Accelerating the Green Transition Using the Flexibility of Buildings

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Challenges for Unlocking the Flexibility

Challenges

Preparatory study on Smart Appliances

European Commission

Ecodesign Preparatory Study performed for the European Commission

Welcome | Project summary | Planning & Meetings | Documents | Register for website | Register for meeting | Contact & Consortium

Home > Project summary

Project Summary

The Ecodesign Preparatory Study on Smart Appliances (Lot 33) has analysed the technical, economic, market an[illegible]tal 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.

Almost no Flexibility

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Existing Markets - Challenges

- Static
- Deterministic
- Linear
- Many power related services (voltage, frequency, balancing, spinning reserve, congestion, ...)
- Speed / problem size
- Characterization of flexibility (bids)
- Requirements on user installations

Markets – Needed changes

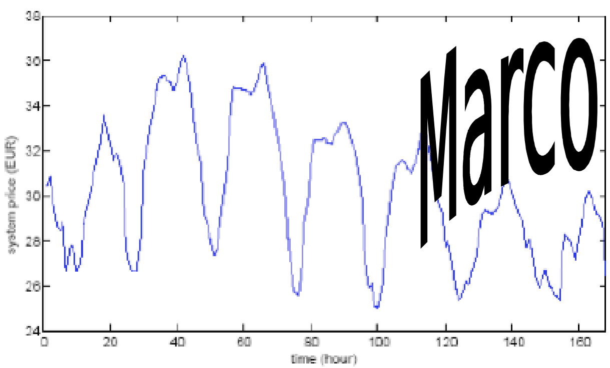
- Static -> **Dynamic**
- Deterministic -> **Stochastic**
- Linear -> **Nonlinear**
- Many power related services (voltage, frequency, balancing, spinning reserve, congestion, ...) -> **Coordination + Hierarchy**
- Speed / problem size -> **Decomposition + Control Based Solutions**
- Characterization of flexibility (bids) -> **Flexibility Functions**
- Requirements on user installations -> **One-way communication**

COMPETITIVE BIDDING AND STABILITY ANALYSIS IN ELECTRICITY MARKETS USING CONTROL THEORY

Main idea: **applying control theory to the study of power markets**

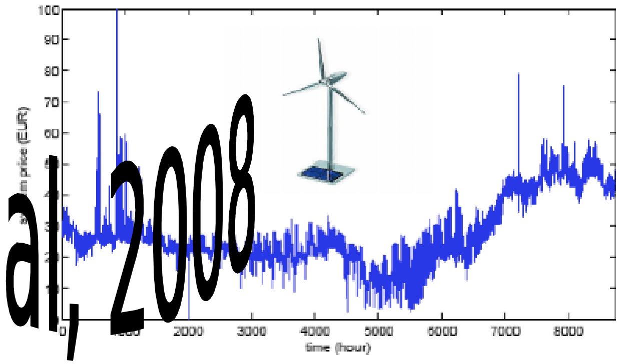
Advantages in handling effectively

Dynamics



Marco Zugno et.al, 2008

Uncertainty



control theory provides ways of modeling the dynamics which is intrinsic in energy markets

↓

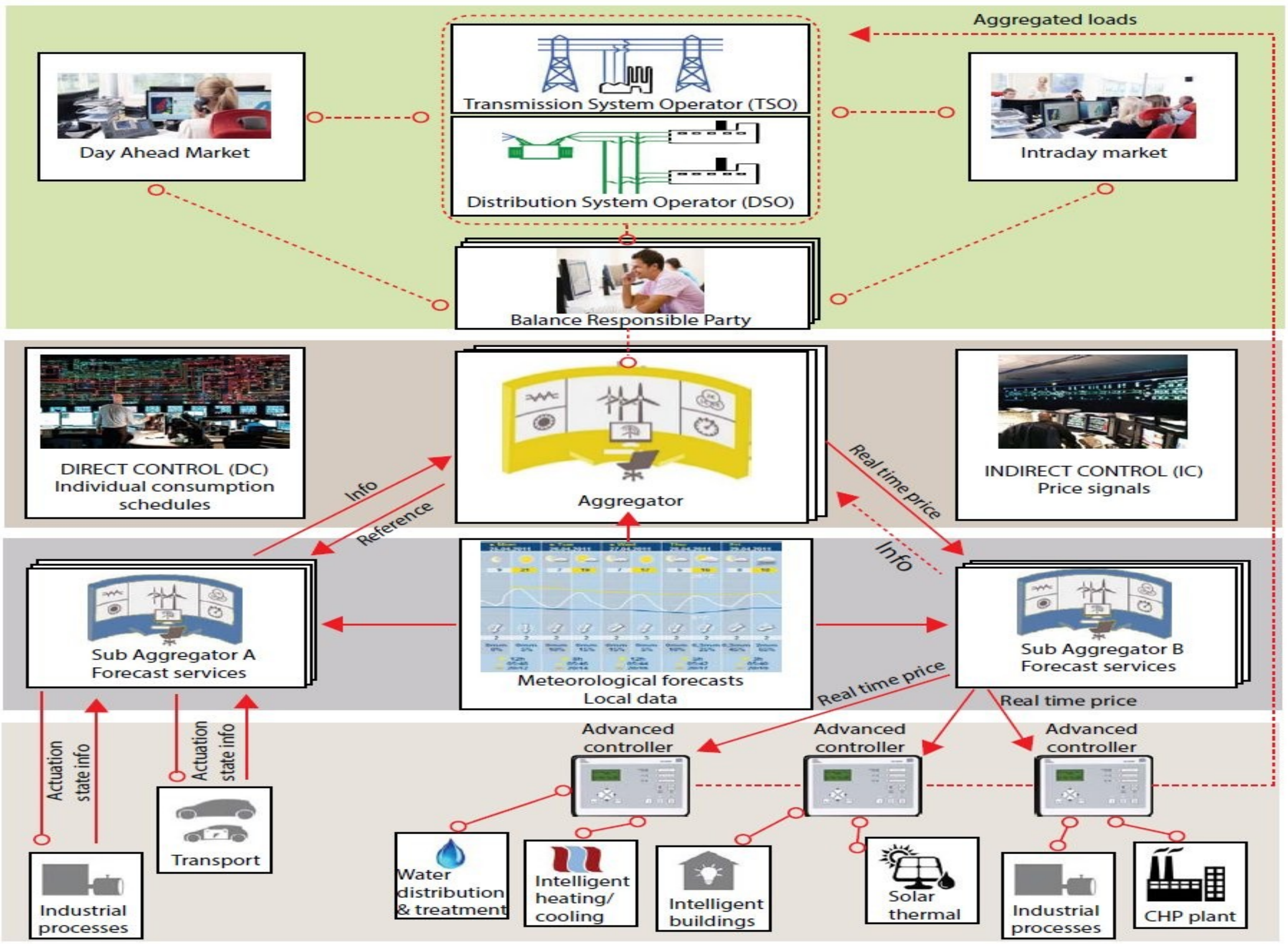
it is possible to develop advanced bidding strategies which exploit the inclusion of the dynamics in the model

stochastic control theory allows for taking into account different sources of uncertainty (wind, ...)

