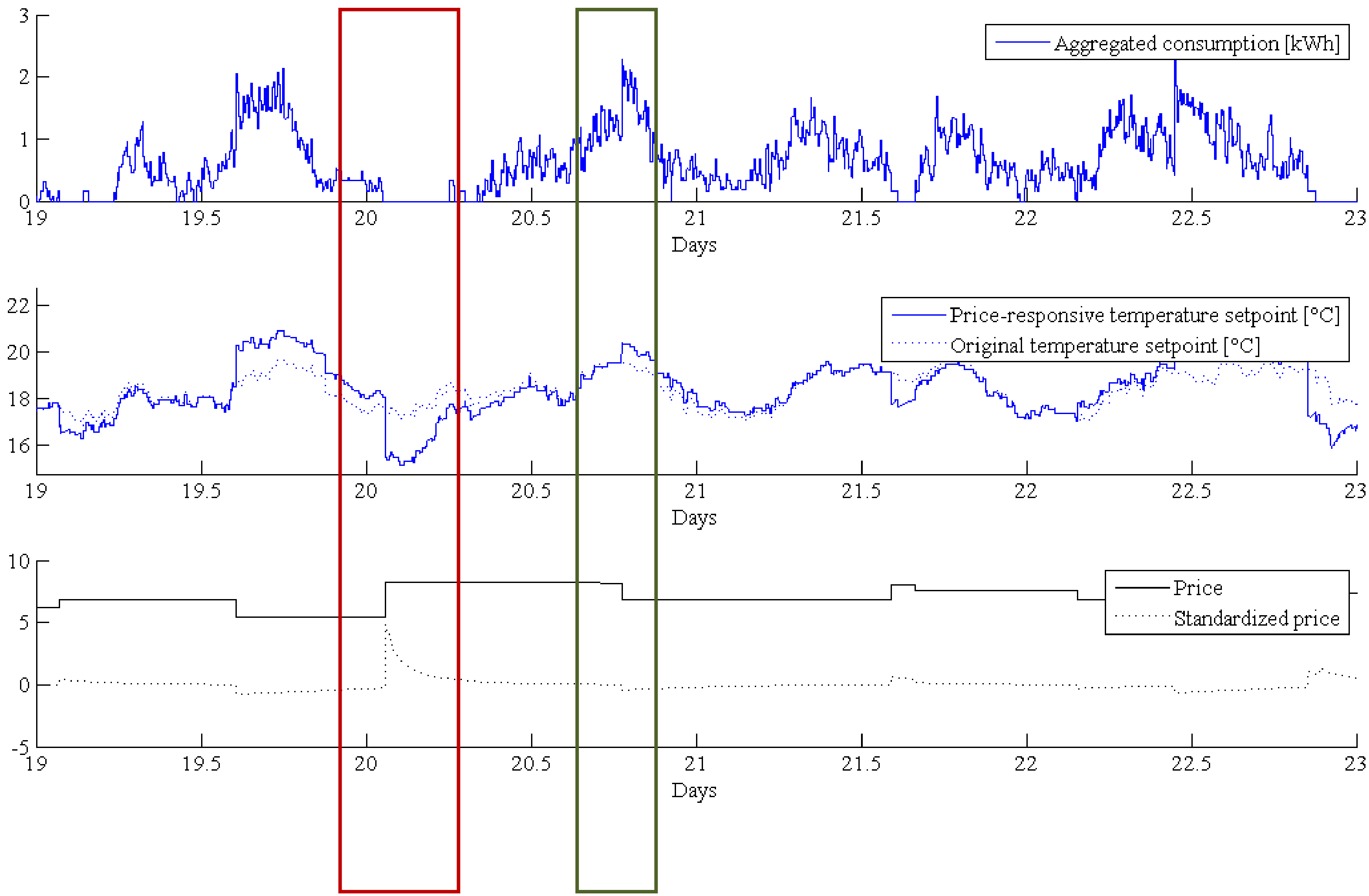
Aggregation (over 20 houses)



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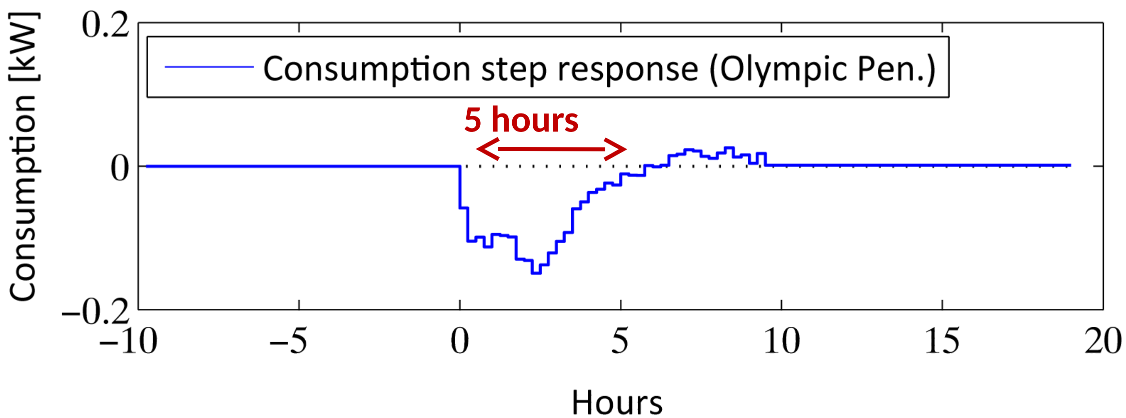
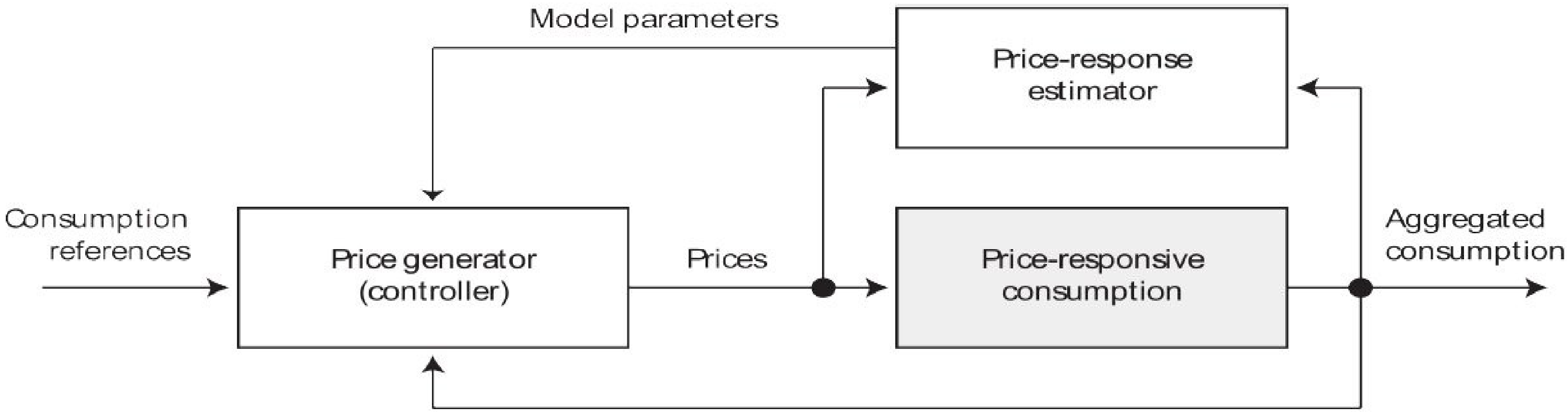
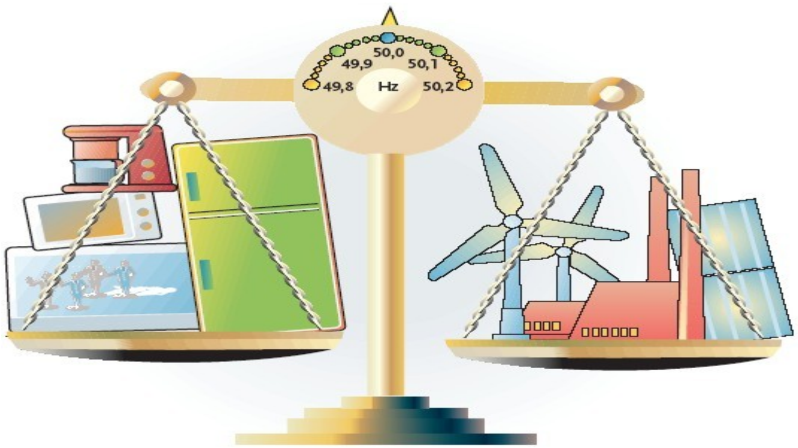
Non-parametric Response on Price Step Change

