SmartNet

Smart TSO-DSO interaction schemes, market architectures and ICT Solutions for the integration of ancillary services from demand side management and distributed generation

Danish Pilot - WP5.3 - Pilot B:

Flexibility in Summer Houses with a Swimming Pool

Henrik Madsen, DTU Compute

Bruxelles Workshop, June 20th., 2018

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691405

Overview of Pilot B

SmartNet

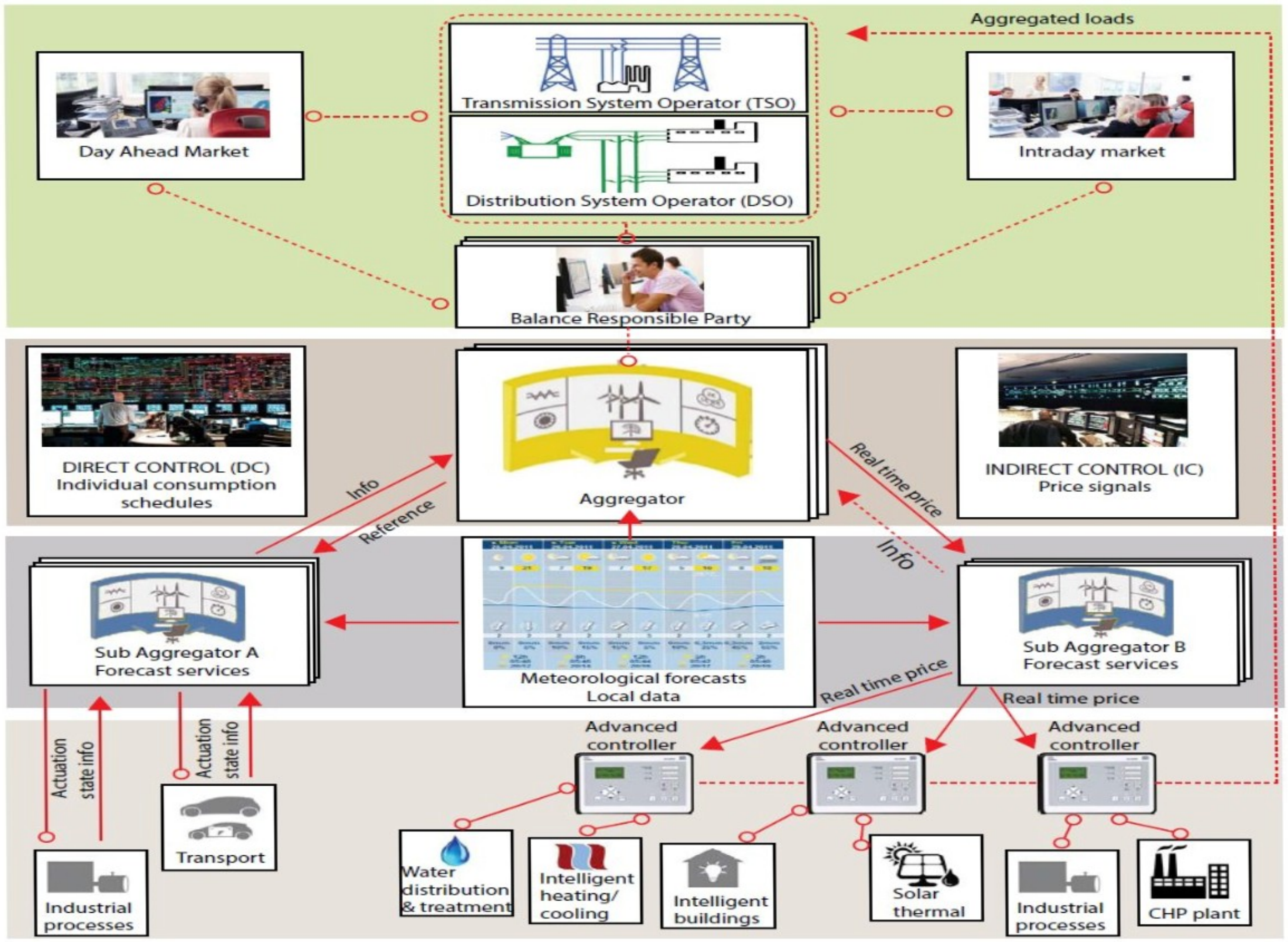
Description:
- 30 Summer houses with a swimming pool – and either boilers or heat pump.
- Indirect control using price (or other penalty signals)
- One way communication

Extension:
- **CO2-base control** since May 2017 for demonstrating how to accelerate the transition to a low fossil future.
- **DSO congestion** based on real-time measurements for better integration of PV, EV and HeatPumps
- Optimize the end-user **flexibility** for the best **integration of wind and solar**

Functionalities:
- **Aggregation of information every 5 minutes** and presented via the SmartNet WEB interface.
- **CO2-based control** since May 2017.
- **Price-based control** since beginning of January 2018.
- **Estimation and forecasting of 5-min balancing prices.**
- Data exchange between 'TSO' and Economical Aggregator (ONE) established
- Data exchange between Eco. Aggregator and Tech. Aggregator (ENFOR) established
- **Flexibility concepts for smart grid applications established.**
- Common TSO-DSO market setup established

Pilot B
Introduction

Smart-Energy OS



Maximizes the flexibility – Simple communication – No contracts

Described in Wiley Book, DTU Annual Report, and several IEEE papers

General Status Pilot B

The SmartNet Technical Aggregator at ENFOR is designed such that we can shift between any external ’penalty signal’. We are able to shift to any ‘penalty signal’ with a very short notice.

Have been up and running with CO2-based control since May 2017.

Shifted to price-based control on January 4th, 2018 – using 5 min balancing prices from ENFOR.

Flexibility function for price-based control is estimated for the aggregated consumption, and ONE has been able to send the prices to ENFOR (Technical Aggregator)

We have learned a lot about how to establish a cloud-based control of smart buildings – and in such a way that they can support the future smart grid (eg. Voltage control)

Danish Pilot participated in the HiL simulation test (WP4.5) a couple of weeks ago.

Penalty Function (examples)

- **Real time CO_2.** If the real time (marginal) CO_2 emission related to the actual electricity production is used as penalty, then, a smart building will minimize the total carbon emission related to the power consumption. Hence, the building will be *emission efficient*.
- **Real time price**. If a real time price is used as penalty, the objective is obviously to minimize the total cost. Hence, the building is *cost efficient*.
- **Constant**. If a constant penalty is used, then, the controllers would simply minimize the total energy consumption. The smart building is, then, *energy efficient*.

Flexibility Function

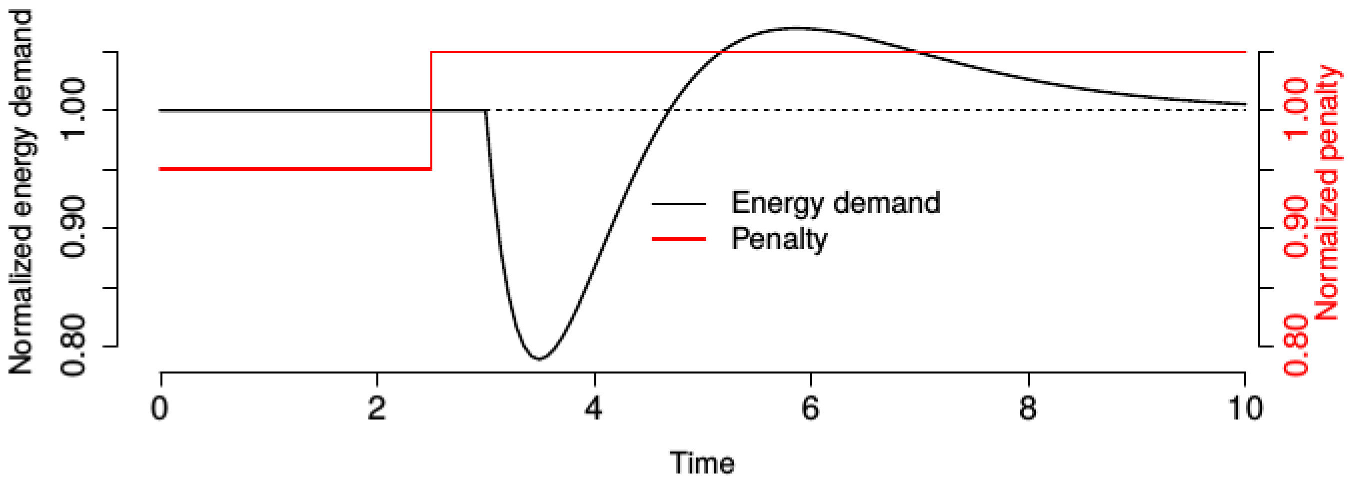


Figure 2: The energy consumption before and after an increase in penalty. The red line shows the normalized penalty while the black line shows the normalized energy consumption. The time scale could be very short with the units being seconds or longer with units of hours. At time 2.5 the penalty is increased,