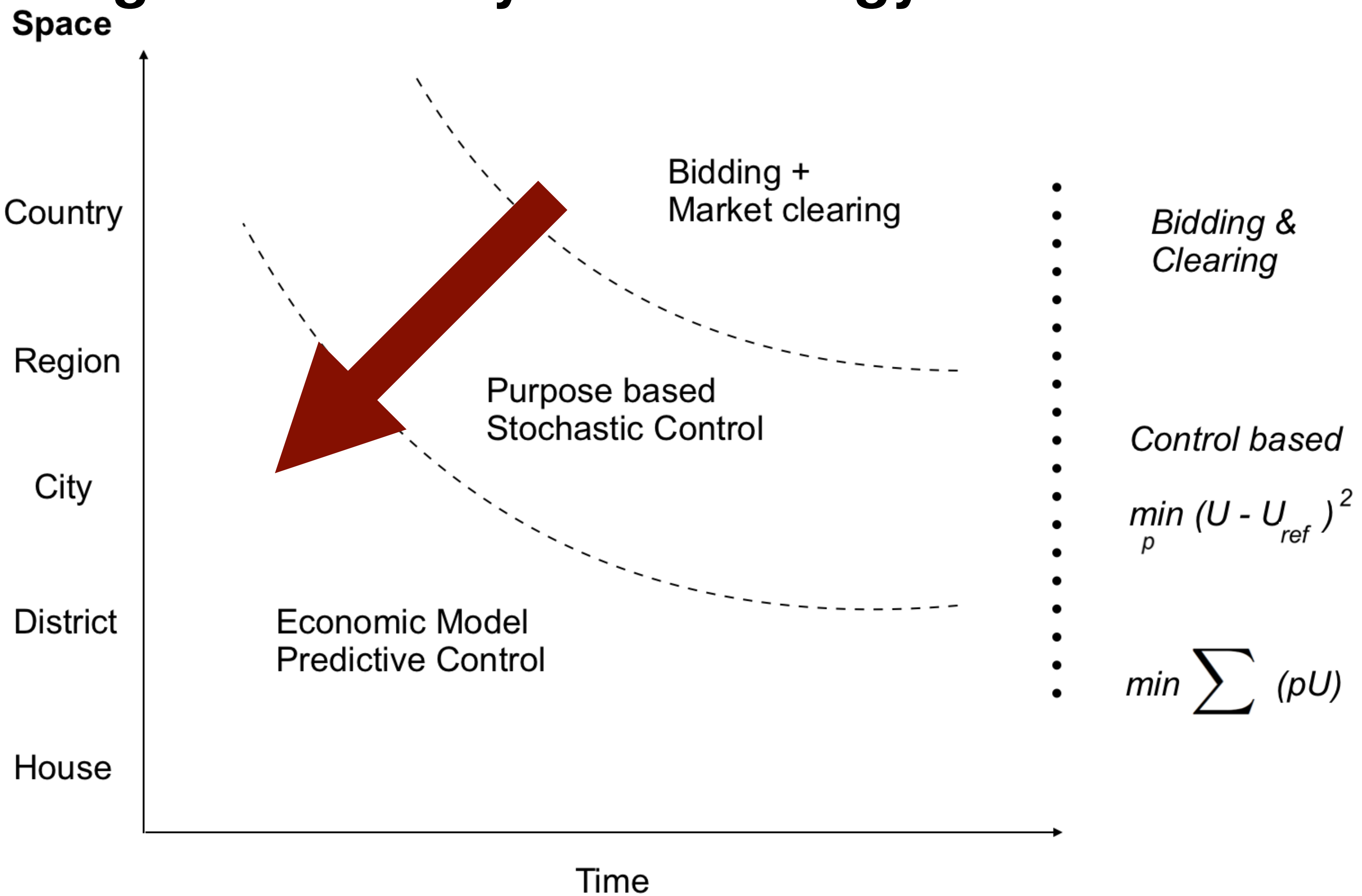
↓

it is possible to develop bidding strategies which are optimal with respect to the stochastic characteristics of the market

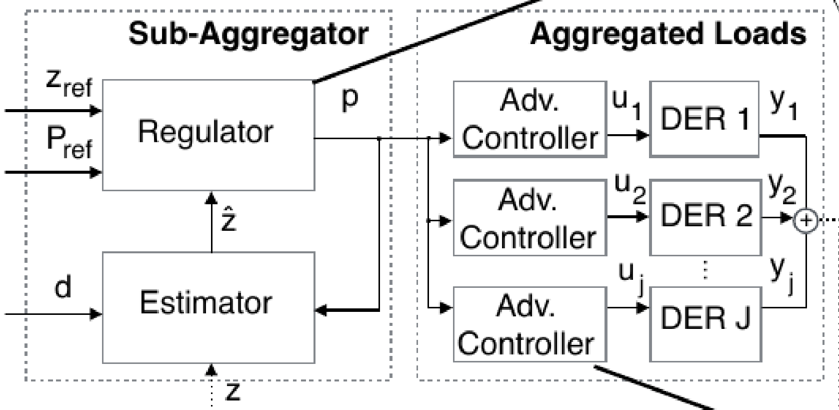
Smart-Energy OS



Digitized and Dynamic Energy Markets



Proposed methodology
Control-based methodology

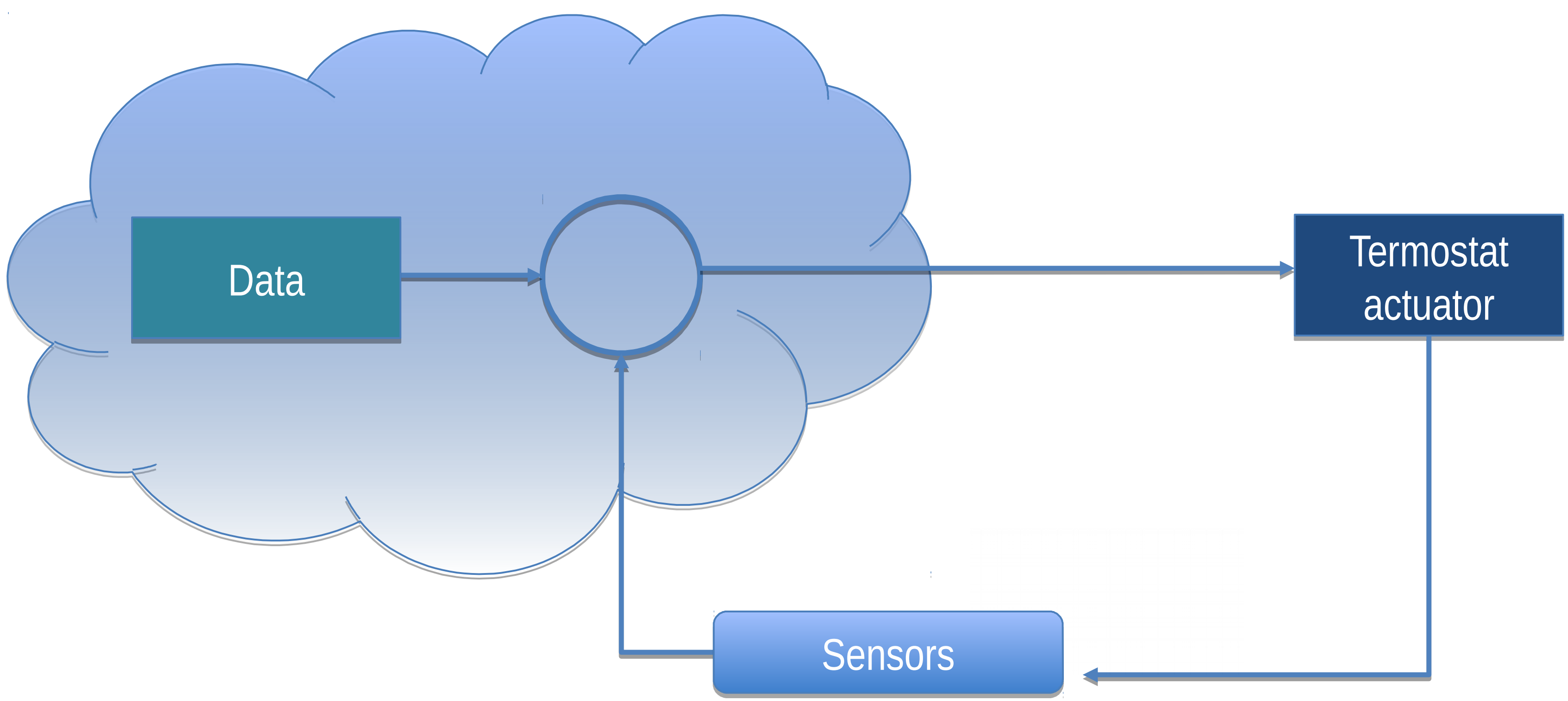


$$\min_{p} \quad \mathrm{E}\Big[\sum_{k=0}^{N} w_{j,k}||\hat{z}_k - z_{ref,k}|| + \mu||p_k - p_{ref,k}||\Big]$$
$$\text{s.t.} \quad \hat{z}_{k+1} = f(p_k)$$

$$\min_{u} \quad \mathrm{E}\Big[\sum_{k=0}^{N}\sum_{j=1}^{J} \phi_j(x_{j,k}, u_{j,k}, p_k)\Big]$$
$$\begin{aligned} \text{s.t.} \quad x_{k+1} &= Ax_k + Bu_k + Ed_k, \\ y_k &= Cx_k, \\ y_k^{min} \leq y_k &\leq y_k^{max}, \\ u_k^{min} \leq u_k &\leq u_k^{max} \end{aligned}$$