Olympic Peninsula



Control of Energy Consumption

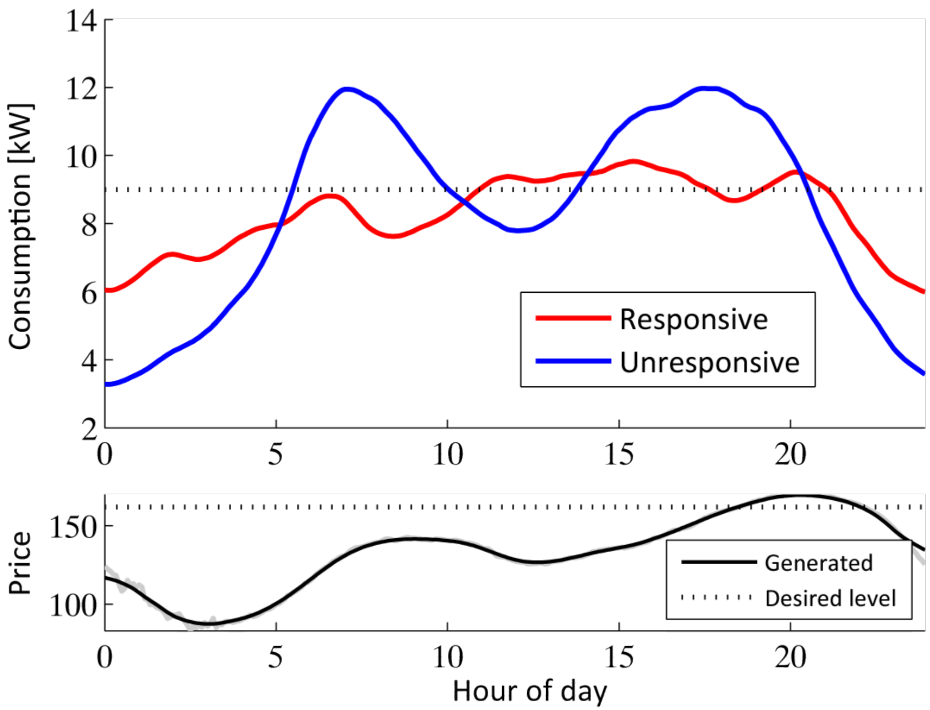




Control performance

Considerable **reduction in peak consumption**

Mean daily consumption shift



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Case study No. 2

Control of Heat Pumps for buildings with a thermal solar collector (minimizing cost)