FF for three buildings

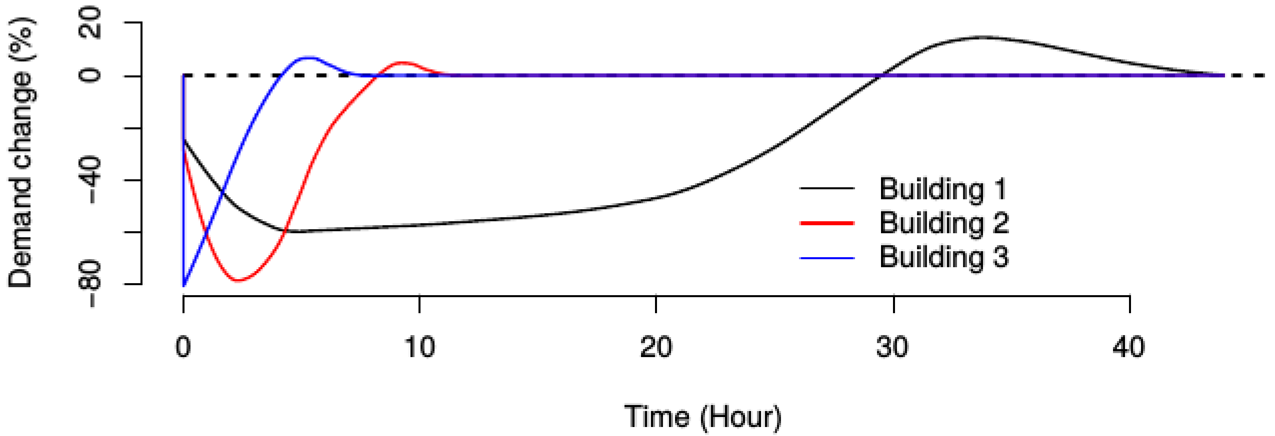


Figure 5: The Flexibility Function for three different buildings.

Flexibility Index

Table 2: Flexibility Index for each of the buildings based reference penalty signals representing wind, solar and ramp problems.

	Wind (%)	Solar (%)	Ramp (%)
Building 1	36.9	10.9	5.2
Building 2	7.2	24.0	11.1
Building 3	17.9	35.6	67.5

Smart Grid Applications

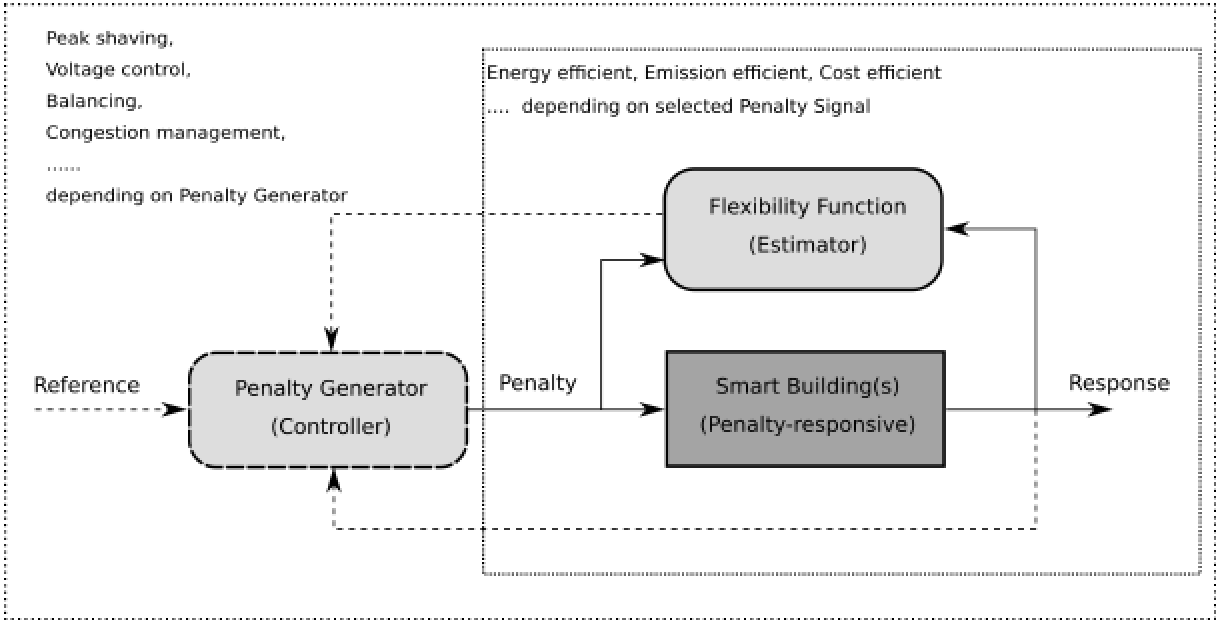
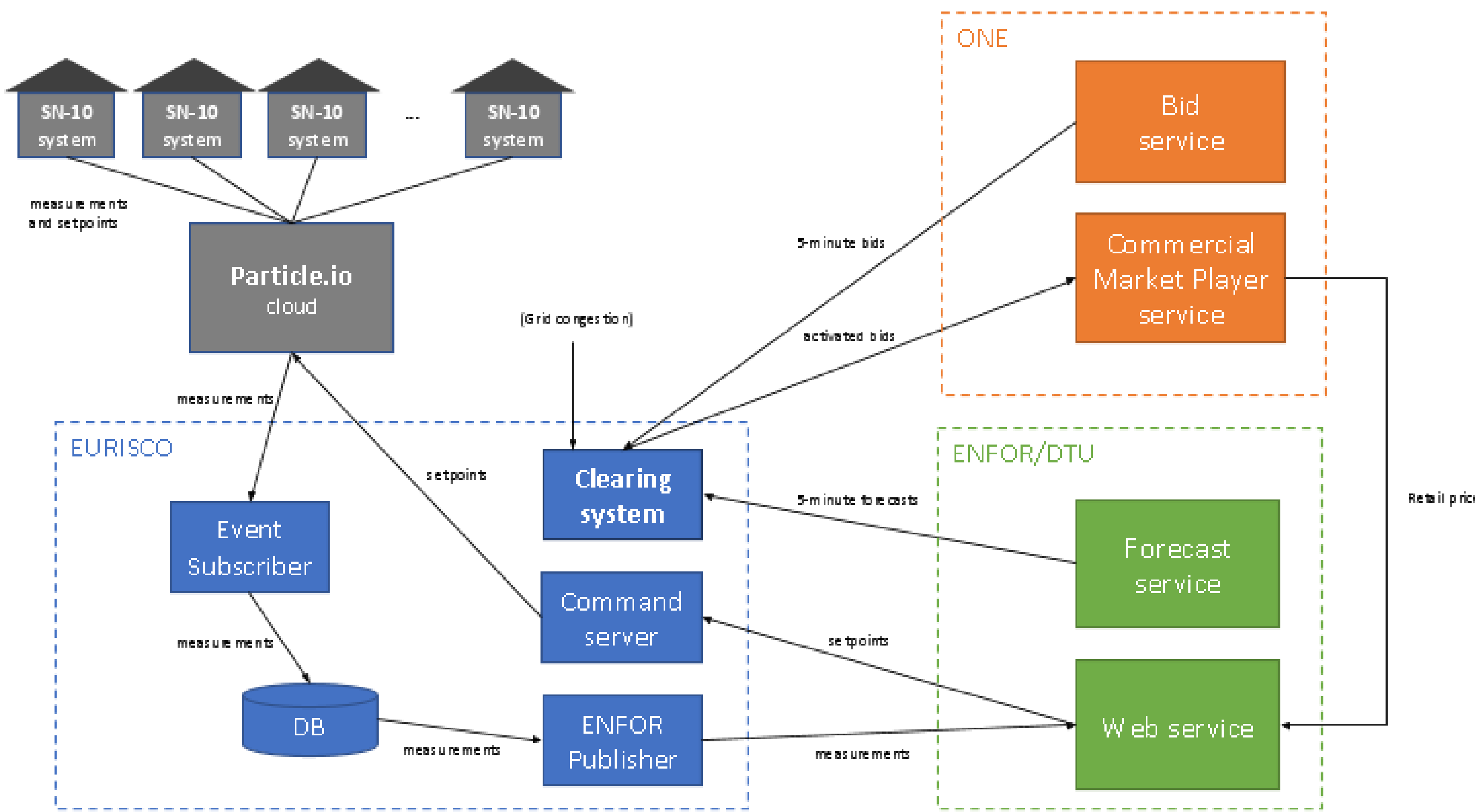


