Methodologies for Integrating Energy Flexible Buildings and Districts into the Future Smart Grid

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https://smartcitiesaccelerator.eu
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•Quote by B. Obama at the Climate Summit 2014 in New York:
  
  •We are the **first generation** affected by climate changes, and we are the **last generation** able to do something about it!
Challenges (example)

Preparatory study on Smart Appliances

Report: Almost no flexibility

We have seen the same conclusion in almost all previous Danish projects.

Project Summary

The Ecodesign Preparatory Study on Smart Appliances (Lot 33) has analyzed the technical, economic, market and societal aspects with a view to a broad introduction of smart appliances and to develop adequate EU standards and regulatory measures.

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

- Scope, standards and targets (Task 1, Chapter 2);
- 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.
FLECH concept
Interaction between DSO, TSO or BRP and Aggregator

**DSO**
- Planning: Generate load profiles
- Scheduling: Derive flexibility demand
- Operation: Update load schedule
- Settlement: Operate grid

**TSO**
- Planning: Estimate grid load flow
- Scheduling: Derive flexibility demand
- Operation: Update load schedule
- Settlement: Operate grid

**BRP**
- Planning: Generate load profiles
- Scheduling: Derive flexibility demand
- Operation: Update load schedule
- Settlement: Metering

**FLECH**
- Request
- Bid
- Contract
- Provision
- Payment

**Aggregator**
- Forecast flexibility
- Aggregate flexibility
- Dispatch plans and reserv.
- Operate plans and activation
- Settle flexibility

IDA Energi meeting, 08.11.16
Energy Systems Integration

Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales

Data Pathway: Information and communication technologies allow a better understanding and control of systems by linking sensor data from multiple locations to control centers.
Flexible Solutions and CITIES

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

CITIES is currently the largest Smart Cities and ESI research project in Denmark – see http://www.smart-cities-centre.org.
The central hypothesis in CITIES is that by intelligently integrating currently distinct energy flows (heat, power, gas and biomass) using grey-box models we can balance very large shares of renewables, and consequently obtain substantial reductions in CO2 emissions in Smart Cities.

Intelligent integration will (for instance) enable lossless ‘virtual’ storage on a number of different time scales.
CITIES goals

To establish methodologies and solutions for design and operation of integrated electrical, thermal, fuel pathways at all scales in Smart Cities.
# Slow approach, but we are sure things get done