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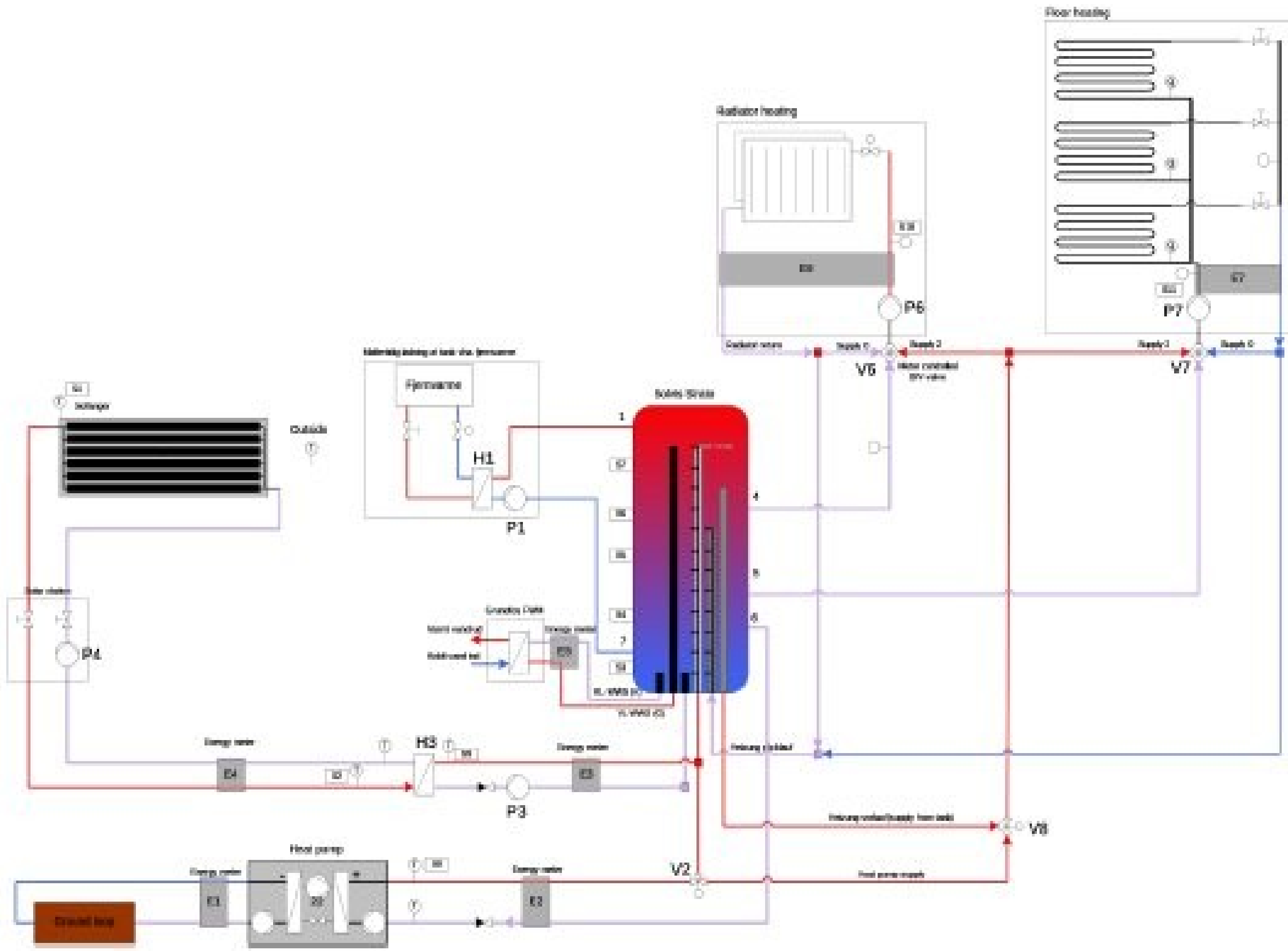
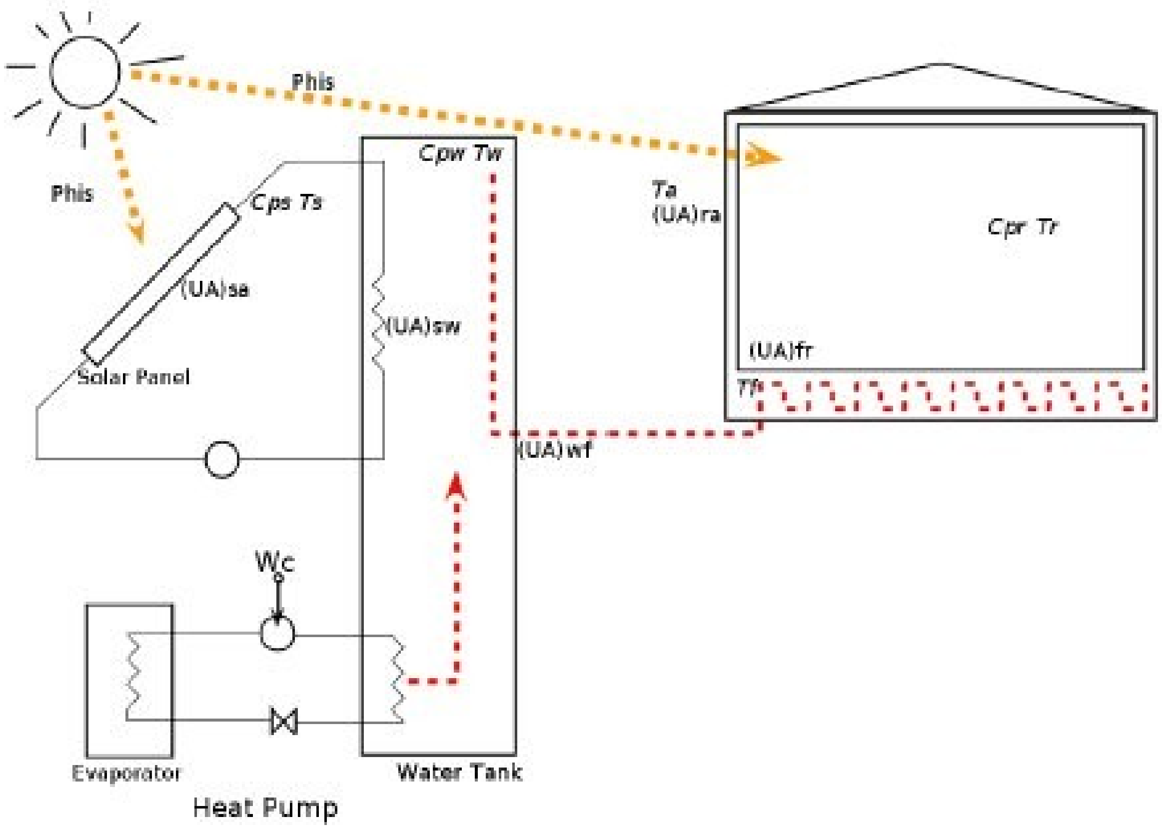
Grundfos Case Study

Schematic of the heating system



Modeling Heat Pump and Solar Collector

Simplified System



Formulation

The Economic MPC problem, with the constraints and the model, can be summarized into the following formal formulation:

$$\min_{\{u_k\}_{k=0}^{N-1}} \phi = \sum_{k=0}^{N-1} c' u_k \qquad (4a)$$

Subject to

$$x_{k+1} = Ax_k + Bu_k + Ed_k \quad k = 0, 1, \ldots, N-1 \qquad (4b)$$

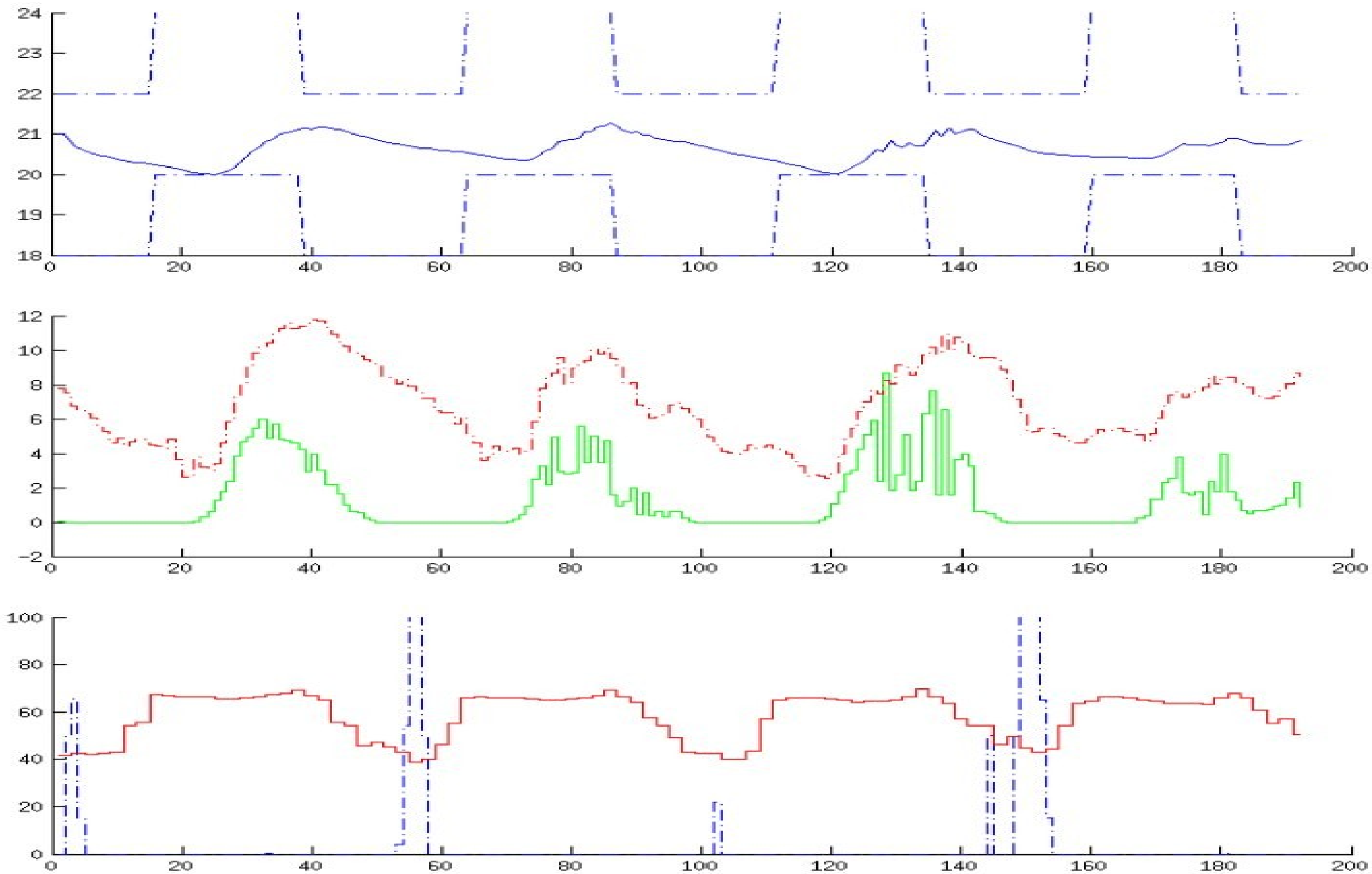
$$y_k = Cx_k \quad k = 1, 2, \ldots, N \qquad (4c)$$

$$u_{min} \leq u_k \leq u_{max} \quad k = 0, 1, \ldots, N-1 \qquad (4d)$$

$$\Delta u_{min} \leq \Delta u_k \leq \Delta u_{max} \quad k = 0, 1, \ldots, N-1 \qquad (4e)$$

$$y_{min} \leq y_k \leq y_{max} \quad k = 0, 1, \ldots, N \qquad (4f)$$

EMPC for heat pump with solar collector (savings 30 pct)



Case study No. 3

Control of heat pumps for swimming pools (CO2 minimization)

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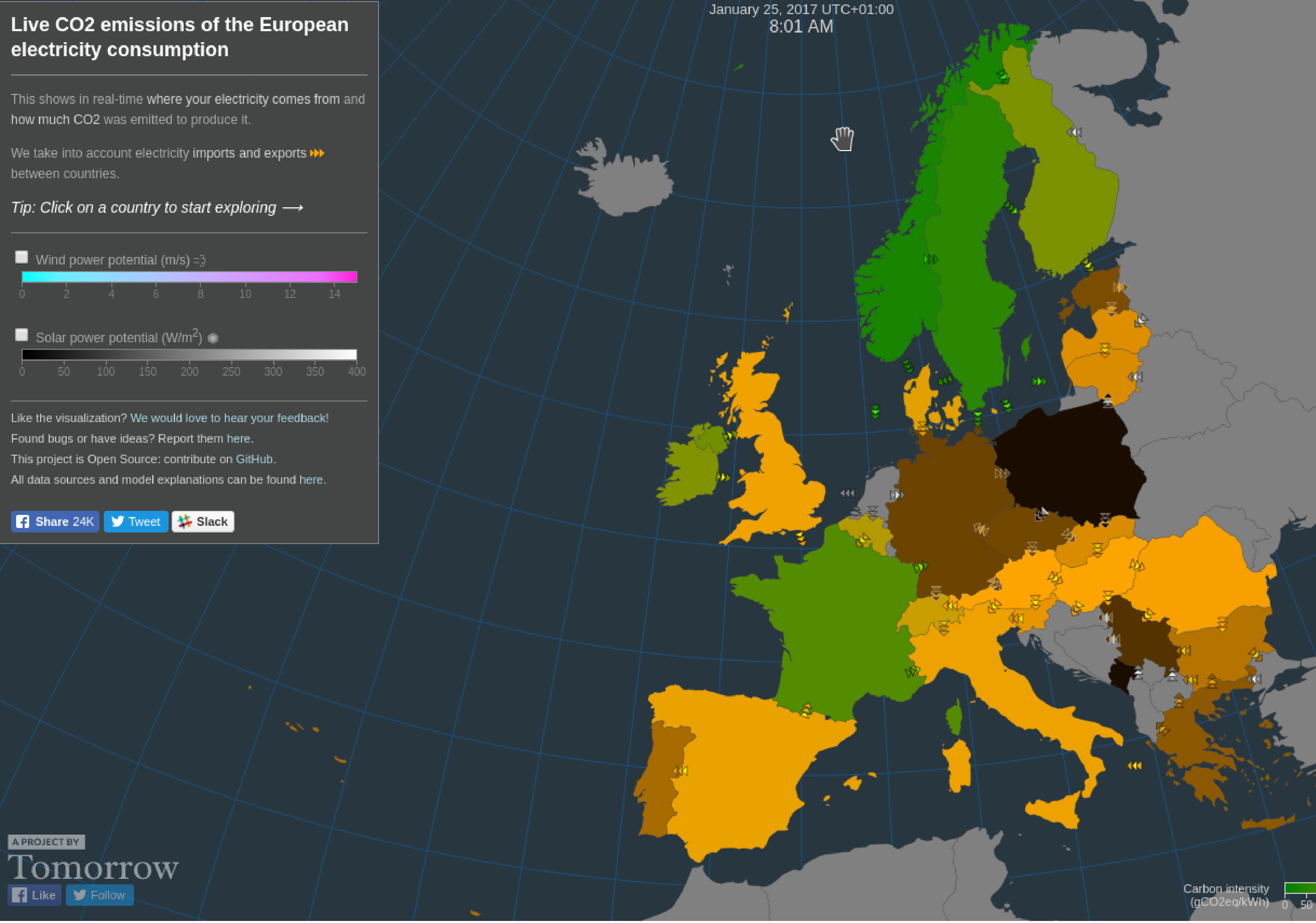

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ZEN Workshop; Energy flexibility in Zero Emission Neighborhoods