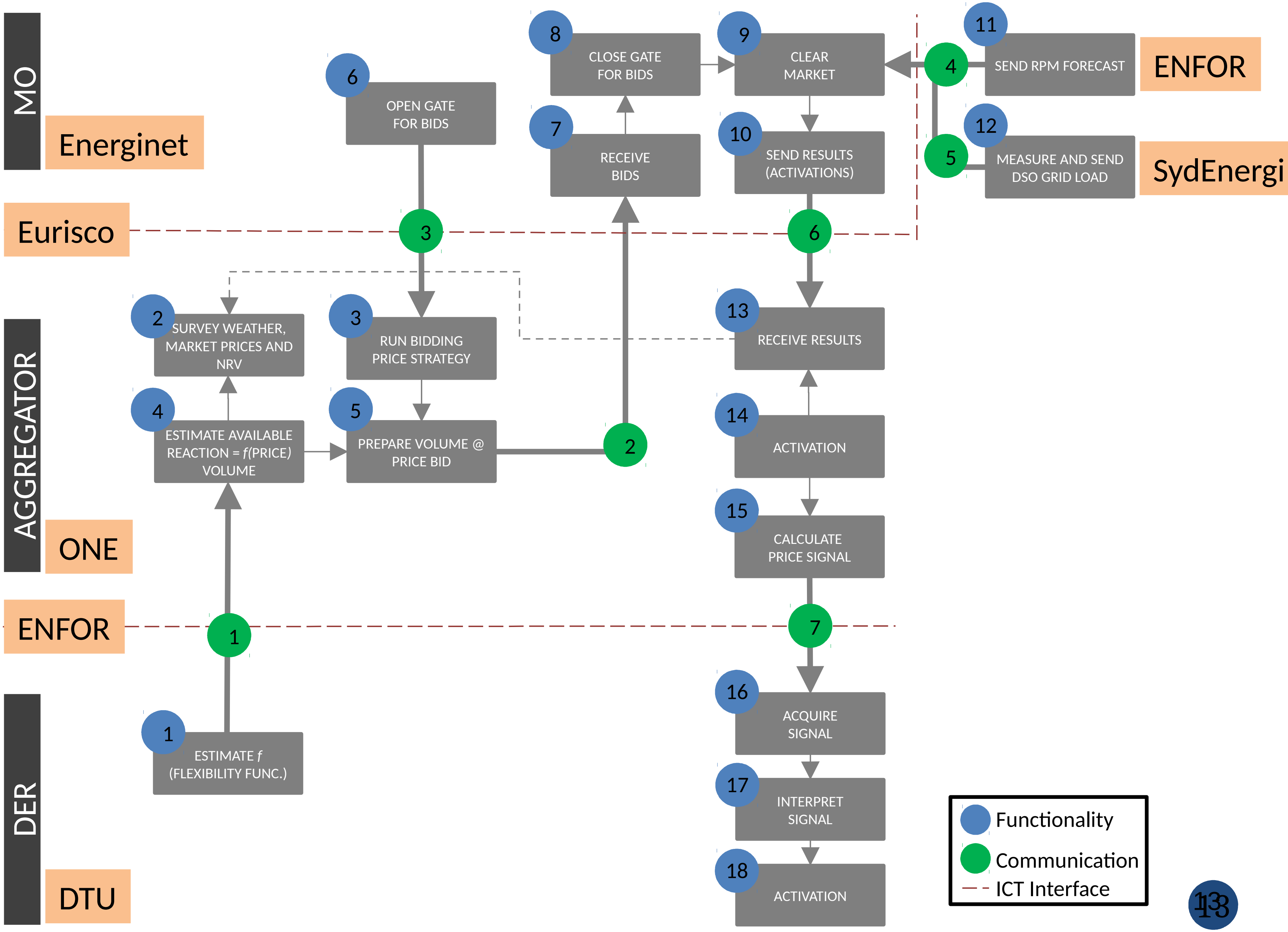
Figure 8: Smart buildings and penalty signals.

