GRID INTERACTION OF TODAY’S BUILDINGS

Case studies from Germany

Peter Engelmann
Fraunhofer Institute for Solar Energy Systems ISE
Energy Flexible Buildings
Potential and Performance
Vienna, September 26th 2017
www.ise.fraunhofer.de
AGENDA

- Background: current situation and goals in Germany
- Grid interaction: methodology and assessment-system
- Grid interaction: present-day buildings
- Grid interaction: case study of grid-supportive potential
- Conclusion and outlook
AGENDA

- Background: current situation and goals in Germany
- Grid interaction: methodology and assessment-system
- Grid interaction: present-day buildings
- Grid interaction: case study of grid-supportive potential
- Conclusion and outlook
Background
pathway to energy supply based on renewables

Background
- Germany's goal: reduce CO₂ emissions ≥80% by the year 2050
- Two step approach:
  - Reduce demand
  - Increase use renewables

Upcoming challenges
- Increased variations in power generation
- Load and generation must balance at any time

Consequence
- More load flexibility will be required
- One option: grid-supportive building energy system

Sources: Netzontwicklungsplan 2013/II, Scenario 2023/33b, Fraunhofer ISE: www.energy-charts.de
Background

Current situation: residual load in Germany in 2015 (I)

- **Wind+PV** acc. for ~50% of total generation
- **Hard coal** almost off; operation required for Frequency Control
- **Lignite** must throttle down

"normal" Day

Days with high RE generation

www.energy-charts.de
Large-scale variations in the national load-generation balance due to renewable generation were already a reality in 2015.
Background

future scenarios for energy supply of buildings

- Study about pathways to transform the energy systems by 2050
- parallel optimization for buildings, industry and transportation
- for heating technologies: large increase for heat pump systems predicted

H.M. Henning and A. Palzer: „Was kostet die Energiewende?“; Report, Fraunhofer ISE, 2015
Background

Demand Response (DR): time ranges and purposes

- Different goals of DR are associated with different time scales
- Buildings cannot provide all DR types due to technical limitations
- In this study, we focus on the ability of building energy systems to adapt their consumption to the generation
AGENDA

- Background: current situation and goals in Germany
- **Grid interaction: methodology and assessment-system**
- Grid interaction: present-day buildings
- Grid interaction: case study of grid-supportive potential
- Conclusion and outlook
Evaluation of grid support
Self-consumption and autonomy\(^1\)

- Self-consumption = \[
\frac{\int \min[g(t), l(t)] \, dt}{\int g(t) \, dt}
\]

„Fraction of local generation that is used on-site“

- Autonomy = \[
\frac{\int \min[g(t), l(t)] \, dt}{\int l(t) \, dt}
\]

„Fraction of local load that is covered by local production“

Not reflected in self-consumption, autonomy:

Is the net load profile „grid-supportive“ or „grid-adverse“?

---

# Evaluation of grid support

## Established metrics

<table>
<thead>
<tr>
<th>symbol</th>
<th>name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{MMC}$</td>
<td>Mismatch compensating factor</td>
<td>Relation of installed capacities of local generation system which give a) net zero energy balance and b) net zero cost balance</td>
</tr>
<tr>
<td>CEF</td>
<td>Carbon Emissions Factor</td>
<td>Load weighted with time-resolved carbon emissions intensity, divided by carbon emissions assuming annual average</td>
</tr>
<tr>
<td>$f_{PE}$</td>
<td>Primary Energy Value</td>
<td>Load weighted with the time-resolved primary energy intensity, divided by primary energy assuming annual average</td>
</tr>
<tr>
<td>RIB</td>
<td>Relative Import Bill</td>
<td>Possible energy cost savings if all energy were consumed at lowest real time price of each day</td>
</tr>
<tr>
<td>-</td>
<td>Flexibility</td>
<td>Possible energy cost savings if all energy were consumed at lowest real time price of each day</td>
</tr>
</tbody>
</table>
Evaluation of grid support