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

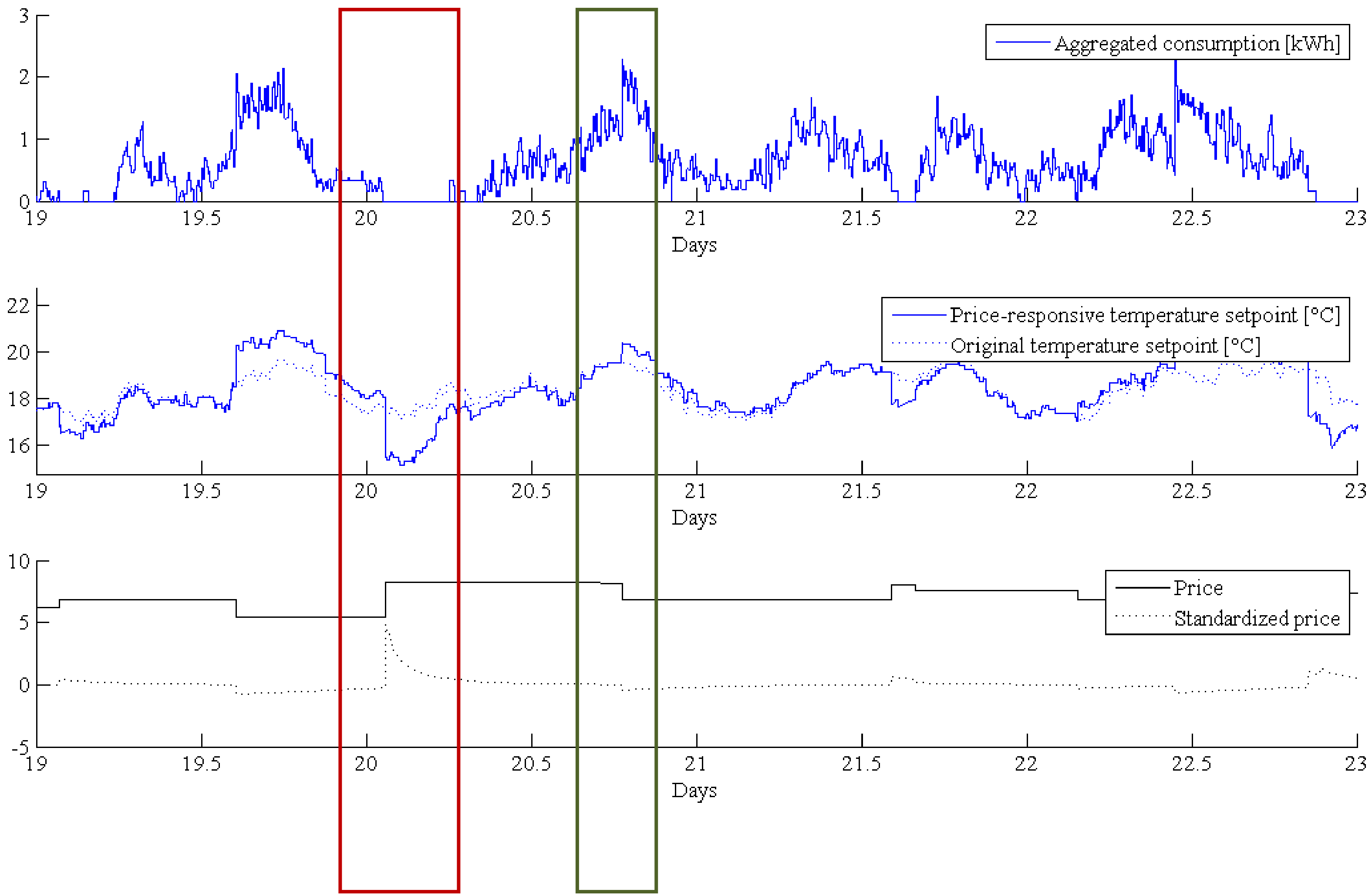
SE-OS – Low level controllers
Control loop design – logical drawing



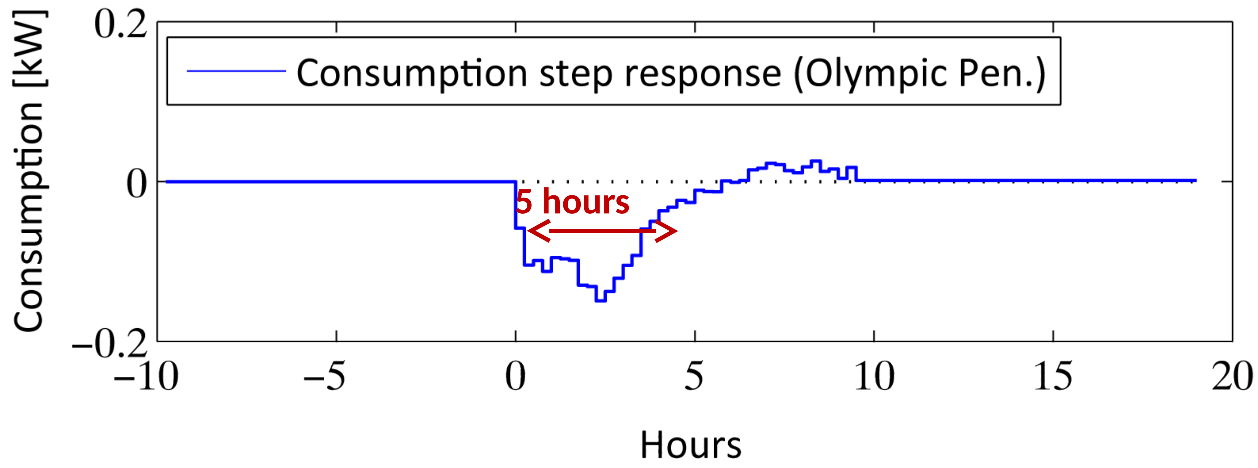
Case study No. 1

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

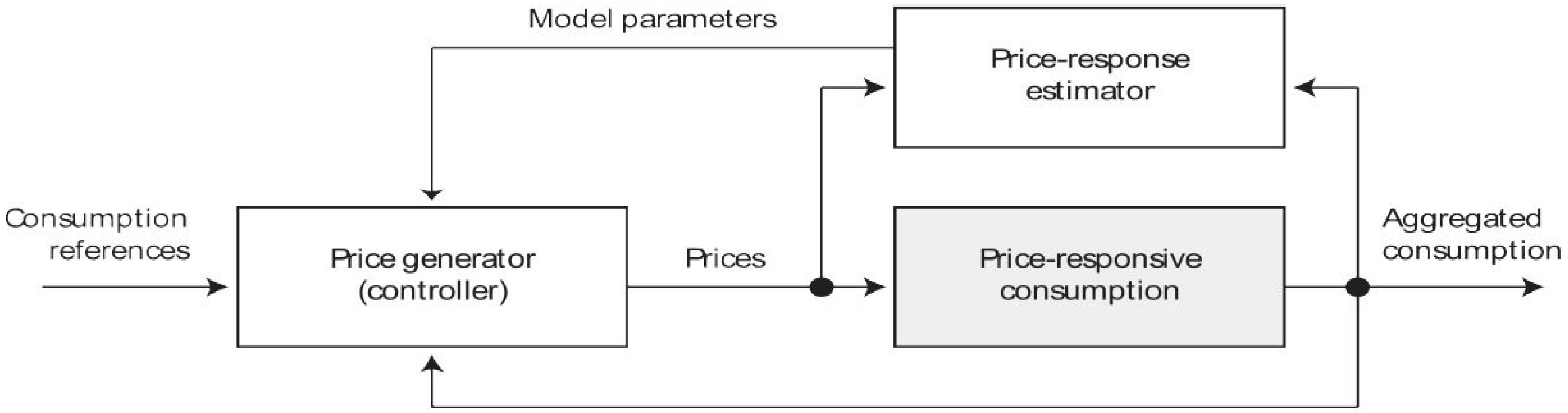
Aggregation (over 20 houses)