Pilot B
Upper Level

Pilot B data exchange and interface overview

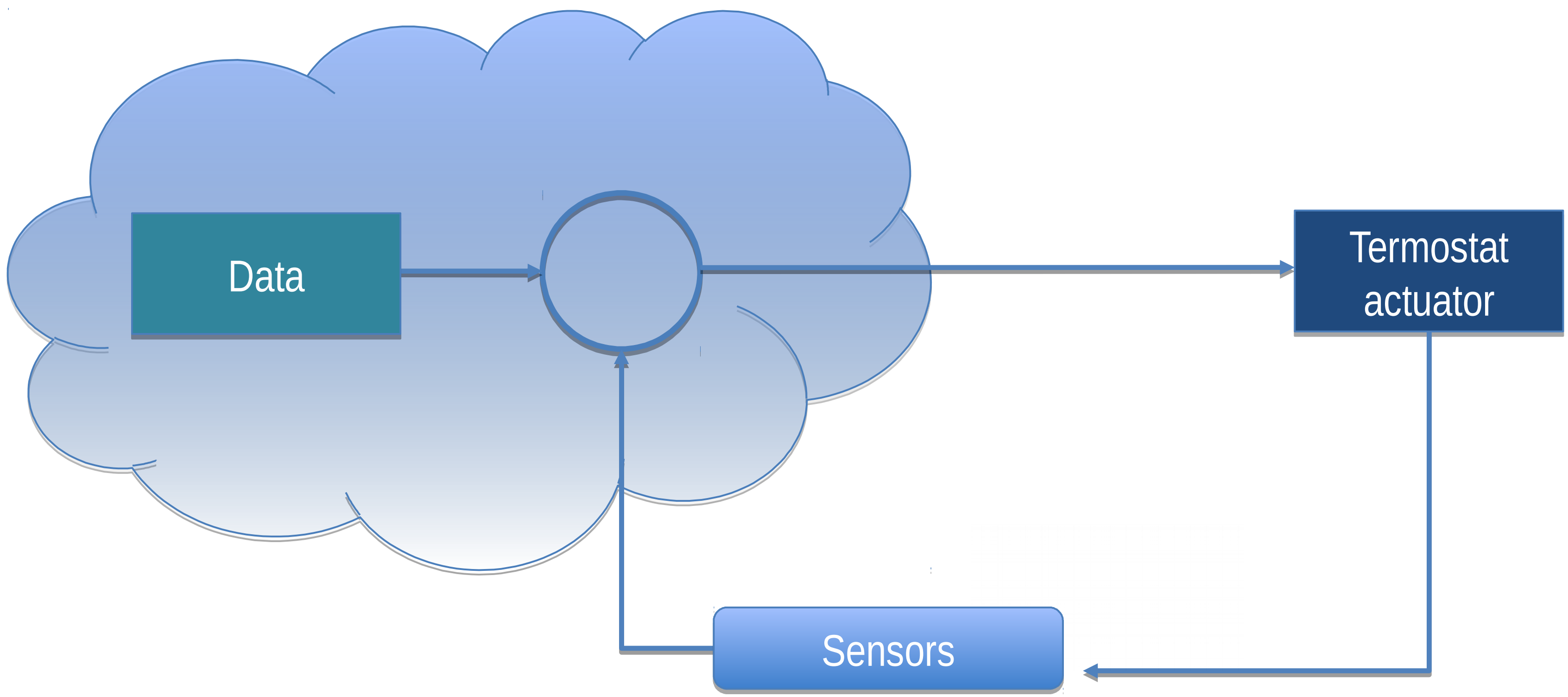


Rev02

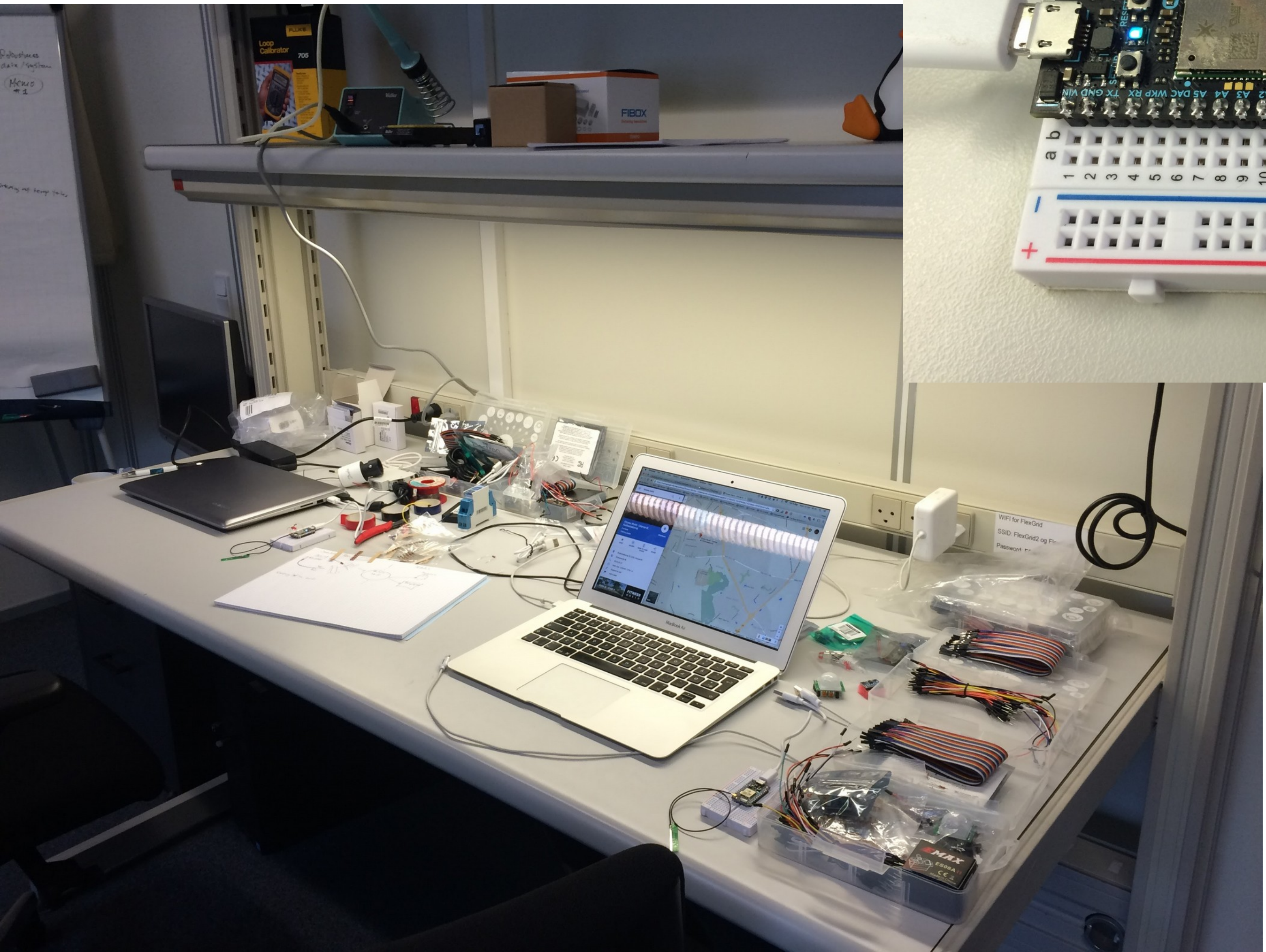

MO
Energinet
Eurisco
AGGREGATOR
ONE
ENFOR
DER
DTU
ENFOR
SydEnergi
1 ESTIMATE f (FLEXIBILITY FUNC.)
2 SURVEY WEATHER, MARKET PRICES AND NRV
3 RUN BIDDING PRICE STRATEGY
4 ESTIMATE AVAILABLE REACTION = f(PRICE) VOLUME
5 PREPARE VOLUME @ PRICE BID
6 OPEN GATE FOR BIDS
7 RECEIVE BIDS
8 CLOSE GATE FOR BIDS
9 CLEAR MARKET
10 SEND RESULTS (ACTIVATIONS)
11 SEND RPM FORECAST
12 MEASURE AND SEND DSO GRID LOAD
13 RECEIVE RESULTS
14 ACTIVATION
15 CALCULATE PRICE SIGNAL
16 ACQUIRE SIGNAL
17 INTERPRET SIGNAL
18 ACTIVATION
1
2
3
4
5
6
7
Functionality
Communication
ICT Interface

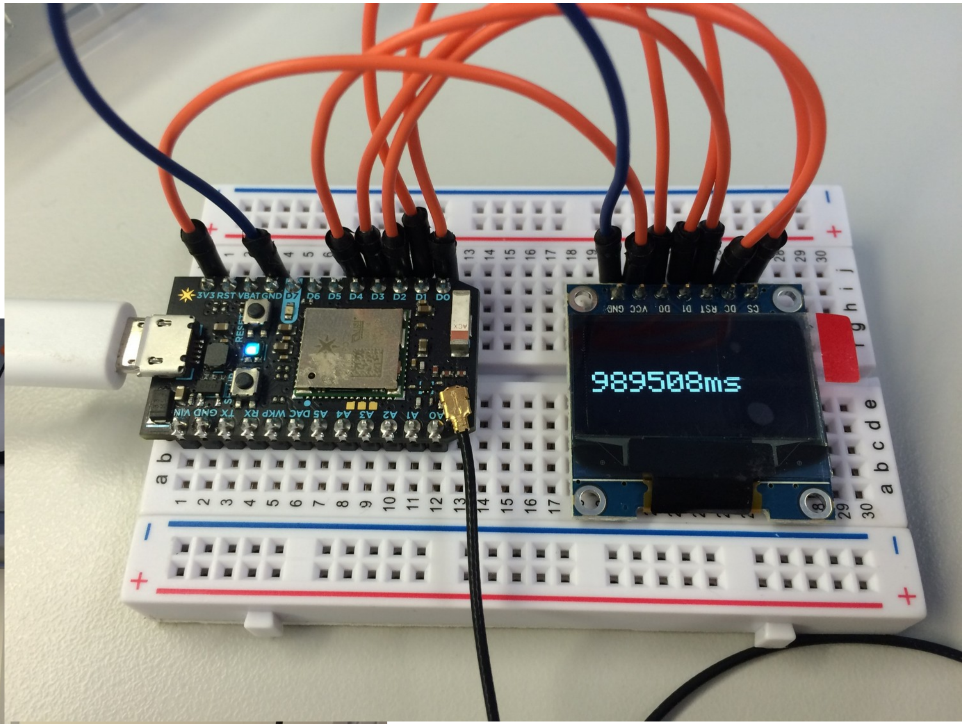
Pilot B
Lower Level

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

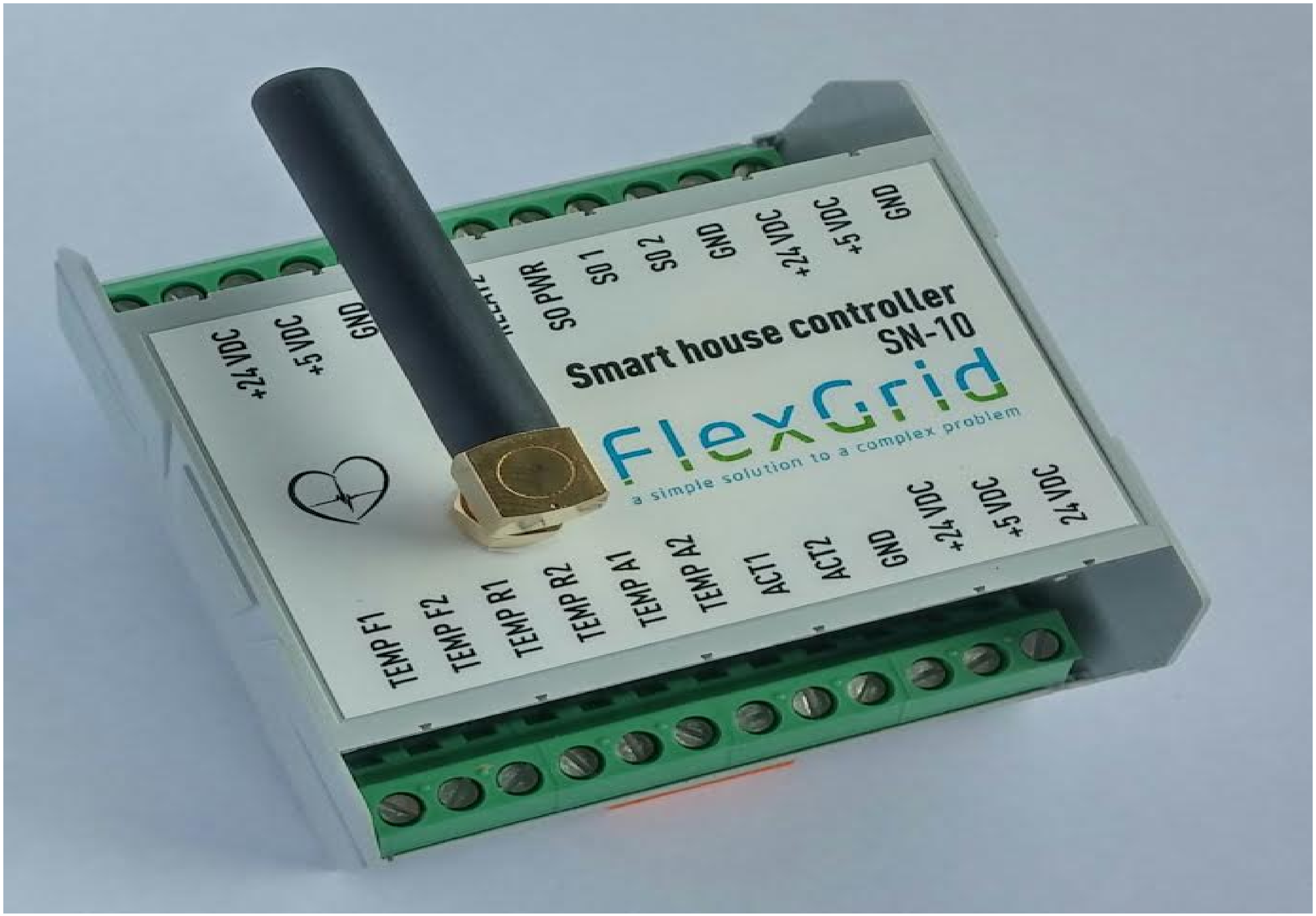


Lab testing ....