Grid support coefficients $GSC_{abs}$ and $GSC_{rel}$

$GSC_{abs}(G) = \frac{\sum_{i=1}^{n} W_{el}^i \cdot G^i}{W_{el} \cdot \bar{G}}$

$W_{el}$: Sum of electricity consumption

$G^i$: Grid-based reference quantity (at time $i$)

$\bar{G}$: Mean of grid-based reference quantity

<table>
<thead>
<tr>
<th>Grid-optimal</th>
<th>Power consumption in hours with lowest residual load</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Most grid-adverse</th>
<th>Power consumption in hours with highest residual load</th>
</tr>
</thead>
<tbody>
<tr>
<td>-100</td>
<td></td>
</tr>
</tbody>
</table>

$GSC_{abs}$ = 1.14

$GSC_{rel}$ = 1.03

$GSC_{abs}$ = 0.97

$GSC_{rel}$ = 0.8
Evaluation of grid support

Grid signals

- The EEX Day-ahead price (EEX) and the residual load (RES) are highly correlated, and the CEC and the share of wind and PV (WPV) are highly inversely correlated.

- All grid signals penalize power consumption in the morning and evening.

- In the future, power consumption around noon will be most favorable.
AGENDA

- Background: current situation and goals in Germany
- Grid interaction: methodology and assessment-system
- **Grid interaction: present-day buildings**
- Grid interaction: case study of grid-supportive potential
- Conclusion and outlook
Grid support of present-day installations
Evaluated field monitoring data

- Long-term field monitoring data of 52 installations
  - 8 heat pumps in office buildings (4.5 – 58 kW\(_{el}\))
  - 4 chillers in office buildings (14.9 - 29 kW\(_{el}\))
  - 2 CHP units in multi-family dwellings (5.5 kW\(_{el}\))
  - 38 heat pumps in single-family dwellings (1.3 – 6.1 kW\(_{el}\))
- Operation years: 2011 and 2012
- Time resolution: 1 to 5 minutes
Grid support of present-day installations
Operation analysis (offices and multi-family buildings)

Heat pumps ("continuous")
- HP operation follows heating load
- Steady profile

Heat pumps ("discontinuous")
- Cut-off times, night setback, operation time programs
- Individual profiles

Chillers
- Thermal load type shapes operation profile

CHP units
- Model-predictive controllers follow EEX market signal
Most installations „grid-neutral“ or moderately „grid-adverse“

- High grid support is achievable in present-day buildings
- Success factors: thermal load profile and implemented control strategy
AGENDA

- Background: current situation and goals in Germany
- Grid interaction: methodology and assessment-system
- Grid interaction: present-day buildings
- **Grid interaction: case study of grid-supportive potential**
- Conclusion and outlook
Case study of grid-support potential
Flexibility and storage options in buildings: working principles

- **Battery storage**: creates a delay between power load and power demand
- **Fuel switch**: changes relation of thermal generation and power demand
- **Thermal storage**: creates a delay between thermal generation and delivery
- **Building mass**: manipulates trajectory of thermal energy delivery

source: Konstantin Klein: „Quantifying the energy flexibility of building energy systems Evaluation of grid-supportive concepts for space heating and cooling in non-residential buildings”; Dissertation, Freiburg 2017
Case study of grid-support potential simulation study: building model

Generic office building

- 2,433 m² useful area
- Simple interior layout
- Thermo-active Building Systems (TABS)
- Modern insulation in compliance with EnEV 2014
- Occupancy times, heat gains, artificial lighting according to DIN-V 18599:10
- Location: Mannheim, Germany
Case study of grid-support potential simulation study: heat supply

HP-case
- variable load 10 kW\textsubscript{el}
- Bore-hole HEX
- Gas boiler
- Heat pump 10 kW\textsubscript{el}

CHP-case
- variable generator 10 kW\textsubscript{el}
- Air
- Chiller
- Gas boiler

Case study of grid-support potential
Simulation workflow and hybrid control concept

Reference simulation
- **Model**: Complete thermo-hydraulic system
- **Language**: Modelica
- **Control**: Low level control, no input signal
- **Significance**: Reference case: no load shifting