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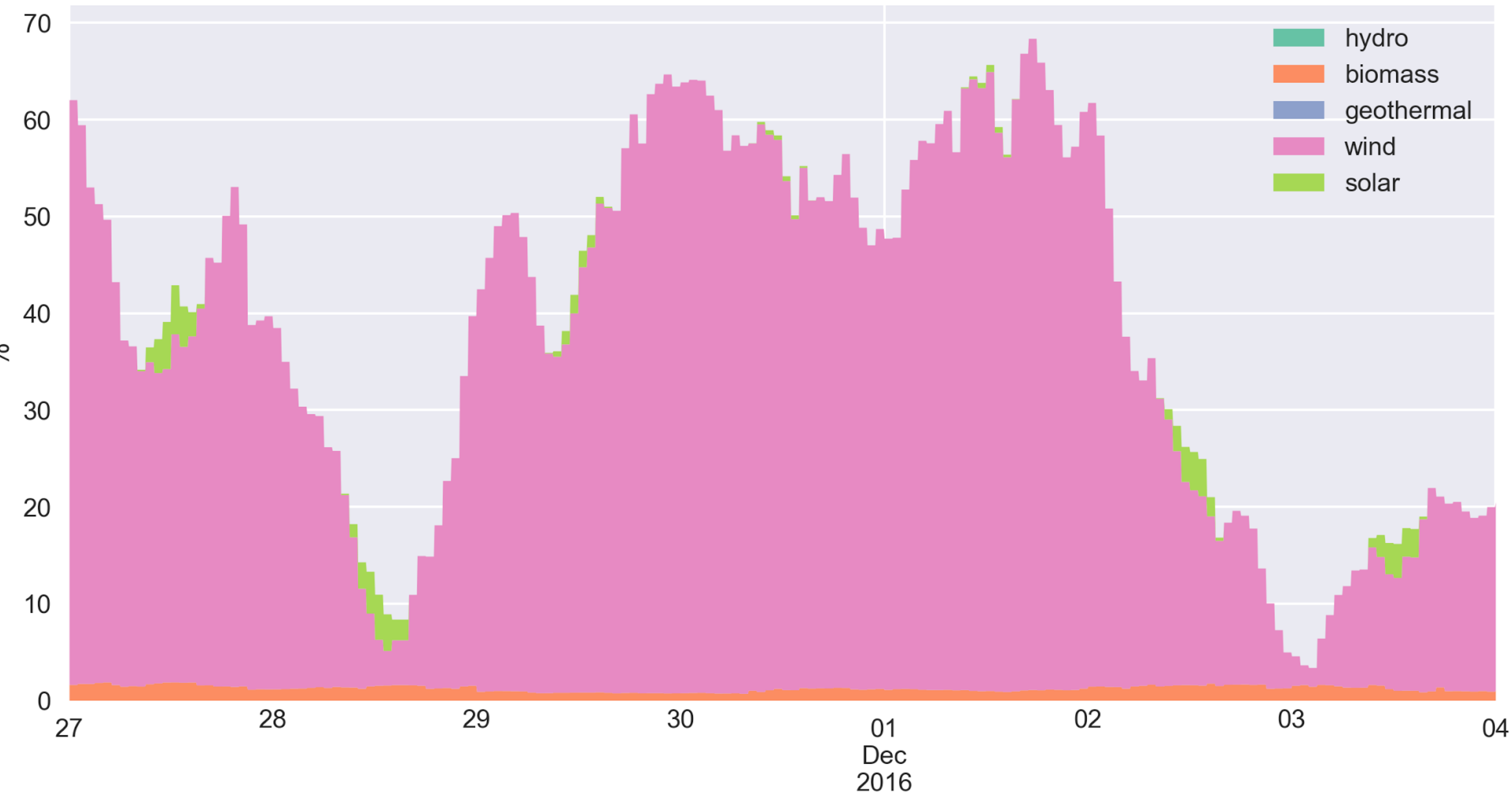
Share of electricity originating from renewables in Denmark Late Nov 2016 - Start Dec 2016



Source: pro.electicitymap.