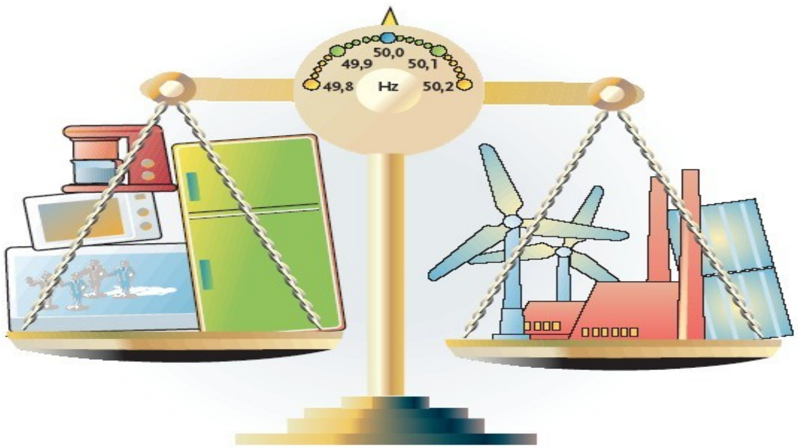


Response on
Price Step Change



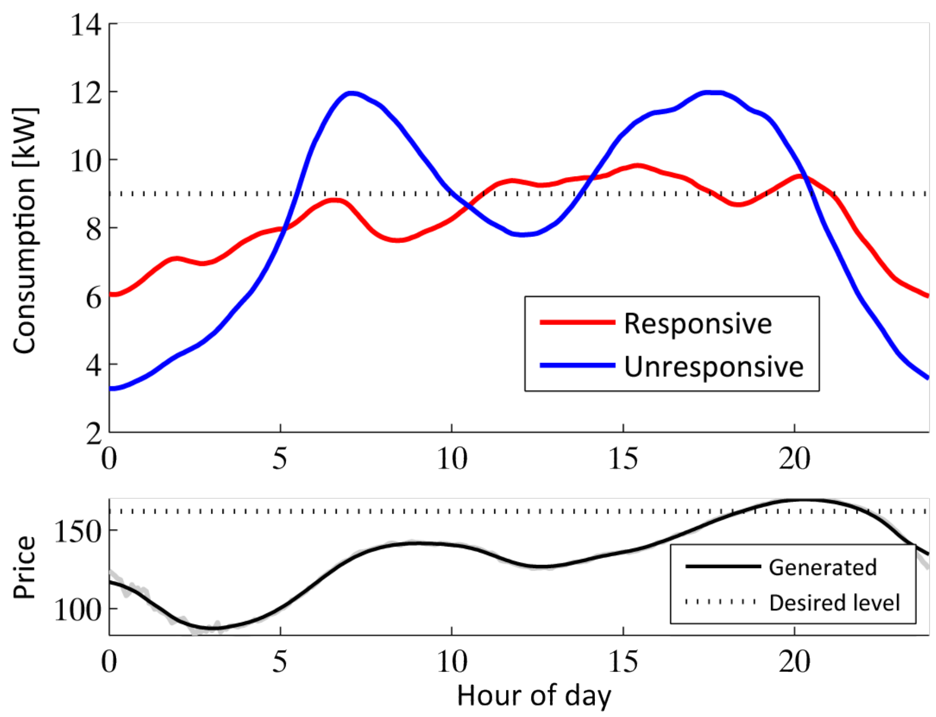
Control of Energy Consumption





Control performance

Considerable **reduction in peak consumption**
Mean daily consumption shift



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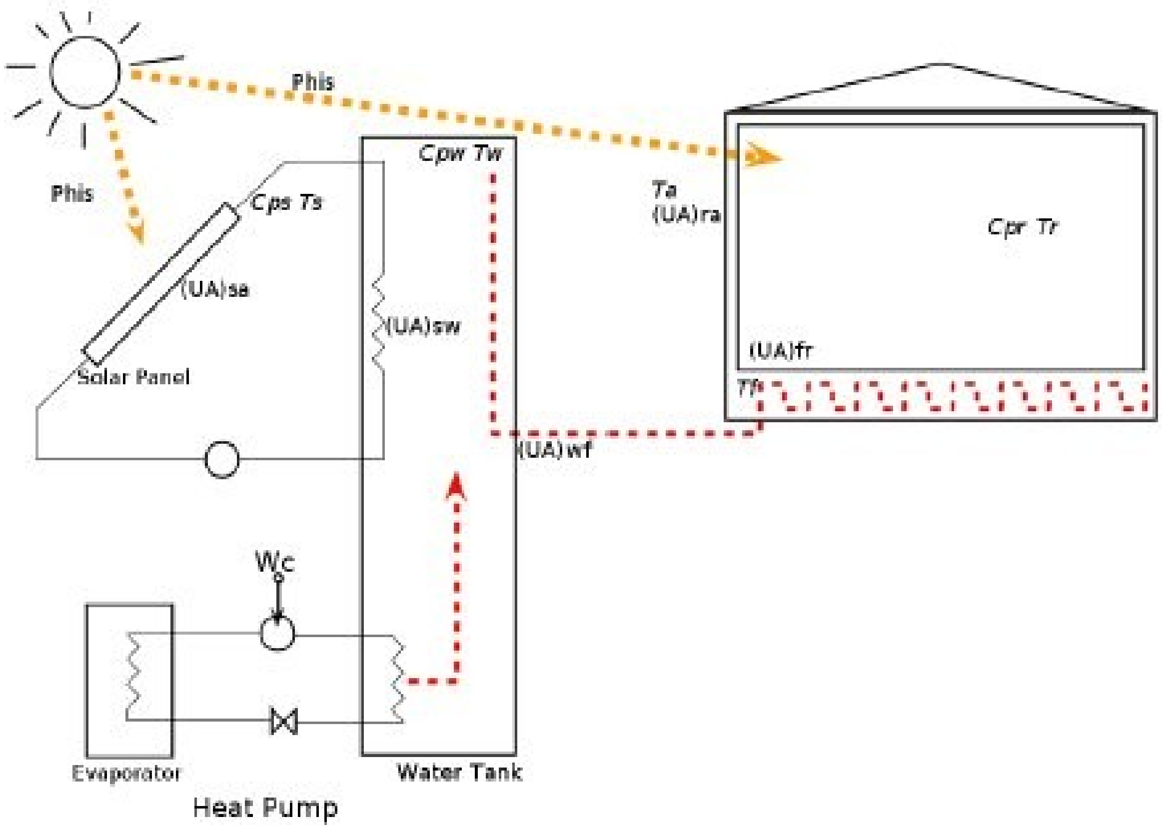
Case study No. 2

