Intelligent Energy Systems in Buildings

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Quote by B. Obama at the Climate Summit in New York in 2014:

We are the **first generation** affected by climate changes, 
and we are the **last generation** able to do something about it!
**Scenario:** We want to cover the world's entire need for power using wind power.

How large an area should be covered by wind turbines?
**Potentials and Challenges for renewable energy**

**Scenario:** We want to cover the world's entire need for power using wind power. How large an area should be covered by wind turbines?

**Conclusion:** Use intelligence ....

Calls for IT / Big Data / Smart Energy/Cities Solutions/ Data Intelligent and Integrated Energy Systems
Case Study No. 1
Thermal Performance Characterization of Buildings using (Smart) Meter Data
Example

Consequence of good or bad workmanship (theoretical value is $U=0.16\text{W/m}^2\text{K}$)
Model for the heat dynamics

Measurements:
- Indoor air temp
- Radiator heat sup.
- Ambient air temp
- Solar radiations

Hidden states are:
- Heat accumulated in the building
- $k$: Fraction of solar radiation entering the interior
## Results

<table>
<thead>
<tr>
<th>UA W/°C</th>
<th>$\sigma_{UA}$</th>
<th>$gA_{\text{max}}$ W</th>
<th>$wA_{E\text{max}}$ W/°C</th>
<th>$wA_{S\text{max}}$ W/°C</th>
<th>$wA_{W\text{max}}$ W/°C</th>
<th>$T_i$ °C</th>
<th>$\sigma_{T_i}$</th>
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<td>715.7</td>
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<td>657.7</td>
<td>41.4</td>
<td>29.4</td>
<td>16.5</td>
<td>21.0</td>
</tr>
</tbody>
</table>
Perspectives

- Identification of most problematic buildings
- Automatic energy labelling
- Recommendations:
  - Should they replace the windows?
  - Or put more insulation on the roof?
  - Or tighten the building?
  - Should the wall against north be further insulated?
  - ......
- Better control of the heat supply (.. see later on ..)
Perspectives (2)

"Skat, jeg kan se på k-værdierne, at vinduerne skal pudes"
Case study No. 2

Control of Power Consumption using the Thermal Mass of Buildings (Peak shaving)
Smart-Energy OS
SE-OS
Control loop design – **logical drawing**
Lab testing ....
SN-10 Smart House Gateway
Aggregation (over 20 houses)
Response on Price Step Change

Olympic Peninsula

![Graph showing consumption step response with 5 hours adjustment](image)
Control of Energy Consumption
Control performance

Considerable **reduction in peak consumption**
Mean daily consumption shift
Case study No. 3

Control of Heat Pumps
Summer Houses with a Swimming Pool
(CO2 minimization)
Live CO₂ emissions of the European electricity consumption

This shows in real-time where your electricity comes from and how much CO₂ was emitted to produce it.

We take into account electricity imports and exports between countries.

Tip: Click on a country to start exploring →

- Wind power potential (m/s) ±
  - 0  2  4  6  8  10  12  14

- Solar power potential (W/m²) ±
  - 0  50  100  150  200  250  300  350  400

Like the visualization? We would love to hear your feedback!

Found bugs or have ideas? Report them here.

This project is Open Source; contribute on GitHub.

All data sources and model explanations can be found here.

Share: 24K, Tweet, Slack

A PROJECT BY
Tomorrow

Cities
Centre for IT Intelligent Energy Systems

Green Tech Center, Vejle - June 2018
Share of electricity originating from renewables in Denmark Late Nov 2016 - Start Dec 2016

Source: pro.electricitymap.org
How does it work?

Price based Control

SN-10 backend

DTU/ENFOR backend

SmartNet
Example: Price-based control
Example: CO2-based control
(40 pct less CO2 emission – 5 pct higher energy consumption)
Flexibility Function and Flexibility Index
Applied for Buildings and Districts
Flexibility Function (FF)

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,

Equivalent to: Impulse response, transfer function, and frequency response
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*. 
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.

<table>
<thead>
<tr>
<th></th>
<th>Wind (%)</th>
<th>Solar (%)</th>
<th>Ramp (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building 1</td>
<td>36.9</td>
<td>10.9</td>
<td>5.2</td>
</tr>
<tr>
<td>Building 2</td>
<td>7.2</td>
<td>24.0</td>
<td>11.1</td>
</tr>
<tr>
<td>Building 3</td>
<td>17.9</td>
<td>35.6</td>
<td>67.5</td>
</tr>
</tbody>
</table>
Summary

- A Smart-Energy OS for data intelligent control of energy systems in buildings is suggested.

- The controller 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

- CO2-based control can be used to accelerate the green transition

- The concepts of a Flexibility Function and Flexibility Index for Smart Buildings and Districts are defined