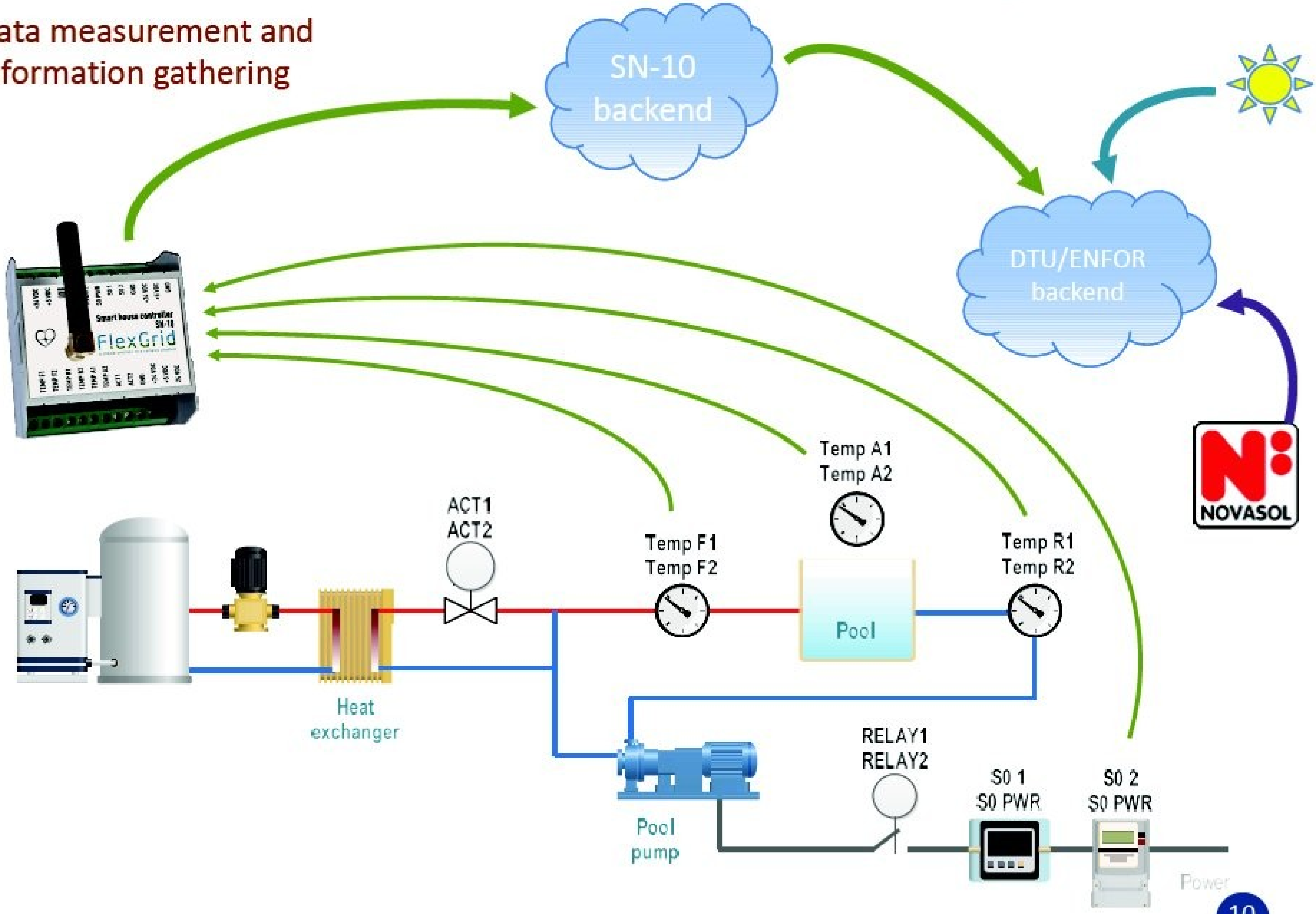


SN-10 Smart House Gateway



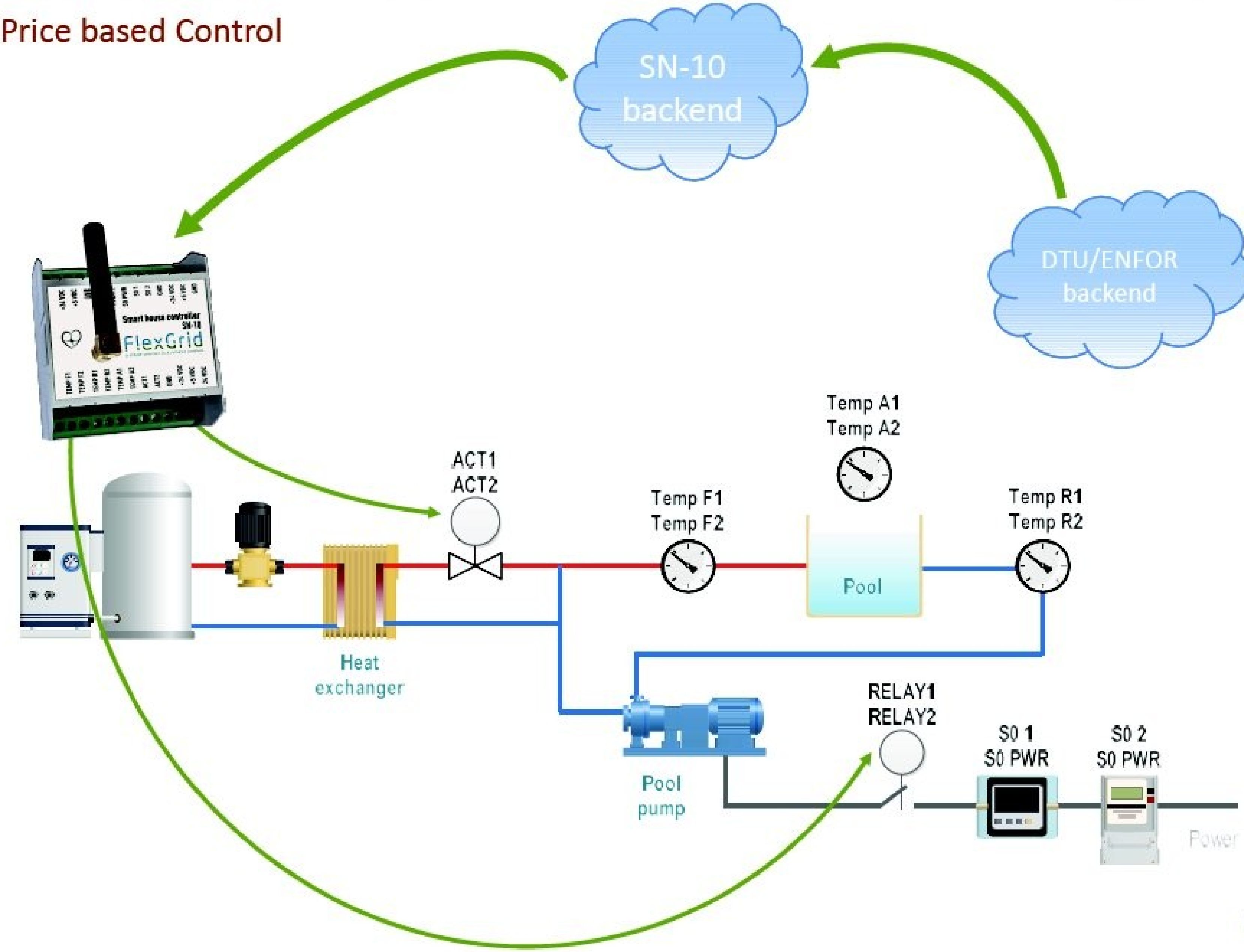
How does it work?

Data measurement and information gathering



How does it work?