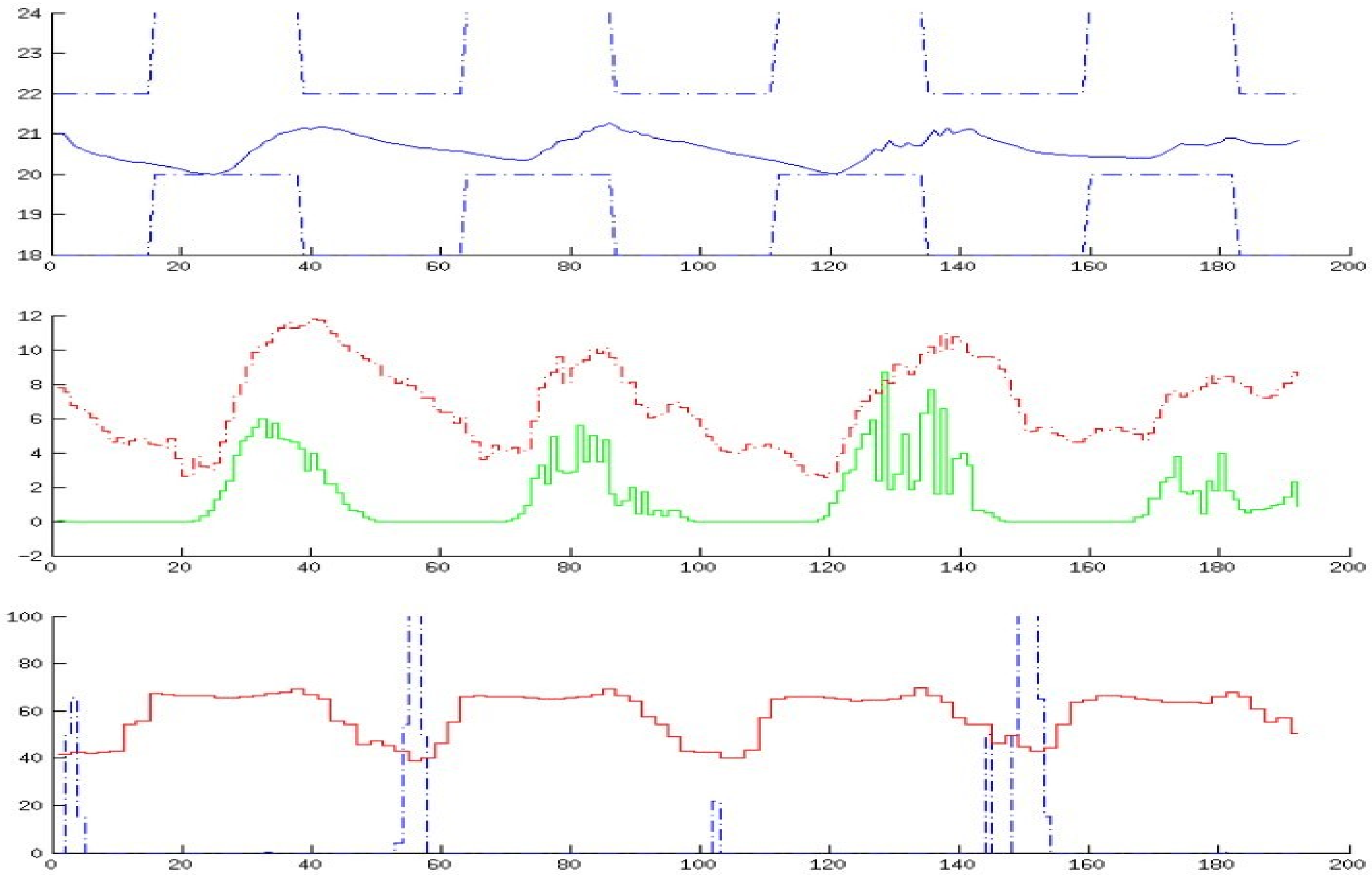
Control of Heat Pumps for buildings with a thermal solar collector (minimizing cost)

Modeling Heat Pump and Solar Collector

Simplified System



EMPC for heat pump with solar collector (savings 20 pct; + 4 pct)



Case study No. 3

Control of heat pumps for swimming pools (CO_2 minimization)

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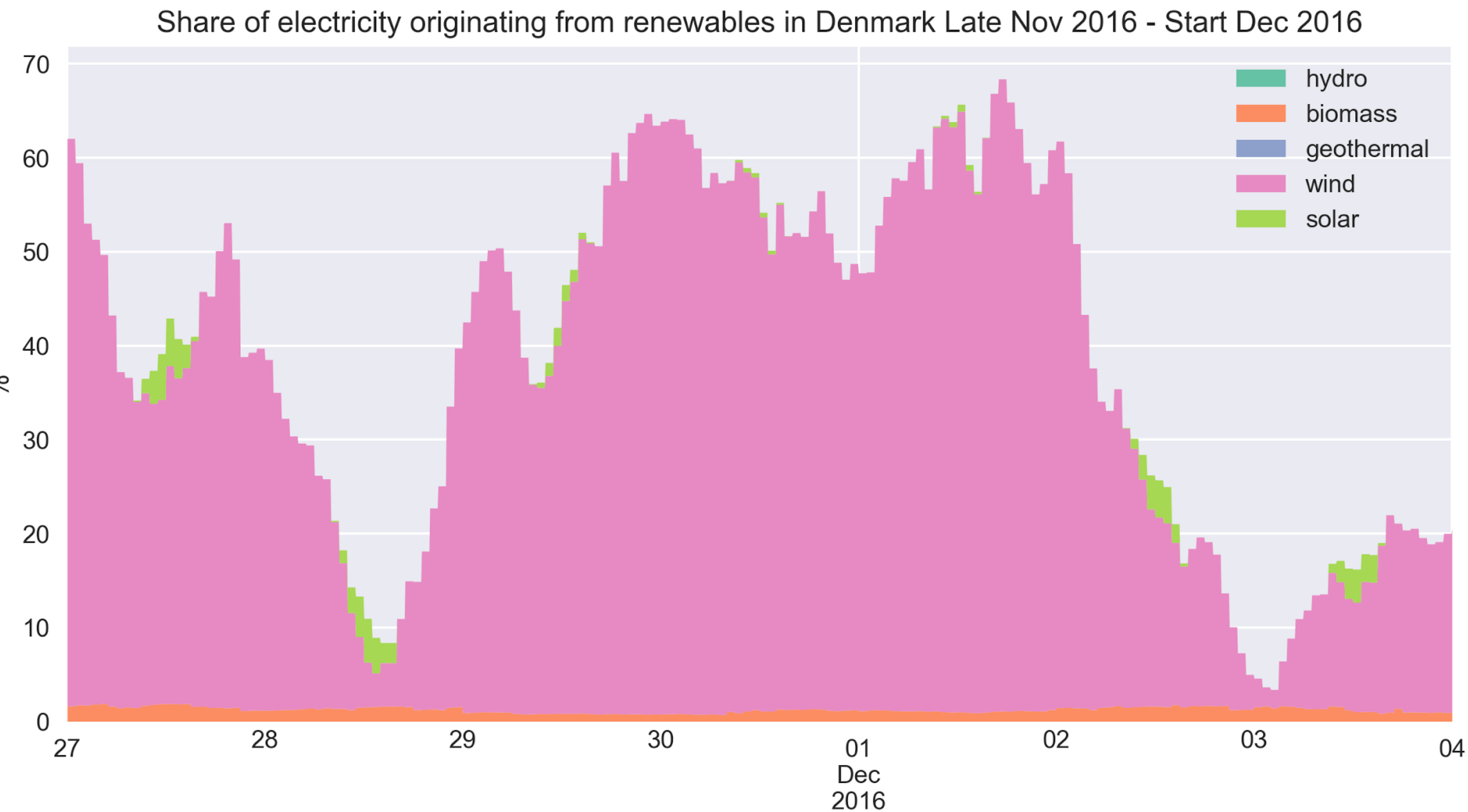