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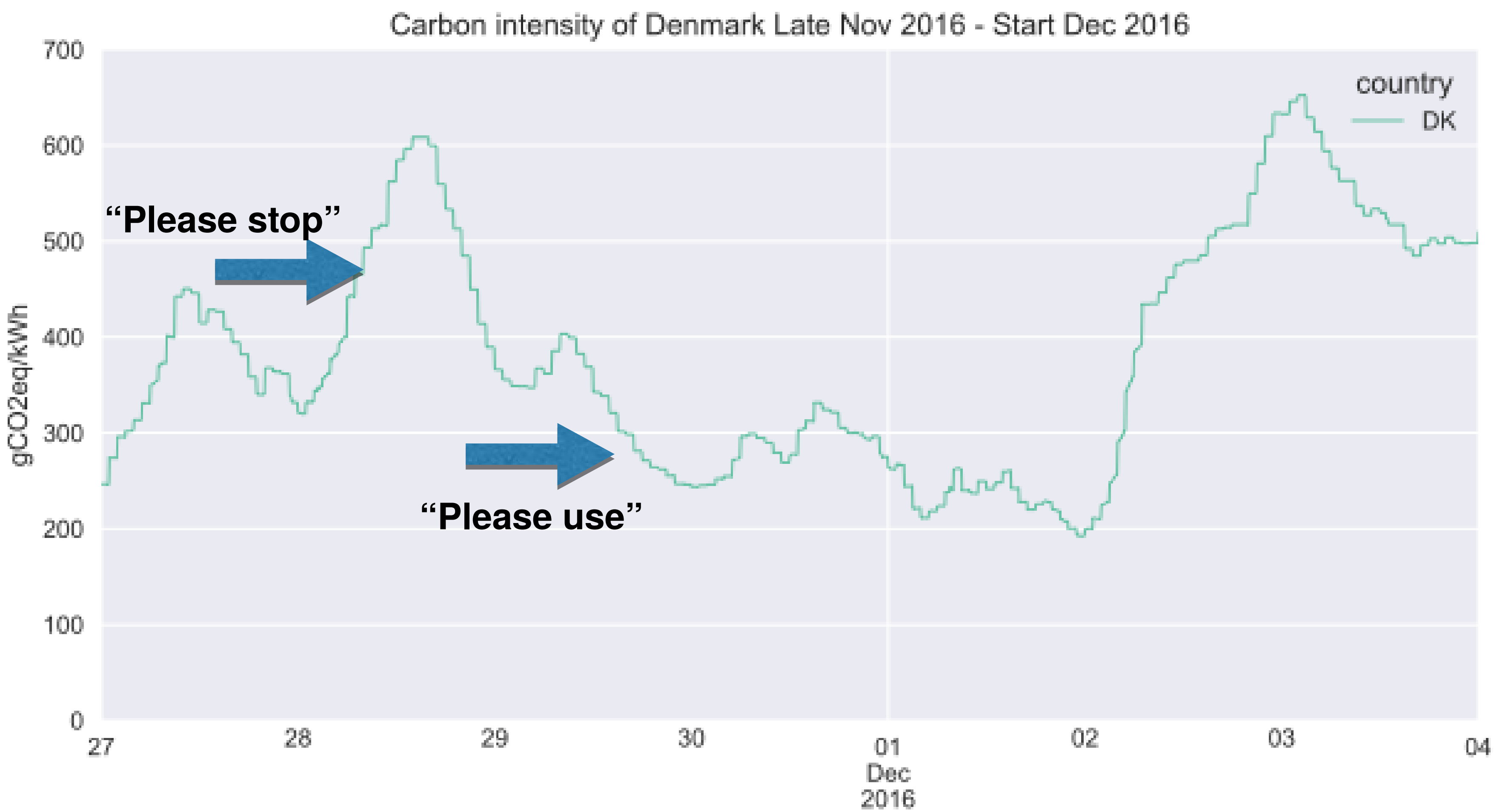
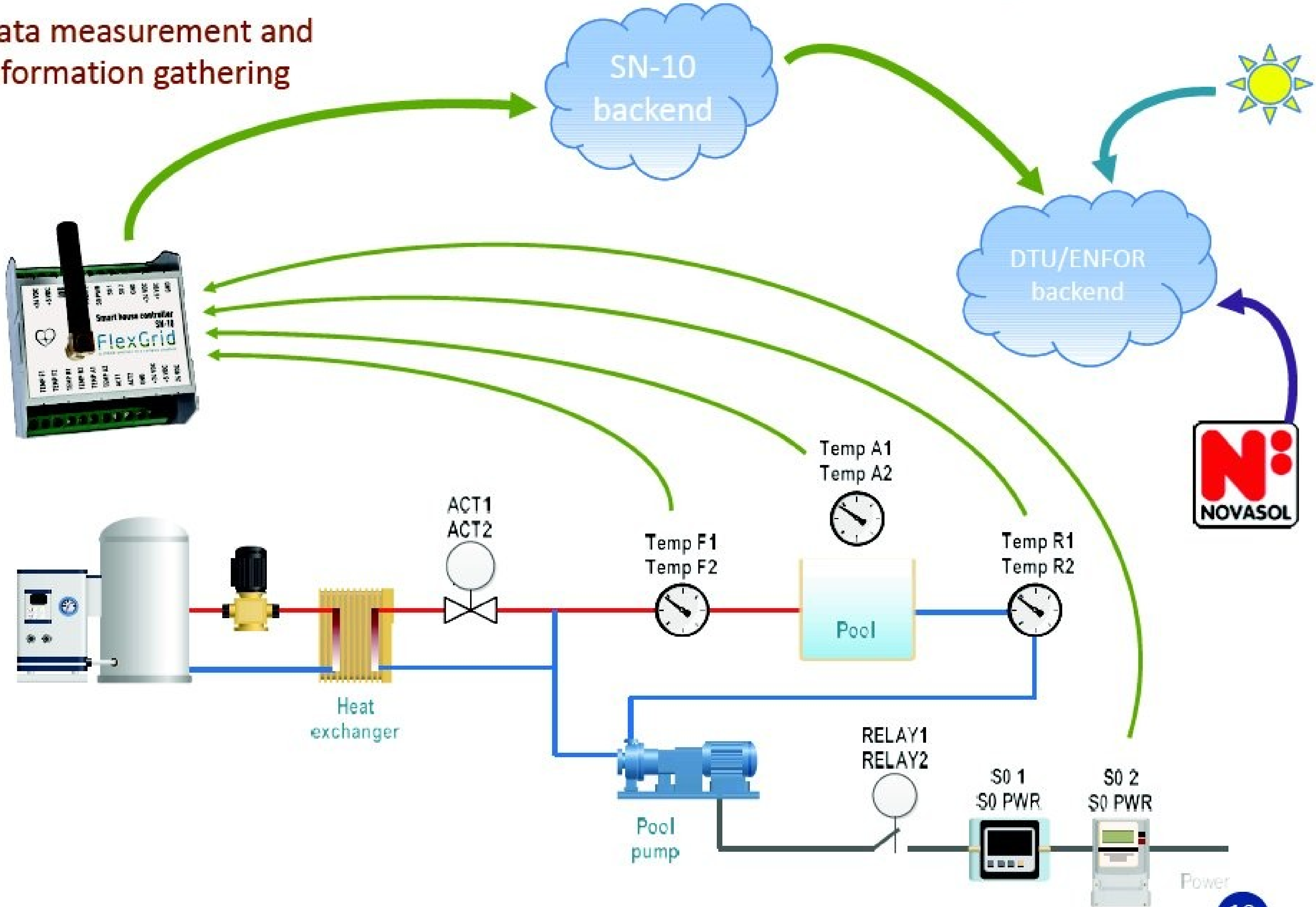


Source: pro.electicitymap.org

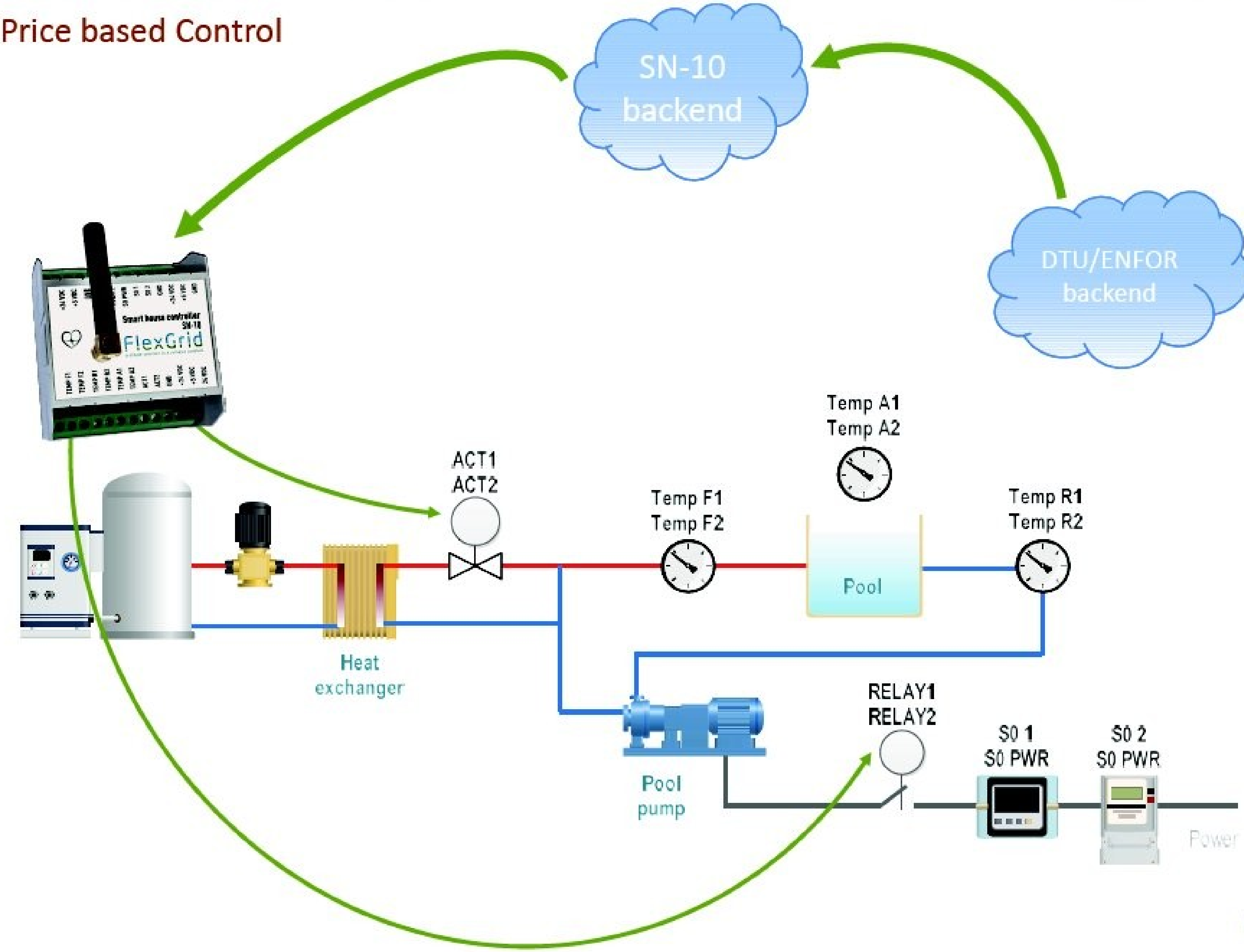
How does it work?

