GRID INTERACTION OF TODAYS 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

Fraunhofer ISE

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

Fraunhofer ISE

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

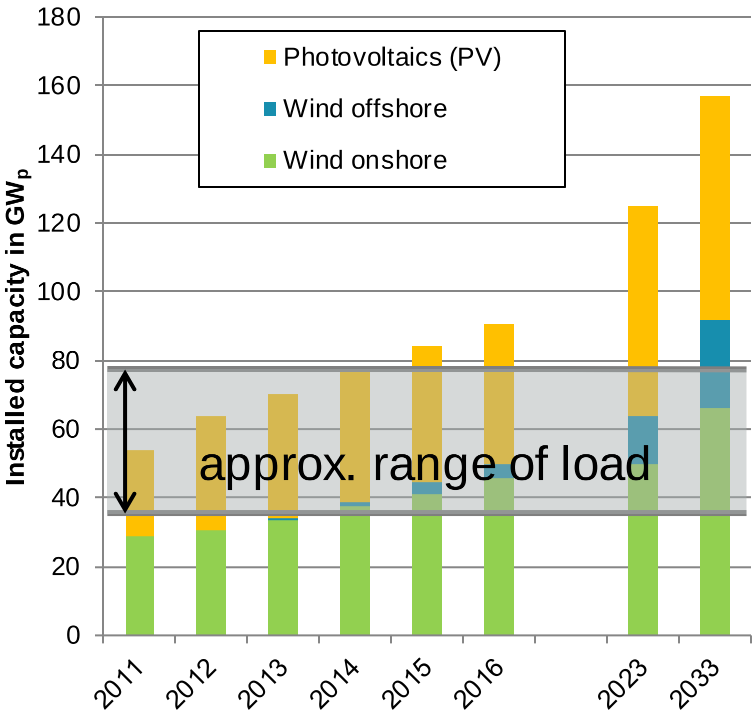
- Germanys goal: reduce CO_2 emissions ≥80% by the year 2050
- Two step approach:
  - Reduce demand
  - Increase use renewables