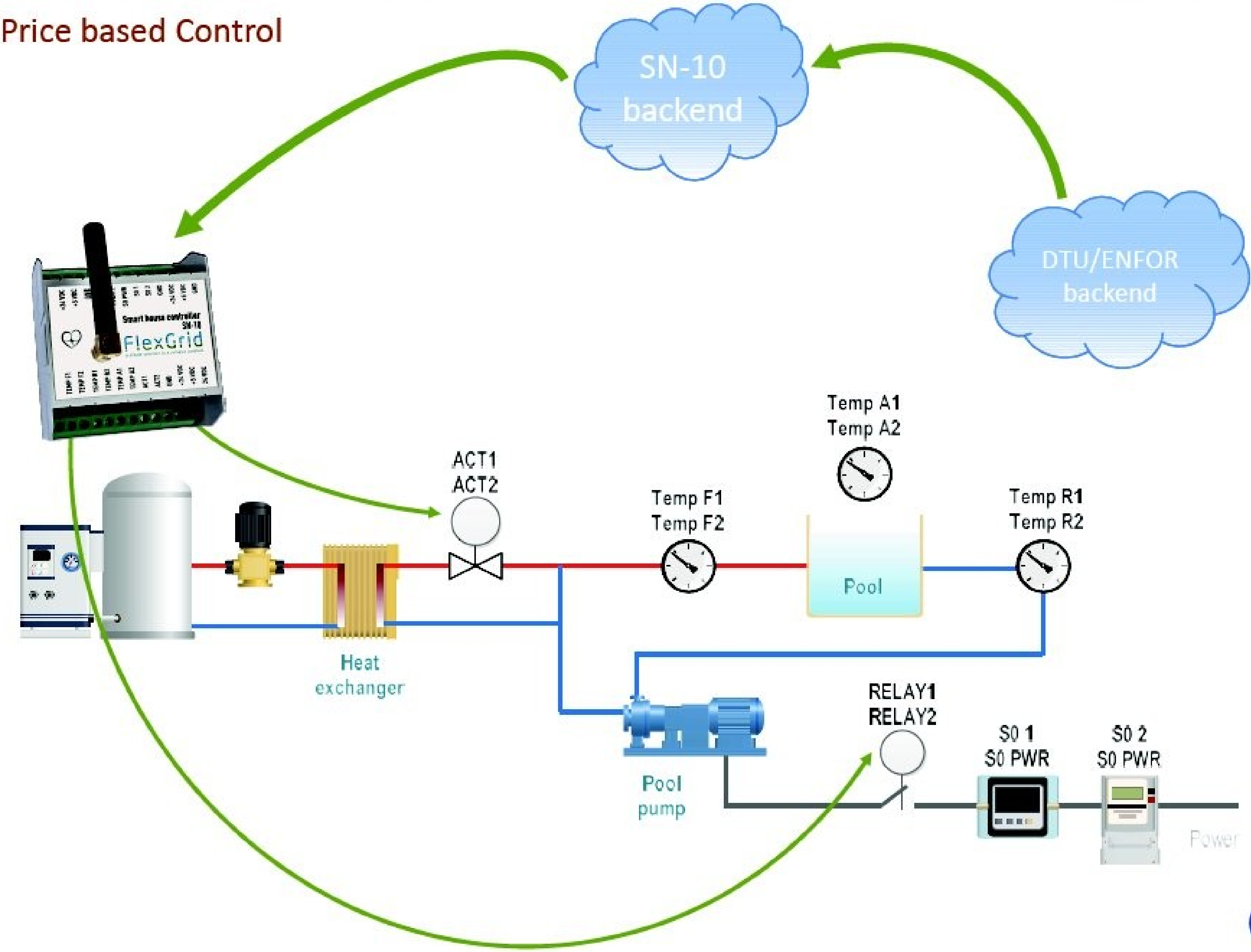
Source: pro.electicitymap.

CITIES
Centre for IT Intelligent Energy Systems

SmartNet

How does it work?

Price based Control



Example: CO_2-based control (savings 15 pct)

Flexibility Setup and Control

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Characteristics

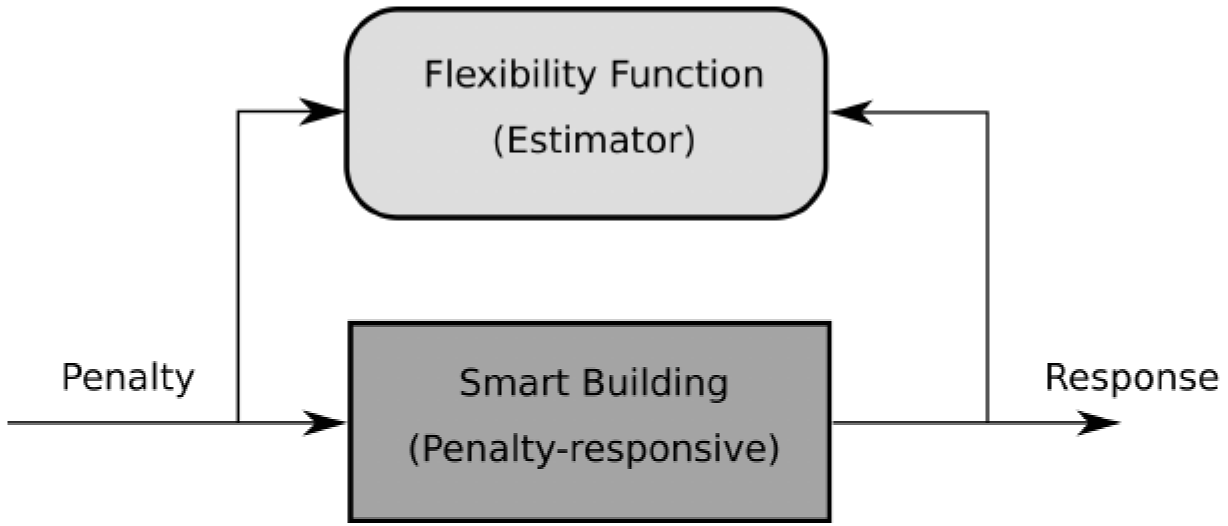


Figure 1: A smart building is able to respond to a penalty or external control signal.

Flexibility Function

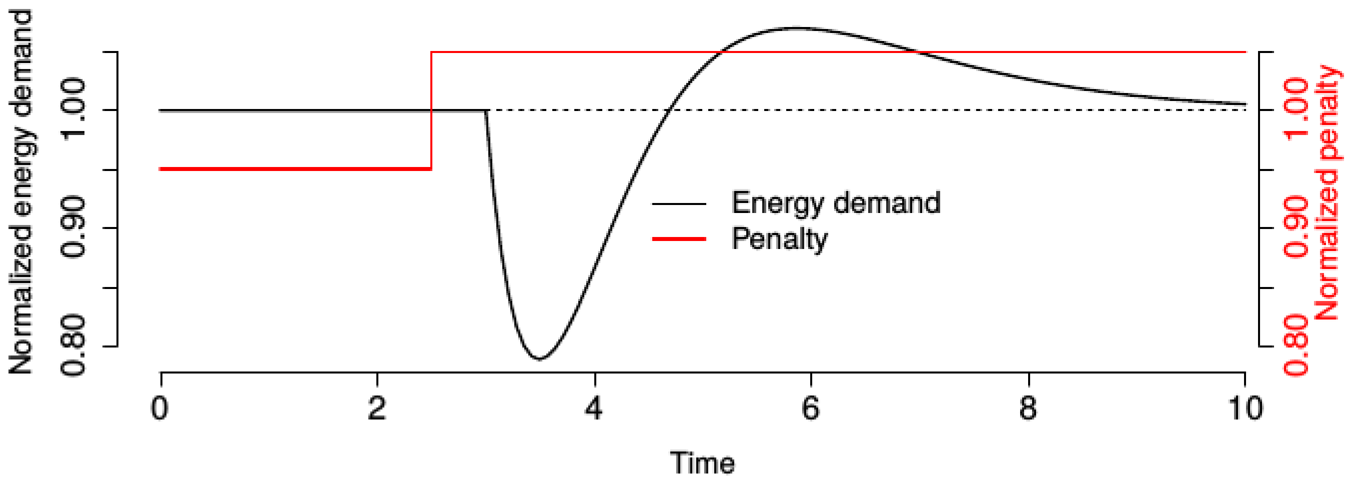


Figure 2: The energy consumption before and after an increase in penalty. The red line shows the normalized penalty while the black line shows the normalized energy consumption. The time scale could be very short with the units being seconds or longer with units of hours. At time 2.5 the penalty is increased,

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*.