Data measurement and information gathering

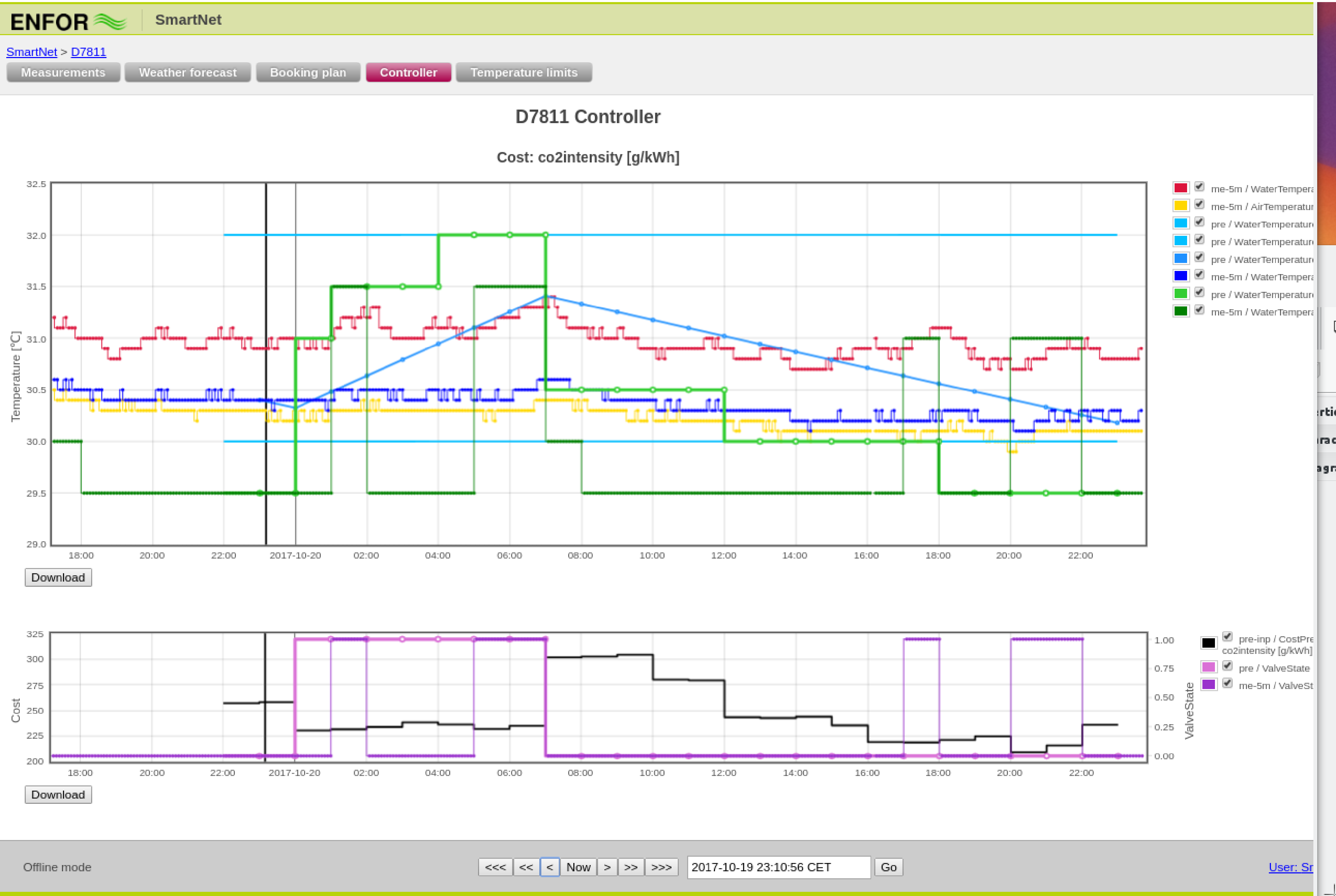


How does it work?

Price based Control



Example: CO2-based control



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Software solutions

Software for combined physical and statistical modelling

Continuous Time Stochastic Modelling (CTSM) is a software package for modelling and simulation of combined physical and statistical models. You find a technical description and the software at CTSM.info.

Software for Model Predictive Control

HPMPC is a toolbox for High-Performance implementation of solvers for Model Predictive Control (MPC). It contains routines for fast solution of MPC and MHE (Moving Horizon Estimation) problems on embedded hardware. The software is available at GitHub.

Search ...

Latest news

Ambassador Louise Bang Jespersen visited CITIES, October 29th 2015

CITIES Korean International Workshop – KIER, Daejeon, Korea, October 22nd 2015

Workshop on Mathematical Sciences Collaboration in Energy Systems Integration – DTU,

Summary

- A procedure for data intelligent control of power load, using the Smart-Energy OS (SE-OS) setup, is suggested.
- The SE-OS controllers can focus on
  - Peak Shaving
  - Smart Grid demand (like ancillary services needs, ...)
  - Energy Efficiency
  - Cost Minimization
  - Emission Efficiency
- We have demonstrated a large potential in Demand Response in Buildings. Automatic solutions and end-user focus are important
- We have suggested a method for characterizing the energy flexibility of buildings which facilitates smart grid applications
- We see large problems with the tax and tariff structures in many countries (eg. Denmark).

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For more information ...