Load shifting
- **Model**: Simplified models
- **Language**: Python
- **Control**: High-level control algorithms
- **Significance**: Determination of input signals

Simulation with load shifting
- **Model**: Complete thermo-hydraulic system
- **Language**: Modelica
- **Control**: Low level control with input signal
- **Significance**: System operation with load shifting

- **Low-level control**: state-of-the-art controller for thermal generators (Modelica)
- **High-level control**: generates input signals for low-level control (Python)
Case study of grid-support potential
High-level control algorithm: water tanks and batteries

Main algorithm steps

1. Determine initial SOC trajectory by thermal load

2. Iteration until SOC > 0 in all time steps:
   - Determine operation time window
   - Select operation interval with best grid signal
   - Update SOC in subsequent time steps

3. Convert SOC trajectory into tank set-point temperature trajectory
Case study of grid-support potential

Results of parameter variations - HP case

- **Fuel switch**: ineffective (regarding grid support) and (energy) inefficient
- **Water tanks**: somewhat effective but relatively inefficient
- **Building mass**: both effective and efficient
- **Batteries**: most effective and most efficient
Case study of grid-support potential

Results of parameter variations - CHP case

- **Fuel switch**: effective and competitively efficient
- **Water tanks**: somewhat effective but least efficient
- **Building mass**: effective and highly efficient
- **Batteries**: most effective and efficient
Case study of grid-support potential advantages and limitations

<table>
<thead>
<tr>
<th></th>
<th>Advantages</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Battery</strong></td>
<td>Can be discharged as electricity independently of thermal loads</td>
<td>High cost, battery degrades with number of charge cycles</td>
</tr>
<tr>
<td><strong>Fuel-Switch</strong></td>
<td>Practically infinite storage capacity (gas grid)</td>
<td>Oversizing required, increased investment cost</td>
</tr>
<tr>
<td><strong>Water storage</strong></td>
<td>Relatively simple control, water storages abundant in building stock</td>
<td>Storage deteriorates efficiency of heat pumps/chillers</td>
</tr>
<tr>
<td><strong>Building mass</strong></td>
<td>High capacity with small temperature differences</td>
<td>Difficult to ensure comfort, only applicable to certain technologies</td>
</tr>
</tbody>
</table>

Which approach is best suited for improving grid support depends on the specified goals and the topology and usage of the considered system.
Case study of grid-support potential economic analysis, HP case

- All DR tariffs lead to a lower specific energy rate. Because of increased consumption, the overall yearly cost increases.

- Two tariffs lead to comparatively low energy rates: HP-tariff (off-time) and real-time-pricing with a variable share of savings.

- DR-revenue (example): HP-tariff: 2.2 % of yearly energy cost
  RTP-var-tariff: 1.2 % of yearly energy cost
Conclusion and outlook

Conclusion

- New evaluation method assesses the grid support of buildings both from the market and from the building perspective
- Present-day buildings are predominantly „grid-neutral“ or slightly „grid-adverse“
- Building energy systems can contribute significantly to load flexibilization
- Different flexibility and storage options can be used, including: batteries, fuel switch, water storages, and the thermal building mass (and combinations)
- Which flexibility and storage option is best suited depends on the available thermal generators and the parametrization of the system
- Load shifting usually comes at the price of an increased final energy consumption
- In todays tariff structure most flexibility options are not economically feasible
Conclusion and outlook

Outlook

- Development of common assessment system (incl. distribution grid)
- Analysis of imperfect load predictions / uncertainties (e.g. user influence)
- Implementation of control strategies in high-level controls (e.g. MPC)
- Application in test bench and demo building

Acknowledgement

- the work is funded by the German Ministry for Economics and Energy, project “FlexControl”, reference number 03ET1359A
- part of the IEA EBC Annex 67 “Energy Flexible Buildings”
Thank you for your attention

Fraunhofer-Institute
for Solar Energy Systems ISE

Dr.-Ing. Peter Engelmann

www.ise.fraunhofer.de
peter.engelmann@ise.fraunhofer.de