Price based Control



Status Lower Level

We have used CO_2-based control since May 2017

We have shifted to price-based control in January 2018, and hence it is possible to connect to the SmartNet market

We have learned a lot about how to establish a cloud-based control of smart buildings – and in such a way that they can support the future smart grid (eg. Voltage control)

Smart Net web portal for Pilot B

ENFOR SmartNet

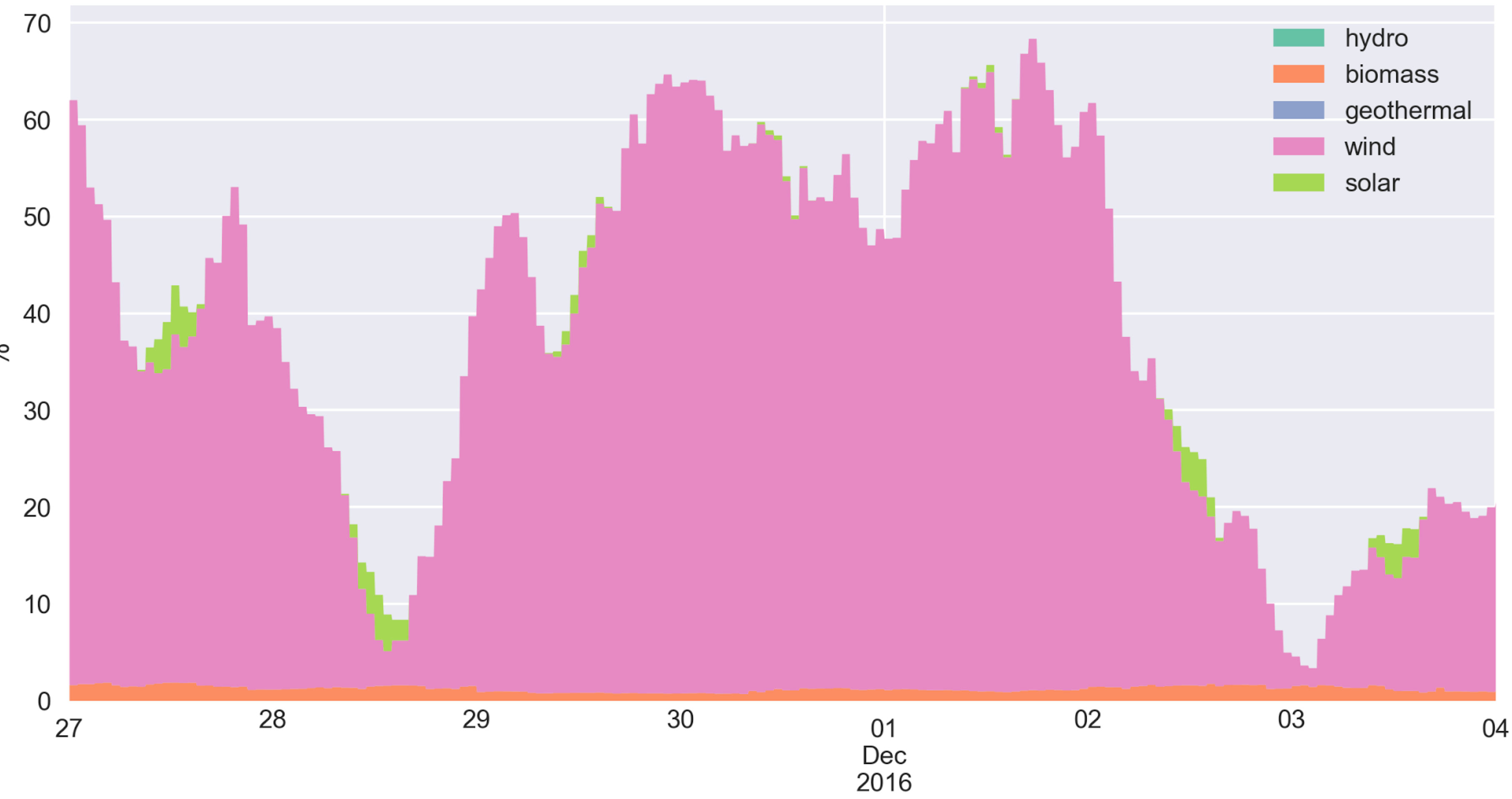
SmartNet

Overview | Measurements | Houses... | DK1 Forecasts

	Postal Code	First Measurement	Latest Measurement	Avail.	+48h	Latest Control Fcs.	TempRet	TempSetPnt	TempRetMin	TempRetMax	Adaptive	Setpoint Endpoint	Accepted at Endpoint
A3067	6857 Blåvand	2018-03-01	2018-06-18 23:00:00	1	1	2018-06-18 22:55:00	28.7 ℃	27.0 ℃	25.0 ℃	30.0 ℃	no	sn10.flexgrid.dk	2018-06-18 22:55:00
A3074	6857 Blåvand	2018-03-01	2018-06-18 23:00:00	0	1	2018-06-18 22:55:00	28.1 ℃	27.5 ℃	28.0 ℃	30.0 ℃	yes	sn10.flexgrid.dk	2018-06-18 22:55:00
A3128	6857 Blåvand	2018-03-01	2018-06-16 06:25:00	0	0	2018-06-16 08:10:00	29.7 ℃	27.5 ℃	28.0 ℃	30.0 ℃	no	sn10.flexgrid.dk	2018-06-16 06:20:00
P32013	6857 Blåvand	2018-03-01	2018-06-18 23:00:00	0	0	2018-06-18 22:55:00	29.1 ℃	27.5 ℃	28.0 ℃	30.0 ℃	no	sn10.flexgrid.dk	2018-06-18 22:55:00
P32037	6857 Blåvand	2018-03-01	2018-06-18 23:00:00	1	1	2018-06-18 22:55:00	28.5 ℃	27.0 ℃	20.0 ℃	30.0 ℃	no	sn10.flexgrid.dk	2018-06-18 22:55:00
P32071	6857 Blåvand	2017-11-22	2018-06-18 20:35:00	1	1	2018-06-18 22:20:00	29.5 ℃	27.0 ℃	25.0 ℃	30.0 ℃	no	server.flex-control.com	2018-06-18 22:55:00
P32121	6857 Blåvand	2017-11-10	2018-06-18 23:00:00	0	0	2018-06-18 22:55:00	28.2 ℃	28.0 ℃	28.0 ℃	30.0 ℃	no	server.flex-control.com	2018-06-18 22:55:00
P32286	6857 Blåvand	2018-03-01	2018-06-18 23:00:00	0	0	*Not enabled*	-	-	-	-	no	sn10.flexgrid.dk	-
P32359	6857 Blåvand	2018-03-01	2018-06-18 23:00:00	1	0	2018-06-18 22:55:00	25.4 ℃	24.5 ℃	25.0 ℃	30.0 ℃	yes	sn10.flexgrid.dk	2018-06-18 22:55:00
P32424	6857 Blåvand	2018-03-01	2018-05-26 10:15:00	0	0	2018-05-26 10:45:00	28.2 ℃	25.5 ℃	20.0 ℃	30.0 ℃	no	sn10.flexgrid.dk	2018-05-26 06:10:00
P32512	6857 Blåvand	2018-03-01	2018-06-13 13:10:00	1	1	2018-06-13 13:10:00	28.7 ℃	27.5 ℃	28.0 ℃	30.0 ℃	no	sn10.flexgrid.dk	2018-06-13 13:05:00
P32641	6857 Blåvand	2018-03-01	2018-06-18 23:00:00	1	1	2018-06-18 22:55:00	27.8 ℃	25.5 ℃	25.0 ℃	30.0 ℃	yes	sn10.flexgrid.dk	2018-06-18 22:55:00
P32731	6857 Blåvand	2018-03-01	2018-06-15 22:25:00	0	0	*Not enabled*	-	-	-	-	no	sn10.flexgrid.dk	-
P32787	6857 Blåvand	2018-03-01	2018-06-18 23:00:00	0	0	2018-06-18 22:55:00	28.4 ℃	27.5 ℃	28.0 ℃	30.0 ℃	no	sn10.flexgrid.dk	2018-06-18 22:55:00
P32788	6857 Blåvand	2018-03-01	2018-06-18 23:00:00	0	0	2018-06-18 22:55:00	28.4 ℃	27.5 ℃	28.0 ℃	30.0 ℃	yes	sn10.flexgrid.dk	2018-06-18 22:55:00
A07395	9480 Løkken	2018-01-26	2018-06-18 23:00:00	0	0	2018-06-18 22:55:00	29.0 ℃	28.5 ℃	29.0 ℃	31.0 ℃	yes	sn10.flexgrid.dk	2018-06-18 22:55:00
A11305	9480 Løkken	2017-11-08	2018-06-18 23:00:00	1	1	2018-06-18 22:55:00	28.1 ℃	25.5 ℃	25.0 ℃	30.0 ℃	yes	sn10.flexgrid.dk	2018-06-18 22:55:00
D7395	9480 Løkken	2018-01-25	2018-06-18 23:00:00	0	0	2018-06-18 22:55:00	27.1 ℃	30.0 ℃	30.0 ℃	32.0 ℃	no	sn10.flexgrid.dk	2018-06-18 22:55:00
A14526	9490 Pandrup	2017-03-28	2018-06-18 23:00:00	0	0	2018-06-18 22:55:00	31.7 ℃	30.0 ℃	30.0 ℃	32.0 ℃	no	sn10.flexgrid.dk	2018-06-18 22:55:00
A13957	9492 Blokhus	2017-03-28	2018-05-26 18:35:00	0	0	*Not enabled*	-	-	-	-	no	sn10.flexgrid.dk	-
A12216	9493 Saltum	2017-03-28	2018-06-18 23:00:00	1	1	2018-06-18 22:55:00	28.1 ℃	25.5 ℃	20.0 ℃	32.0 ℃	yes	sn10.flexgrid.dk	2018-06-18 22:55:00
A12486	9493 Saltum	2018-01-25	2018-06-18 23:00:00	0	0	*Not enabled*	-	-	-	-	no	sn10.flexgrid.dk	-
A12979	9493 Saltum	2017-11-08	2018-06-18 23:00:00	0	0	2018-06-18 22:55:00	27.3 ℃	30.0 ℃	30.0 ℃	32.0 ℃	no	sn10.flexgrid.dk	2018-06-18 22:55:00
D7105	9493 Saltum	2017-03-28	2018-06-18 23:00:00	1	1	2018-06-18 22:55:00	27.7 ℃	25.5 ℃	25.0 ℃	32.0 ℃	yes	sn10.flexgrid.dk	2018-06-18 22:55:00
D7227	9493 Saltum	2016-09-26	2018-06-18 23:00:00	1	1	2018-06-18 22:55:00	28.7 ℃	27.0 ℃	25.0 ℃	32.0 ℃	no	sn10.flexgrid.dk	2018-06-18 22:55:00
D7320	9493 Saltum	2017-03-28	2018-06-18 23:00:00	1	0	2018-06-18 22:55:00	29.6 ℃	27.0 ℃	26.0 ℃	32.0 ℃	no	sn10.flexgrid.dk	2018-06-18 22:55:00
D7811	9493 Saltum	2017-03-28	2018-06-18 23:00:00	0	0	2018-06-18 22:55:00	30.3 ℃	29.5 ℃	30.0 ℃	32.0 ℃	yes	sn10.flexgrid.dk	2018-06-18 22:55:00
C7224	9690 Fjerritslev	2018-01-25	2018-06-18 23:00:00	1	1	2018-06-18 22:55:00	28.5 ℃	27.0 ℃	25.0 ℃	32.0 ℃	yes	sn10.flexgrid.dk	2018-06-18 22:55:00