See for instance

www.smart-cities-centre.org

...or contact

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Acknowledgement - DSF 1305-00027B

Further Aspects

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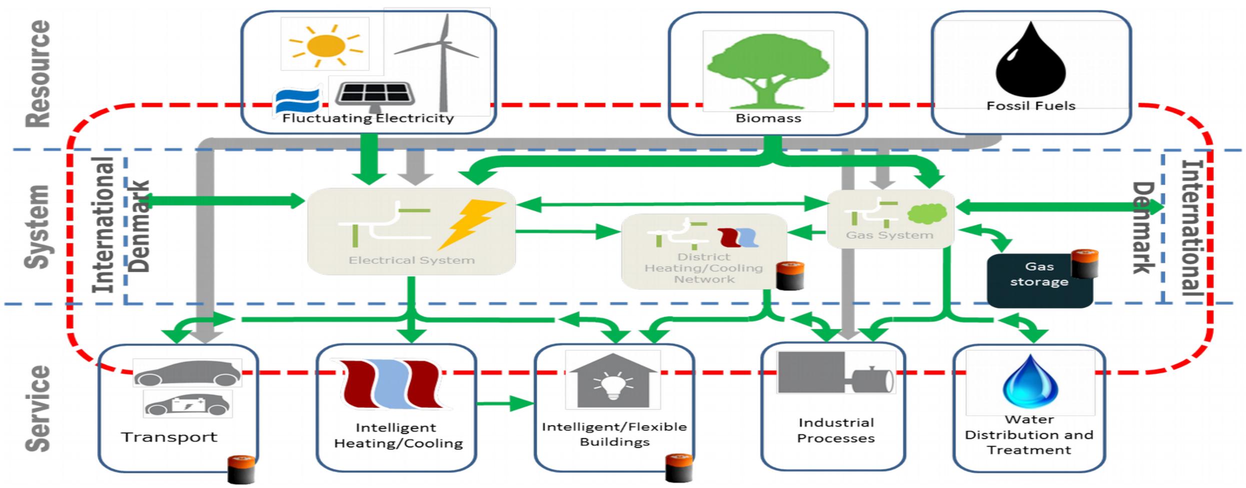
(Virtual) Storage Solutions



- **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, 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

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Labelling proposal

for energy, price and emission based labelling

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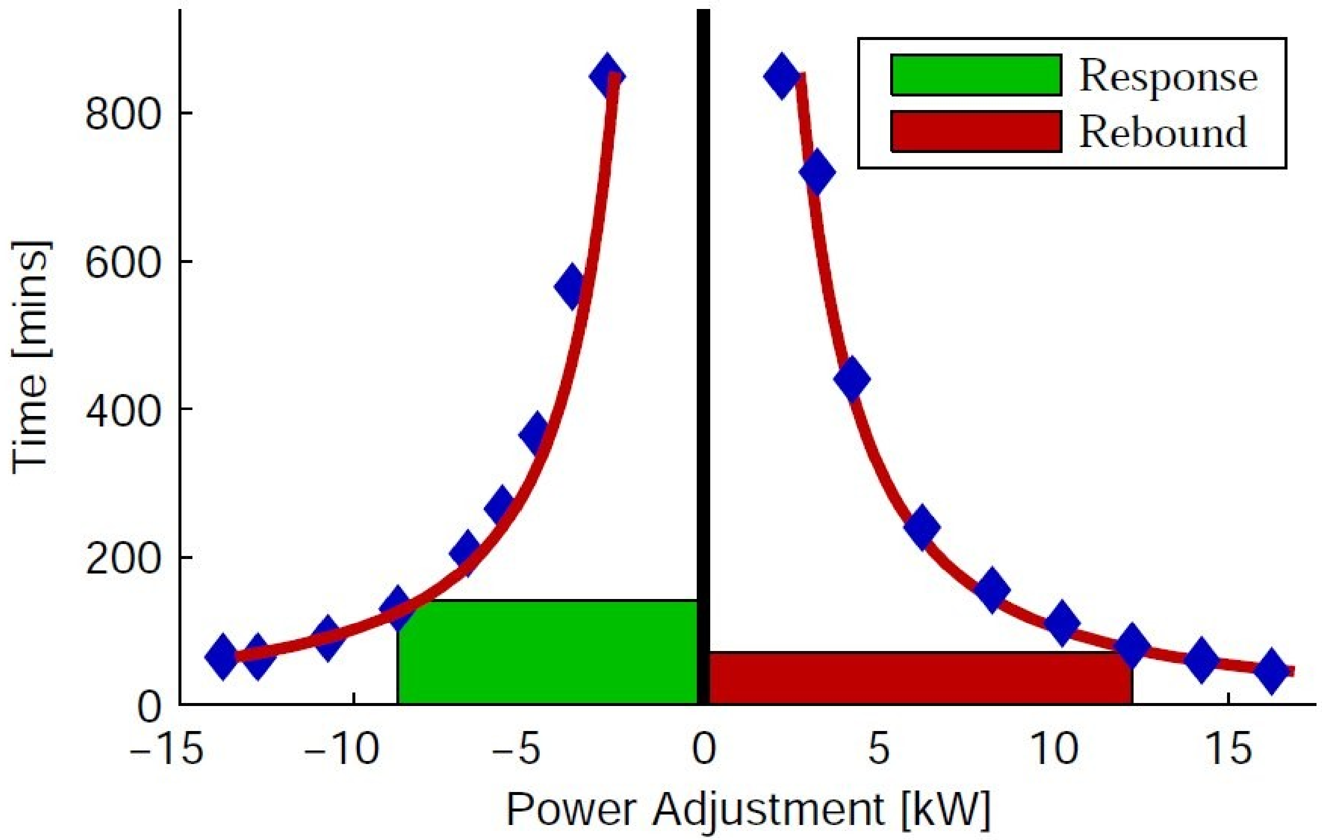
The test consists of the following steps:

1. Let λ_t be the price of electricity at time t.
2. Simulate the control of the building *without considering* the price, and let u_t^0 be the electricity consumption at time t.
3. Simulate the control of the building *considering* the price, and let u_t^1 be the electricity consumption at time t.
4. The total operation cost of the price-ignorant control is given by $C^0 = \sum_{t=0}^{N} \lambda_t u_t^0$.
5. Similarly the operation cost of the price-aware control is given by $C^1 = \sum_{t=0}^{N} \lambda_t u_t^1$.
6. $1 - \frac{C^1}{C^0}$ is the result of the test, giving us the fractional amount of saved money.

This test is inspired by minimizing total costs for varying electricity prices, but in general λ_t could just represent ones desire to reduce electricity demand at time t.

Flexibility Represented by Saturation Curves

(for market integration using block bids)



Understanding Power/Energy Flexibility Some Demo Projects in CITIES:

- Control of WWTP (ED, Kruger, ..)
- Heat pumps (Grundfos, ENFOR, ..)
- Supermarket cooling (Danfoss, TI, ..)
- Summerhouses (DC, ENDK, Nyfors, ..)
- Green Houses (NeoGrid, ENFOR, ...)
- CHP (Dong Energy, EnergiFyn, ...)
- Industrial production
- EV (Eurisco, Enfor, ...)
- ....