Energy Flexible Buildings

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Department of Civil Engineering
Need for Flexibility

The future energy system will be characterized by a significant penetration of renewable energy:

- Challenge for the stability of the system, as both the production and the consumption side would have fluctuating patterns.

- The concept of energy flexibility will be necessary in order for the consumption to match the production patterns.
Renewable Energy in the Danish Energy System

Wind power 42%

By Energinet.dk, last update in Sep. 2016


Gathered by: Rongling Li
The Danish Wind Power Case

... balancing of the power system

25% wind energy (West Denmark January 2008)

50% wind energy

Wind power covers the entire demand of electricity in 200 hours (West DK)

In the future wind power will exceed demand in more than 1,000 hours

Source: Henrik Madsen
For District Heating

- District heating companies also need flexibility
- They can avoid “turning on” a power plant in situations with peak heating demand – possibly saving on the need for fossil energy!
Most Buildings Have the Ability to Become Energy Flexible

Building thermal mass
Building energy systems

Gathered by: Rongling Li
Why Flexible Buildings?

The building sector is dominating in terms of energy demand:
In most European countries 32% of the total final energy use or 40% of the primary energy use are related to buildings.

→ Ideal platform to integrate **smart energy solutions** for the future.

Hypothesis:
*Buildings could provide energy flexibility to the system, thus facilitating the integration of a larger share of renewable energy.*

Interconnection of buildings with the energy network is crucial to form **energy hubs**.
Energy Flexibility in Buildings

Techniques:

- **Demand-Side Management (DSM)** → any activity adopted on the demand side that ultimately changes the utility’s system load profile

- **Demand Response (DR)** → a set of techniques to induce the customer to change their energy demand

- **Electric Load Management (ELM)** → any policy devised to manage a set of electric loads to obtain the desired goal, such as peak load reduction or energy usage optimization

[Benetti et al., 2015]

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**Demand-Side Management includes:**

- Reduce peak loads
- Shift load from on-peak to off-peak
- Increase the flexibility of the load
- Reduce energy consumption in general

[Müller et al., 2015]
Energy Flexibility in Buildings

Aspects:

- **Technical parameters of buildings:**
  - Thermal mass: Building thermal properties
  - HVAC: System characteristics
- **Occupants**
- **Micro-climate and other external influences**

**Storage in the thermal mass of the buildings:**

- Store energy during periods with high availability of RE
  - No additional CO₂
- No investments required for this method, apart from controllers

**Flexible users:**

- Informed and motivated users
- A building management system (BMS) will be extended with smart energy management.
Grid need and flexibility potential in buildings

District heating grid
- Reduction of peak load
- Reduction of heat generation costs
- Reduction of GHG emissions

Heat demand flexibility in buildings
- Building thermal mass
- Hot water storage tank
- Heat pump

Source: Rongling Li
User behaviour

Stochastic daily activities

- Occupancy
- Lighting
- Thermostat adjustment
- Use of white goods
  - Window opening
  - Blinds adjustment
  - etc.

Building performance simulation

- Occupancy
- Lighting
- Thermostat adjustment
- Use of white goods
  - Window opening
  - Blind adjustment
Categorization of heating energy flexibility for thermal flexibility integration

- Heat flexibility quantification for different building types
- Applicable indicator development
- Flexibility integration to district level
Example 1
Energy flexibility potential of building stock

- 11 archetypes of buildings
- Mainly built in 1950-1970s
- Heating cut-off experiment applied on a winter day with reduced solar radiation
- Pre-heating strategy up to 25°C for 4h was applied followed by heating cut-off

Source: Panagiota Gianniou
Energy flexibility potential of building stock

Findings

- Reduced energy flexibility potential: mean thermal autonomy duration after cut-off = 1 h
- Operative temperature falls below 10° C in some cases, which is indicative of poor building envelope and cold ambient temperatures
Building typologies
Types of Danish houses

Source: SBi 2012:04
# Categorization of Buildings for Heating Energy Flexibility

<table>
<thead>
<tr>
<th>Country</th>
<th>Region</th>
<th>Construction Year Class</th>
<th>Additional Classification</th>
<th>SFH</th>
<th>TH</th>
<th>MFH</th>
<th>AB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Denmark</strong></td>
<td>(Hele Danmark...)</td>
<td>1979 ... 1998</td>
<td>Generic (Standard)</td>
<td>DK.N.SFH.06.Gen</td>
<td>DK.N.TH.06.Gen</td>
<td>DK.N.AB.06.Gen</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DK.N.SFH.08.Gen</td>
<td>DK.N.TH.08.Gen</td>
<td>DK.N.AB.08.Gen</td>
<td></td>
</tr>
</tbody>
</table>

- **SFH**: Single Family House
- **TH**: Terraced House
- **MFH**: Multi Family House
- **AB**: Apartment Block

**Notes:**
- **AT.O.E.B.SUH.01**: AT.O.E.B.C Gen.01
- **AT.Bio.WP.B.WP.Gen.01**: AT...Gen.01

**Ventilation System:**
- **AT...Gen.01**: AT...Gen.01
Example 2 – more modern buildings

From EnergyLab Nordhavn
Project:
Case Terra Nova
Sensors in Structures to Study Flexibility with Thermal Mass
Scenario

- For the Danish District Heating system, the main goal to be achieved is to avoid the utilization of peak load boilers.

  → Scenario examined: When there is limited/no availability of RES, heat supply needs to stop at specific city districts for certain time intervals.

![Scenario Diagram]

Source:
Kyriaki Foteinaki
Methodology

Building simulation tool IDA ICE

- An apartment belongs to a multi-family house low-energy building
  - 81 m² area; 2.6 m height; North and South walls exposed to the ambient; East and West walls, floor and ceiling attached to similarly heated spaces.

- Connected to the DH system; Floor heating system
- Mechanical ventilation with heat recovery
- Low Infiltration
Objective

• The purpose of the study is to identify the effect of such a stop on an apartment.
  – Focus on impact of thermal mass on the apartment’s thermal behaviour.
  – Key parameter is the duration of preheating period before the stop, in order to maintain thermal comfort.
Results

Day #6 to #8 [h]

Temperature [°C]

Day #6 [h]

Temperature [°C]

- Ceiling
- External Wall
- Internal Wall
- Oper. Temp.

Kyriaki Foteinaki
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Results
Results

<table>
<thead>
<tr>
<th>Basic case apartment</th>
<th>Preheating duration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 h</td>
</tr>
<tr>
<td>Max operative temperature difference during preheating [°C]</td>
<td>0.3</td>
</tr>
<tr>
<td>No. of hours operative temperature above 20°C [h]</td>
<td>8.3</td>
</tr>
</tbody>
</table>

**Need for Flexibility indicator**

- effect of thermal capacity of the internal walls on the load shifting potential
- effect of the heat losses of the building envelope on the load shifting potential

=> Time constant: > 800 hours
Building energy flexibility

Definition by **IEA EBC Annex 67 – Energy Flexible Buildings**

The Energy Flexibility of a building is the ability to manage its energy demand and generation according to **local climate conditions**, **user needs** and **grid requirements**.

*IEA EBC: International Energy Agency, Energy in Buildings and Communities Programme*
Consequences of Use of Flexible Heating Paradigms

Flexibility causes:
• Peak shaving
• Higher energy use
• Less use of fossil fuel in energy system
• May influence occupant comfort – is it acceptable?

• More research needed (Occupant <-> City Scale)

Thank you for your attention!