Try to parallelize anyway

```r
require(multicore)
numcores <- multicore:::detectCores()
mclapply(1:N,
  function(i, data) {
    print(paste(i, "/", N))
    # Find the indices of rows corresponding to
    j <- which(data$dt_agg %in% aggdata$dt[i])
    # Filter out those who are NA
    j <- j[!is.na(data$last_one_min_power[j])]
    # Count number of readings
    aggdata$num_readings[i] <- length(j)
  }
```

```
Lab testing ....
SE-OS
Control loop design – logical drawing
SN-10 Smart House Prototype
Case study No. 1

Control of Power Consumption using the Thermal Mass of Buildings (Peak shaving)
Aggregation (over 20 houses)
Non-parametric Response on Price Step Change

Olympic Peninsula

![Graph showing consumption step response on Olympic Peninsula with a drop and recovery over 5 hours.](image)
Control of Energy Consumption

Diagram:

- Consumption references
- Price generator (controller)
- Model parameters
- Price-response estimator
- Prices
- Price-responsive consumption
- Aggregated consumption

Visual: A scale with high and low consumption, representing the balance of energy consumption.
Control performance

Considerable **reduction in peak consumption**

Mean daily consumption shift

![Graph showing consumption and price changes with responsive and unresponsive scenarios.](image)
Case study No. 2

Control of Heat Pumps for buildings with a thermal solar collector (minimizing cost)
Grundfos Case Study
Schematic of the heating system
Modeling Heat Pump and Solar Collector
Simplified System
Advanced Controller
Economic Model Predictive Control

Formulation

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

\[
\min_{\{u_k\}_{k=0}^{N-1}} \phi = \sum_{k=0}^{N-1} c' u_k
\]

Subject to

\[
x_{k+1} = A x_k + B u_k + E d_k \quad k = 0, 1, \ldots, N - 1
\]
\[
y_k = C x_k \quad k = 1, 2, \ldots, N
\]
\[
u_{\min} \leq u_k \leq u_{\max} \quad k = 0, 1, \ldots, N - 1
\]
\[
\Delta u_{\min} \leq \Delta u_k \leq \Delta u_{\max} \quad k = 0, 1, \ldots, N - 1
\]
\[
y_{\min} \leq y_k \leq y_{\max} \quad k = 0, 1, \ldots, N
\]
EMPC for heat pump with solar collector (savings 35 pct)
Case study No. 3

Control of heat pumps for swimming pools (CO2 minimization)
How does it work?

Price based Control

SN-10 backend

DTU/ENFOR backend

FlexGrid

Heat exchanger

Pool pump

Pool

Temp A1
Temp A2

Temp F1
Temp F2

Temp R1
Temp R2

ACT1
ACT2

RELAY1
RELAY2

S0 1
S0 0 PWR

S0 2
S0 0 PWR

Power
Example: CO2-based control
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.
Some Smart Cities Collaborators
Oslo Municipality: Furuset

The project will include building upgrades and new builds, a smart thermal micro-grid and both public and private actors.
Media

For media inquiries, use our contact form for fastest response. If you are writing about our Youth-Led Tech program, contact Interim Executive Director Kyla Williams at (312) 565-2933 or kwilliams@cct.org

Here’s the Smart Chicago logo in jpg and eps formats.

The name of the organization is “Smart Chicago Collaborative” (“Smart Chicago” for short). It’s never abbreviated to “SCC”.

Here are hundreds of photos of the work we do: Civic User Testing Group, OpenGov Chicago meetups, Connect Chicago meetups, hackathons, and #CivicSummer. All of these photos are licensed as Creative Commons—free for you to use for any purpose, with attribution.
The Western Harbour

Welcome to Malmö’s most sustainable district!

Hållbarhet is located in the heart of the Western Harbour, which – thanks to our smart energy solutions and residents – has been a sustainable district for over a decade now. From Hållbarhet we take our next leap – into the future.
A new neighbourhood that will include approximately 1000 homes will be developed over a 10-15 year period. A school and kindergarten will be built in the neighbourhood. Elverum tomteselskap is the property owner. Plans for the area include the extensive use of wood, and smart mobility.
Test i et mini samfund beliggende på 40 Hektar naturgrund
- Test i et fungerende driftsmiljø bestående af mange forskellige typer bygninger

Ældre bygninger:
1. Møllen: Urban Farming
   1. Bygning 228 m²
   2. Bygning 590 m²
   3. Bygning 290 m²
   4. Bygning 230 m²
   5. Bygning 155 m²
2. Privathus, 183 m²
3. Privathus, 153 m²
4. Privathus, 166 m²
5. Gård 140 m²
6. Gård 4-længer 231 m²
7. Rækkehus 140 m²
8. Rækkehus 130 m²
9. Depot 140 m²
10. Kontor 110 m²
11. Lager 450 m²
12. Erhverv produktion 450 m²
13. Privat hus 160 m²
14. Vingården 110 m²
   1. Erhverv 70 m²
   2. Produktion Vin 25 m²
   3. Kølerum 5 m²
   4. Klimarum kaffe 10 m²
15. Shelter 60 m²

Nye bygninger:
1. Smart City 2030
   1. Urban Farming
   2. Rækkehus
   3. Parcel huse
   4. Kollegi værelser
   5. Undervisningsbygning
   6. Laboratorier
2. Center Danmark 4800 m²
3. Ny Gudsgård 2600 m²
   1. Privat hus 280 m²
   2. Erhverv 280 m²
   3. Stald 280 m²
   4. Ridehal 1700 m²
   5. Produktion Gødning

Lyngby-Taarbæk Vidensby, November 2017
A procedure for data intelligent control of power load, using the Smart-Energy OS (SE-OS) setup, is suggested.

- Built on ICT solutions, Cloud Computing, Edge Computing, IoT, IoS, DMS, Forecasting and Control
- Energy communities, Blockchain, Transactive Energy, Agents
- 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. Automatic solutions, and end-user focus are important.

We see large problems with the tax and tariff structures in many countries (eg. Denmark).
For more information ...

See for instance

www.smart-cities-centre.org

...or contact

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Further Aspects
Some references


Some references (cont.)


Some 'randomly picked' books on modeling ....
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
Understanding 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, ...)

.............
Figure 4: Six characteristics of the demand response to a step increase in electricity price. \(\tau\): The delay from adjusting the electricity prize and seeing an effect on the electricity demand, equal to approximately 0.5 here. \(\Delta\): The maximum change in demand following the price change, in this case close to 0.2. \(\alpha\): The time it takes from the change in demand starts until it reaches the lowest level, approximately equal to 0.5 here. \(\beta\): 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.
Labelling proposal for energy, price and emission based labelling

The test consists of the following steps:

1. Let $\lambda_t$ be the price of electricity at time $t$.

2. Simulate the control of the building without considering the price, and let $u^0_t$ be the electricity consumption at time $t$.

3. Simulate the control of the building considering the price, and let $u^1_t$ be the electricity consumption at time $t$.

4. The total operation cost of the price-ignorant control is given by $C^0 = \sum_{t=0}^{N} \lambda_t u^0_t$.

5. Similarly the operation cost of the price-aware control is given by $C^1 = \sum_{t=0}^{N} \lambda_t u^1_t$.

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 $\lambda_t$ could just represent one's desire to reduce electricity demand at time $t$. 
Flexibility Represented by Saturation Curves
(for market integration using block bids)