Smart Grid Application

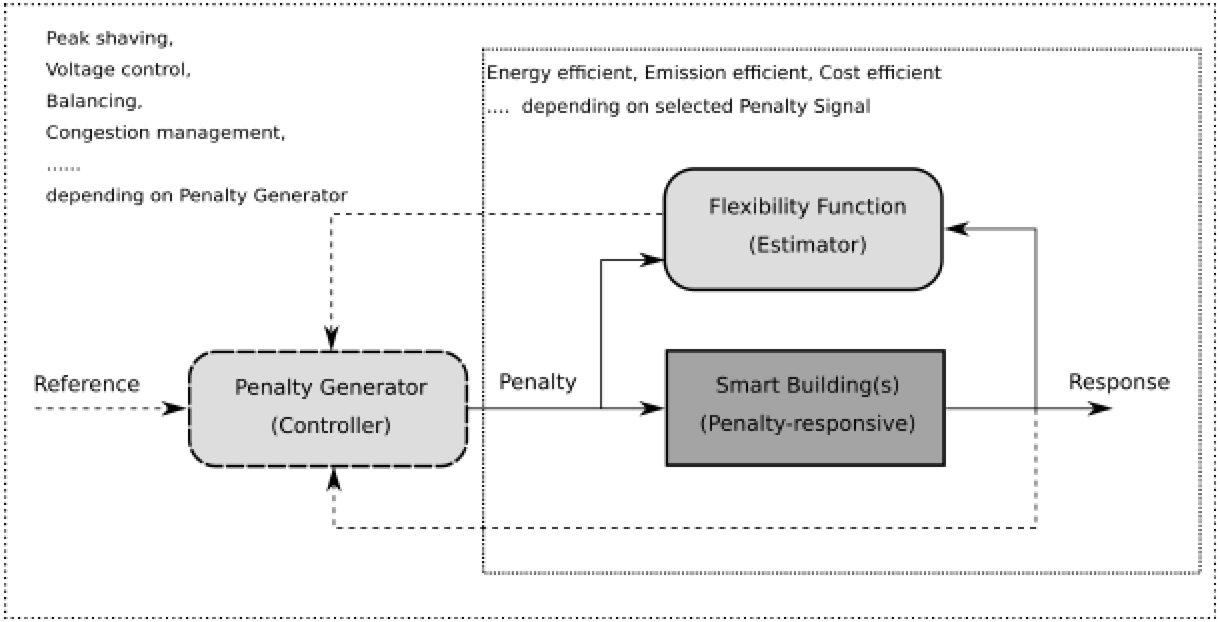


Figure 8: Smart buildings and penalty signals.

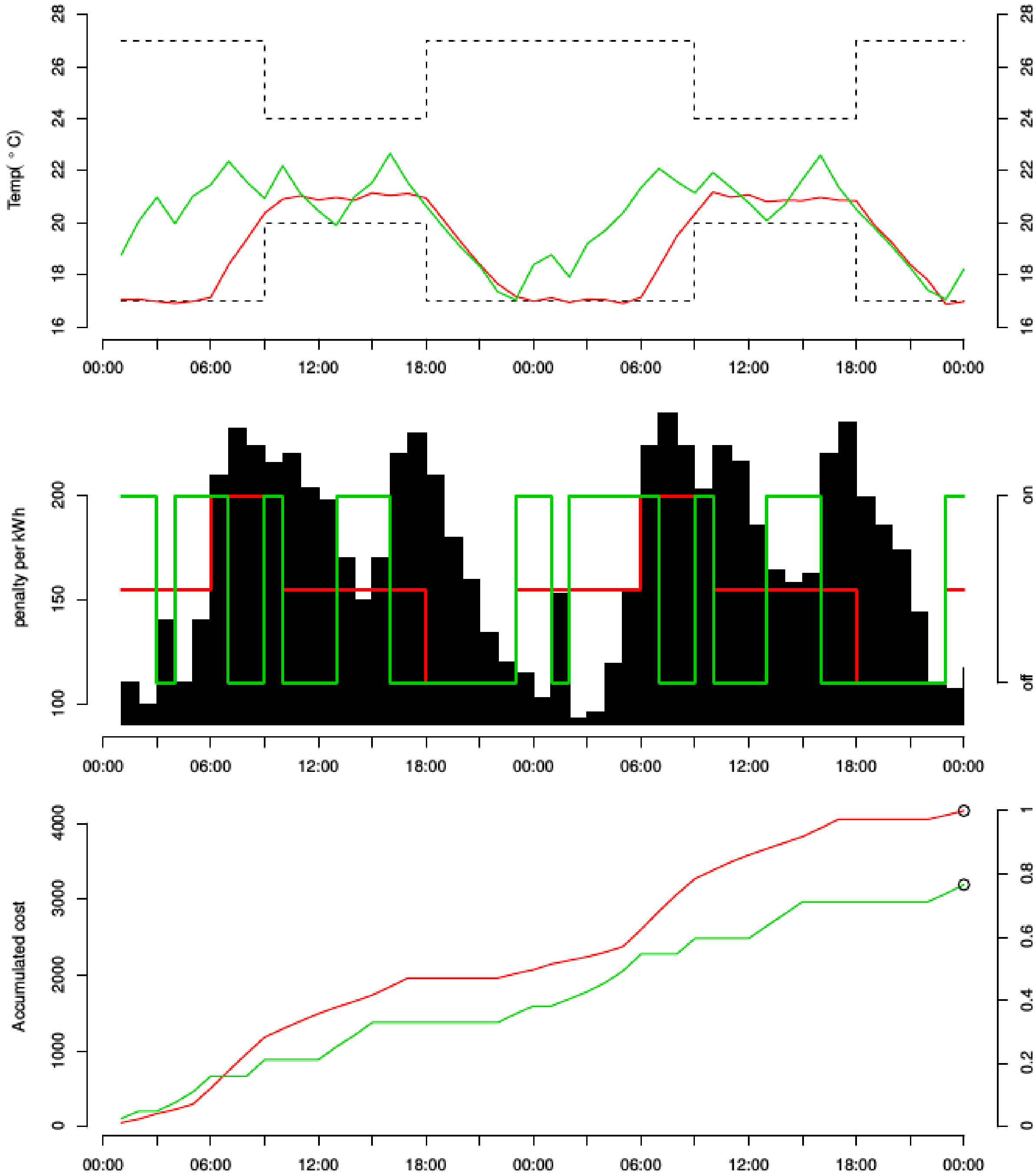
Procedure for calc. Flex. Index

for energy, price and emission based flexibility char.

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.