Upcoming challenges

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

Consequence

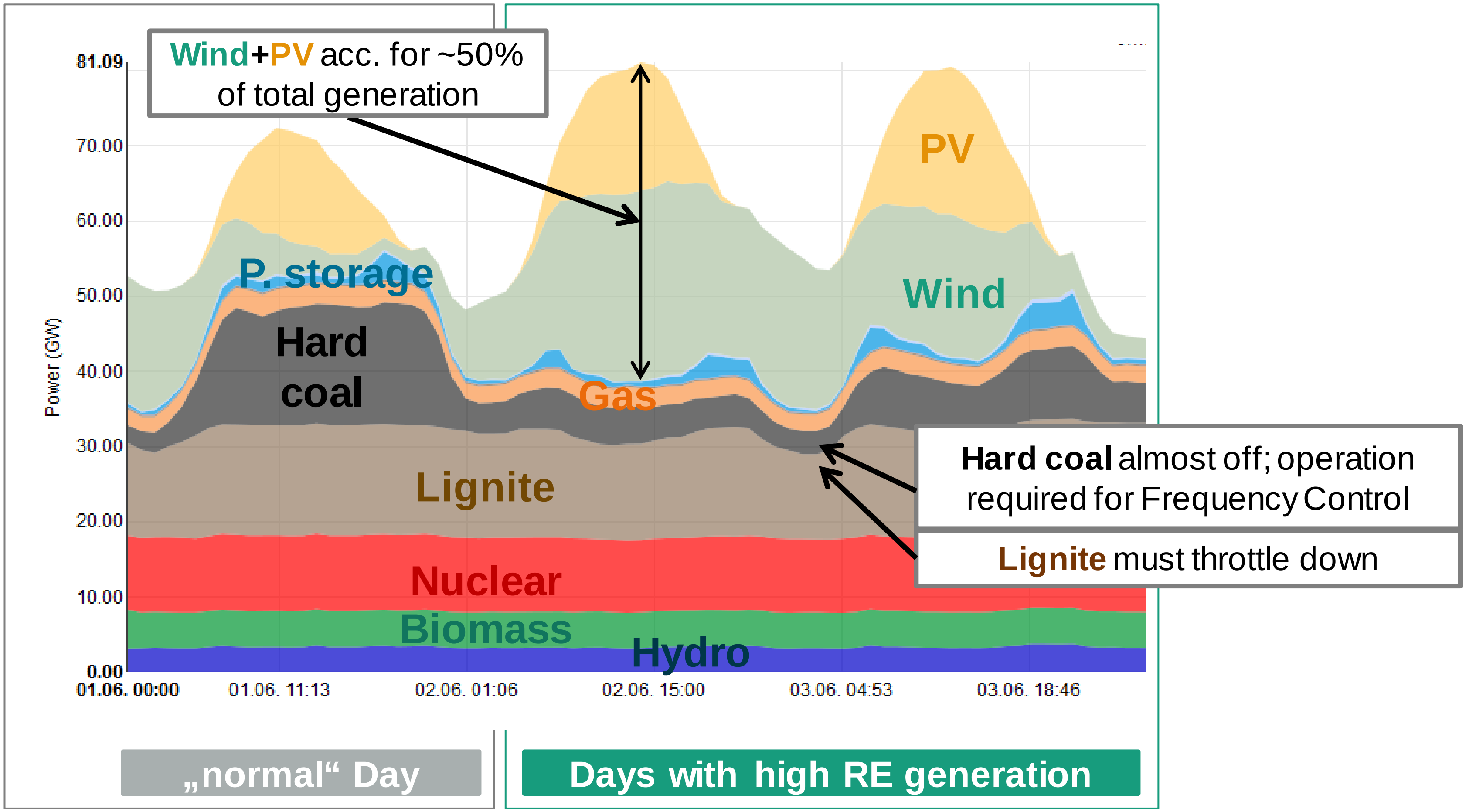
- More load flexibility will be required
- One option: grid-supportive building energy system