Time	2018-06-18 22:55:00
PTime	2018-06-18 22:55:00
ATime	2018-06-18 22:58:08
Value	27.0 ℃

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



Source: pro.electicitymap.

Example: Price-based control

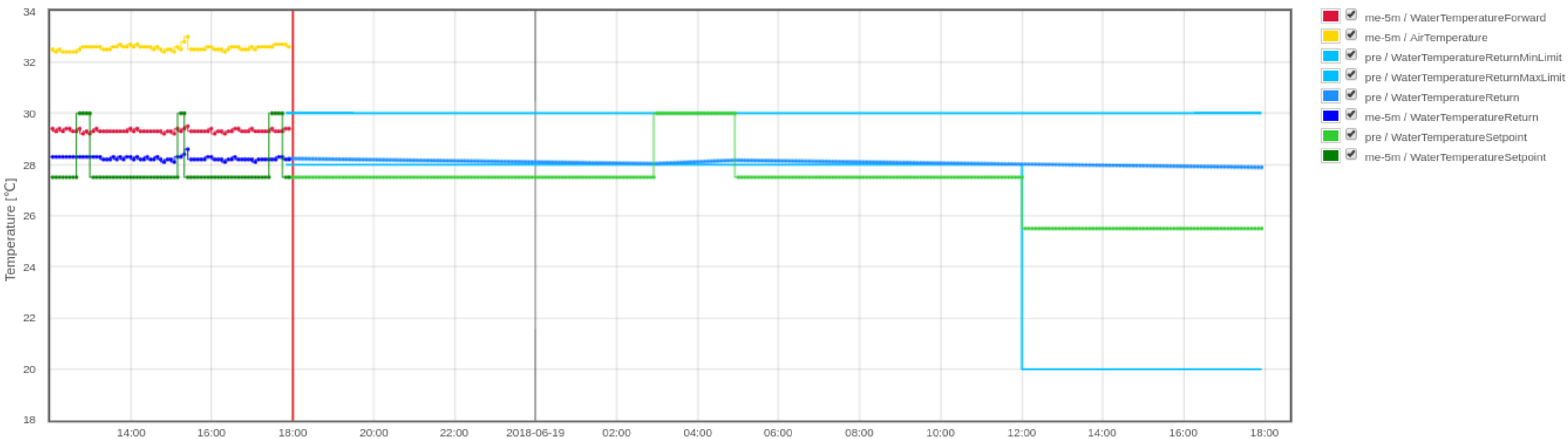
ENFOR SmartNet

SmartNet > A3074

Measurements | Weather forecast | Booking plan | Controller | Temperature limits

A3074 Controller

Cost: DK1 Imbalance Price Consumption [EUR/MWh], Adaptive Estimation



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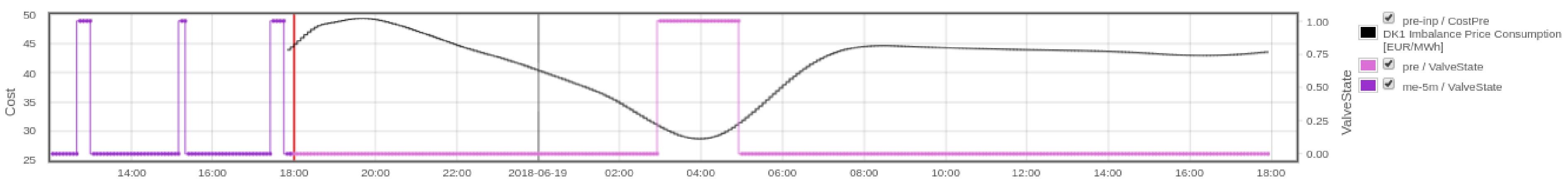

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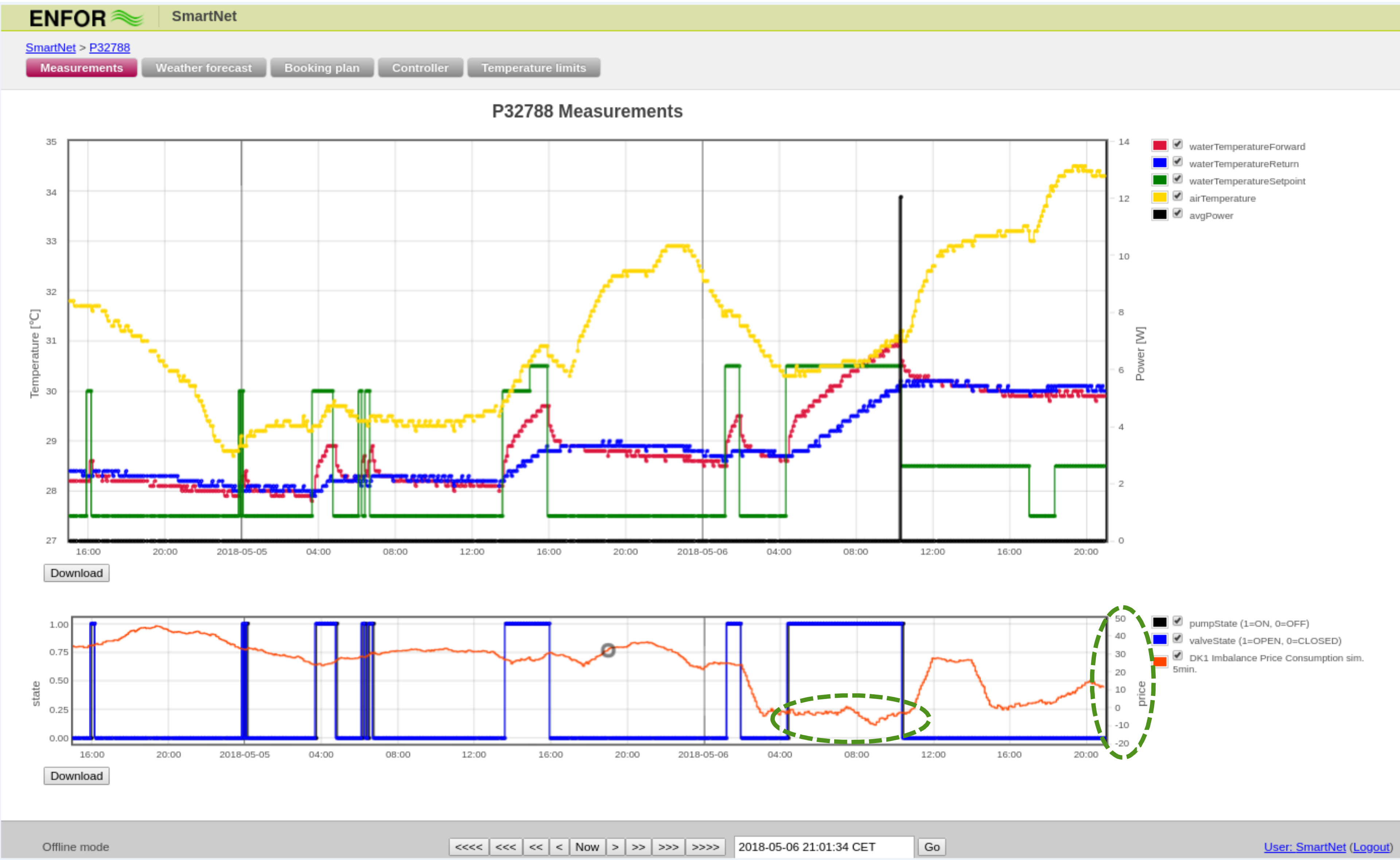
Example: CO2-based control

Example with negative power prices



Pilot B – Some highlights

The SmartNet Technical Aggregator at ENFOR is designed such that we can shift between any external 'penalty signal'. We are able to shift to any 'penalty signal' with a very short notice. It can be **energy efficient, price efficient** or **emission efficient**. Have been up and running with CO2-based control since May 2017 and price-based control since January this year.