Temp(° C)
16 18 20 22 24 26 28
penalty per kWh
100 150 200
on
off
Accumulated cost
0 1000 2000 3000 4000
0 0.2 0.4 0.6 0.8 1
00:00 06:00 12:00 18:00 00:00 06:00 12:00 18:00 00:00

FF for three buildings

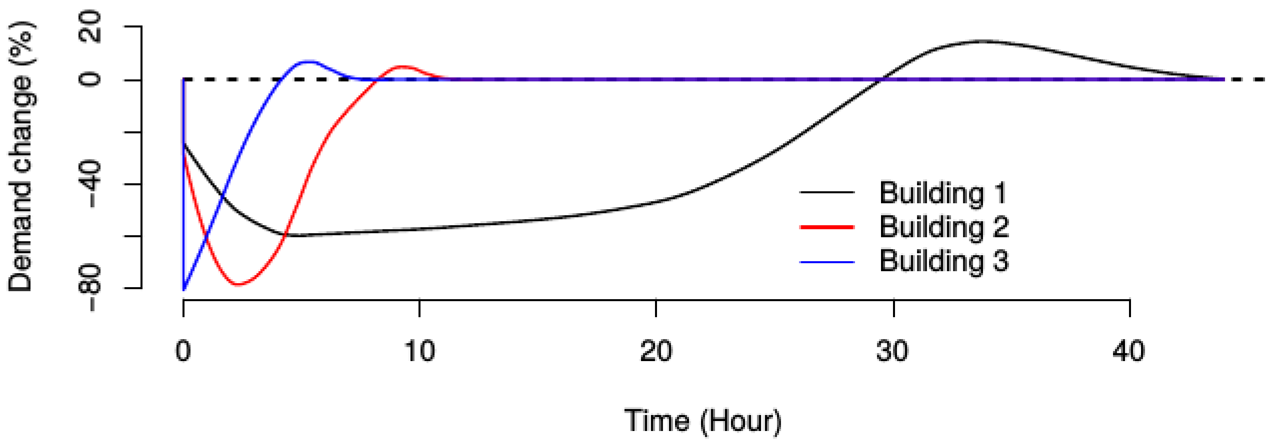


Figure 5: The Flexibility Function for three different buildings.

Realistic Penalties for DK

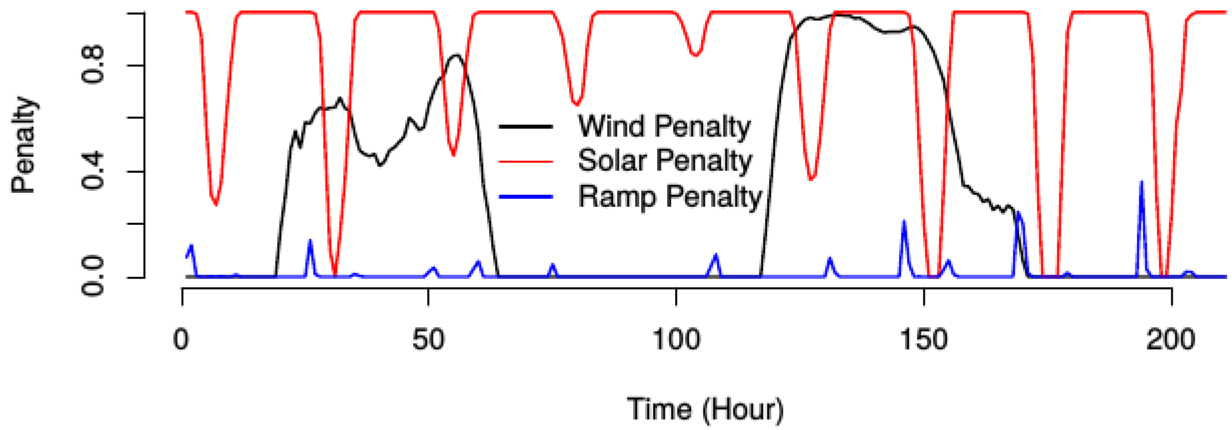


Figure 6: Penalty signals based on wind and solar power production in Denmark during some days in 2017.

Expected Flexibility Savings Index

Table 1: Expected Flexibility Savings Index (EFSI) for each of the buildings based on wind, solar and ramp penalty signals.

	Wind (%)	Solar (%)	Ramp (%)
Building 1	11.8	3.6	1.0
Building 2	4.4	14.5	5.0
Building 3	6.0	10.0	18.4

Reference Penalties

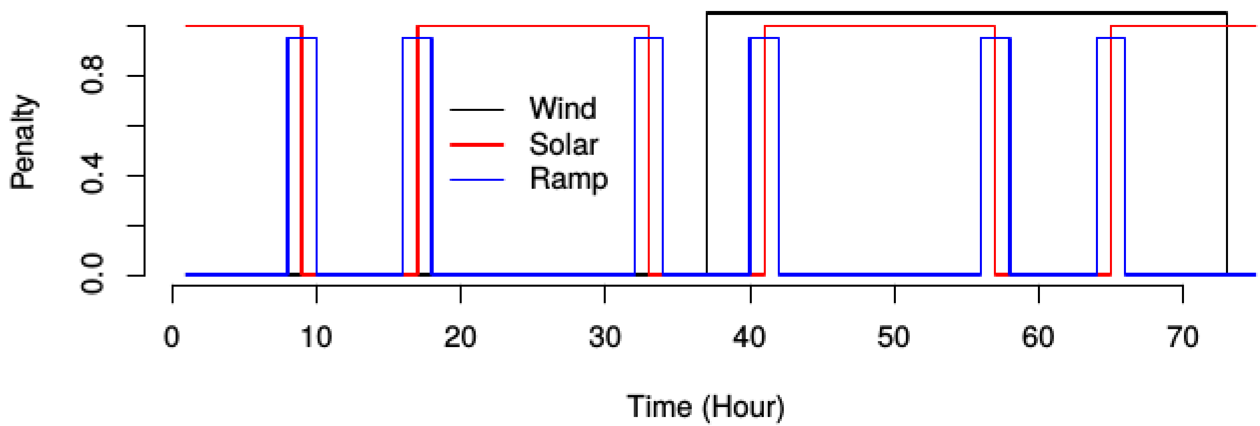


Figure 7: Reference scenarios of penalty signals related to ramping or peak issues as well as the integration of wind and solar power.

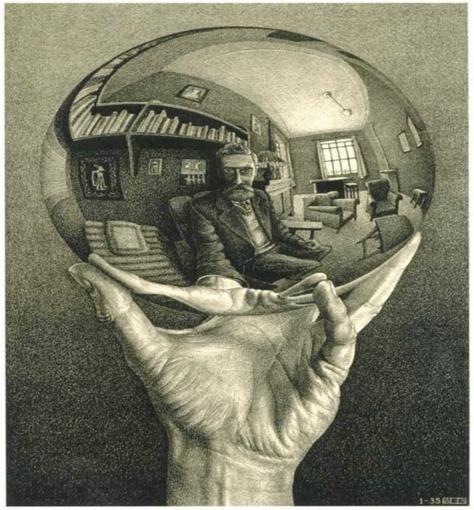
Flexibility Index

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

Understanding Energy Flexibility
Some Demo Projects in CITIES:

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



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Summary

- A Flexibility Function is suggested for describing the energy flexibility
- Using our SE-OS with FF-based control we have seen large potentials for Demand Response. Automatic solutions are important.
- A Flexibility Index (FI) for buildings (peak, solar, wind, ...) is suggested; can be used for an optimal design of buildings depending on climate zone etc.
- Procedure for data intelligent control of the electricity load is suggested
- The controllers can provide
  - Energy Efficiency
  - Cost Minimization
  - Emission Efficiency
  - Peak Shaving
  - Smart Grid demand (like ancillary services needs, ...)

We see large problems with the tax and tariff structures in many countries (eg. Denmark; we will suggest a new design of taxes and tariffs)

Summary

- We need to put more focus on energy efficiency – but using meter data (which is now possible)
- Methods for automatic energy labelling and characterization are suggested
- Procedures for data intelligent control of power load are also suggested.
- The controllers can provide
  - Energy Efficiency
  - Cost Minimization
  - Emission Efficiency
  - Peak Shaving
  - Smart Grid demand (like ancillary services needs, …)
- We have demonstrated a large potential in Demand Response. Automatic solutions, and end-user focus are important
- We see large problems with the tax and tariff structures in many countries (eg. Denmark; we are working on a new design of taxes and tariffs.

For more information ...

See for instance

www.smart-cities-centre.org

...or contact

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Acknowledgement - DSF 1305-00027B