A real clearing platform is established with connection from our 'TSO', DSO, Aggregator and the Technical Cloud-based Aggregator/controller

We have learned a lot about how to establish a cloud-based control of smart buildings – and in such a way that they can support the future smart grid (eg. Voltage control and congestion management)

Danish Pilot participated in the HiL simulation test with simulations at AIT a couple of weeks ago.

Huge national interest in the Pilot B setup due to similarities with District Heating systems wrt. flexibility

New project with NREL: Here we are simulating a grid with 2000 buildings and using our concepts of price-based control. We have two people at NREL for the moment. Report and papers will be published jointly with NREL.

We are invited to present the results of Pilot B at the European Parliament on June 27th.

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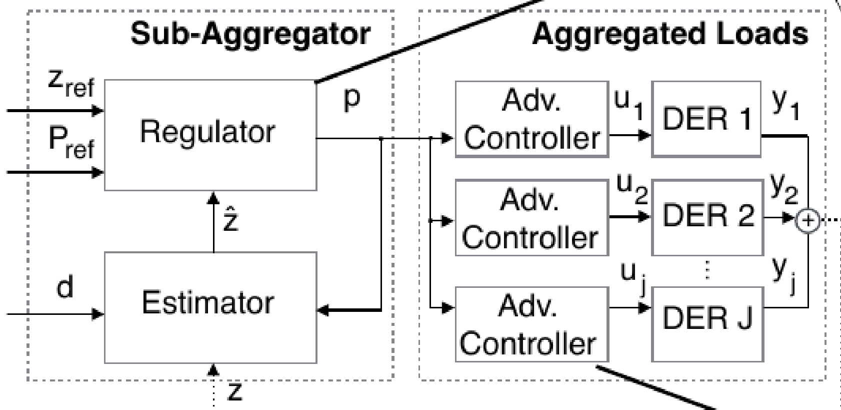
Pilot B

Misc.

Proposed methodology
Control-based methodology

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

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

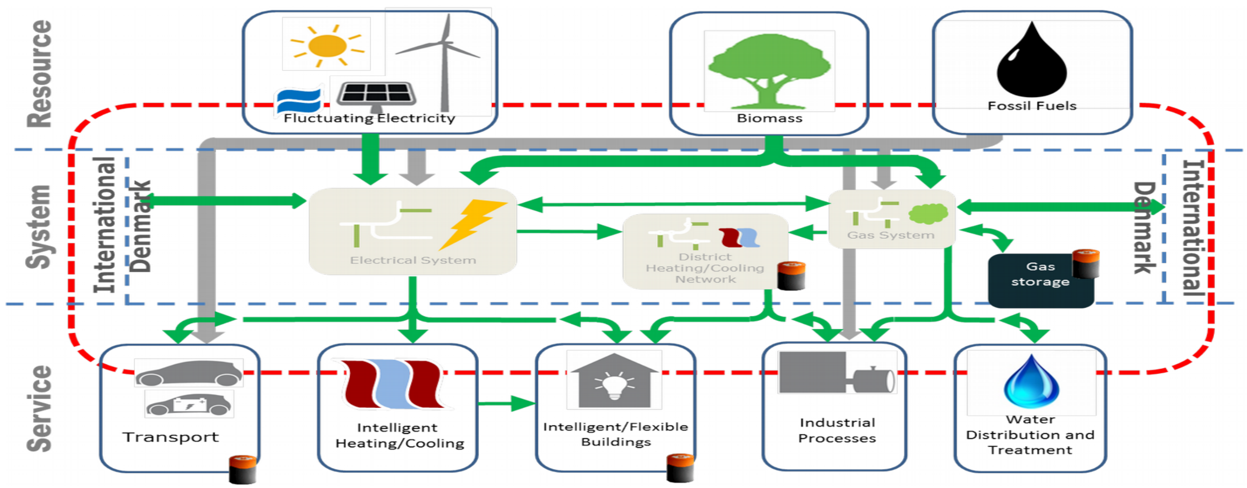


We adopt a control-based approach where the **price** becomes the driver to **manipulate** the behaviour of a certain pool flexible prosumers.

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

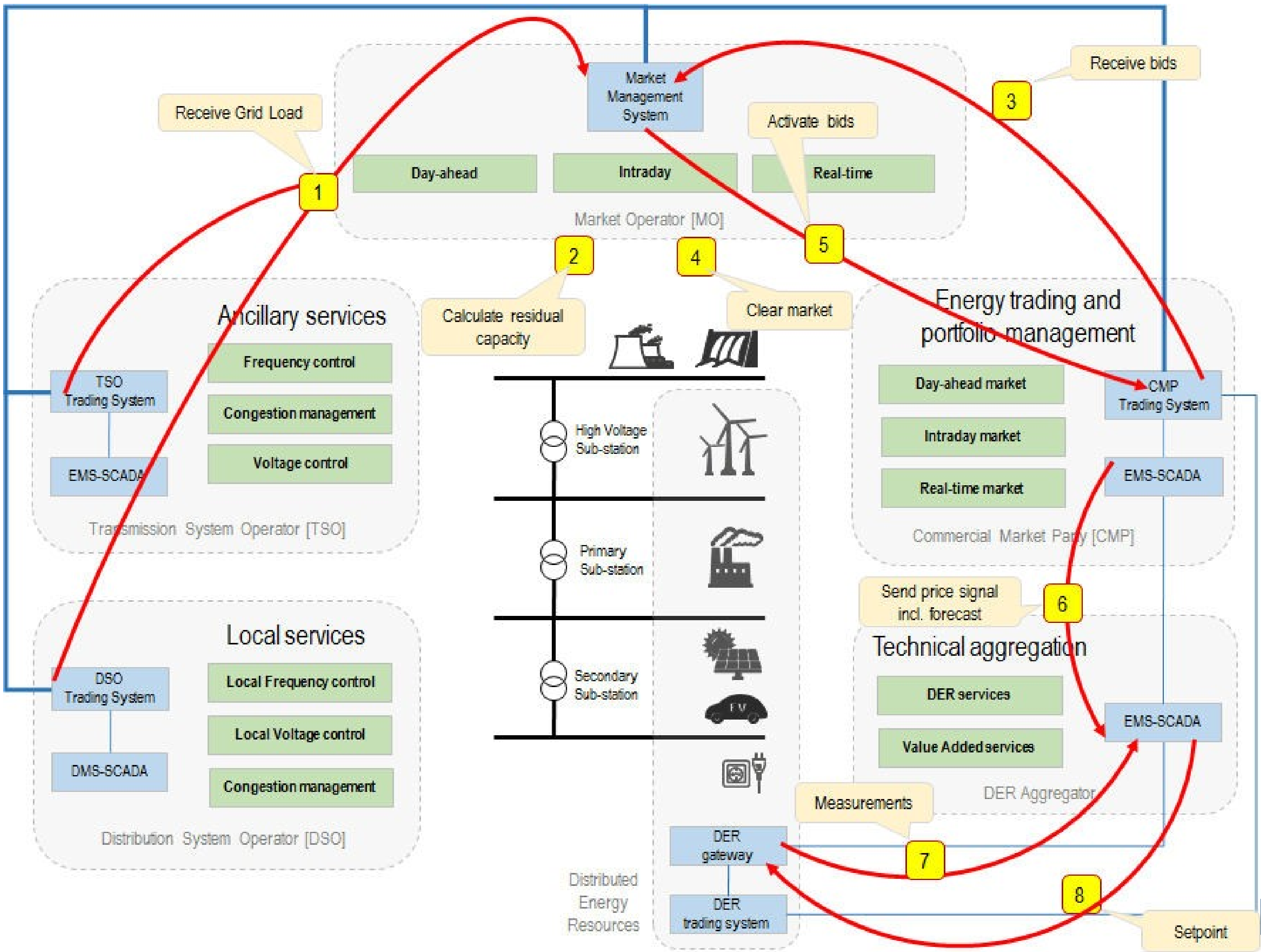
$$\begin{aligned} \text{s.t.} \quad x_{k+1} &= Ax_k + Bu_k + Ed_k, \\ y_k &= Cx_k, \\ y_k^{min} \leq y_k &\leq y_k^{max}, \\ u_k^{min} \leq u_k &\leq u_k^{max} \end{aligned}$$

(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

Overview (on top of Figure D3.2)



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