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

Background

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

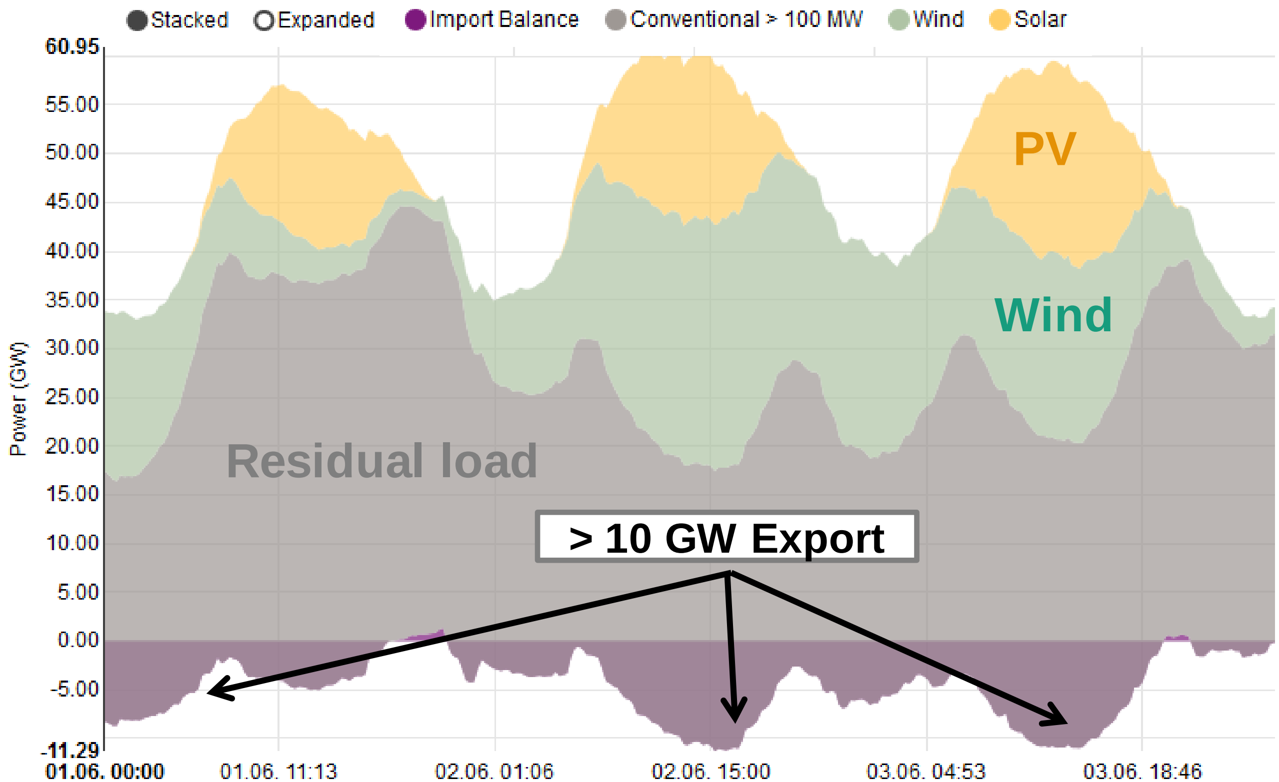


www.energy-charts.de

Fraunhofer ISE

Background

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



Large-scale variations in the national load-generation balance due to renewable generation were already a **reality** in 2015.

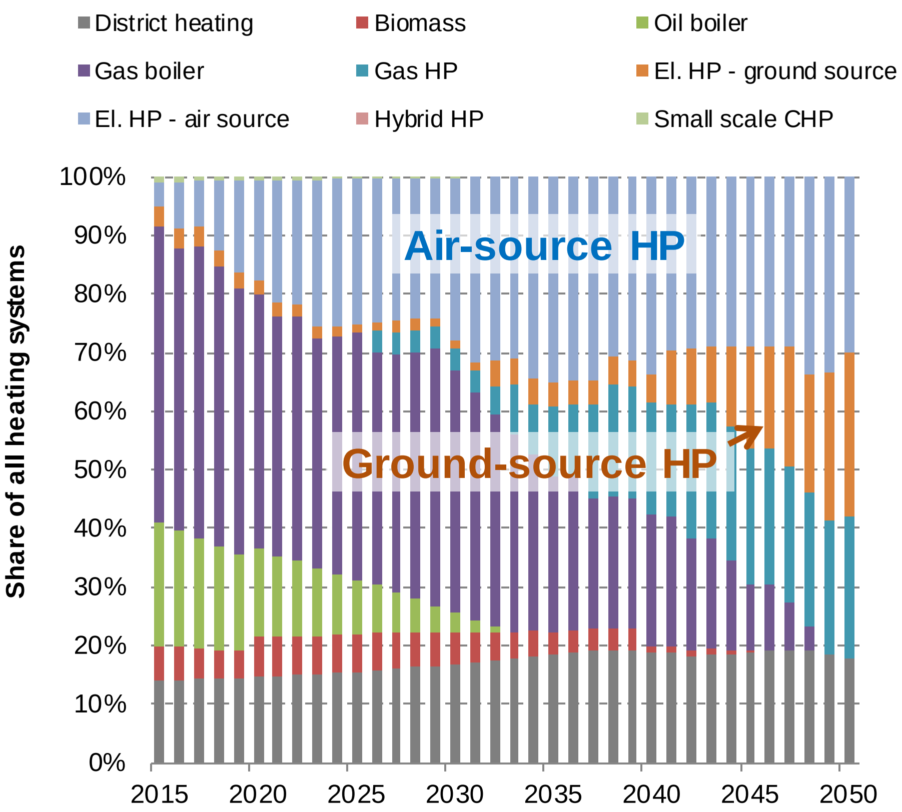
www.energy-charts.de

Fraunhofer ISE

Background

future scenarios for energy supply of buildings

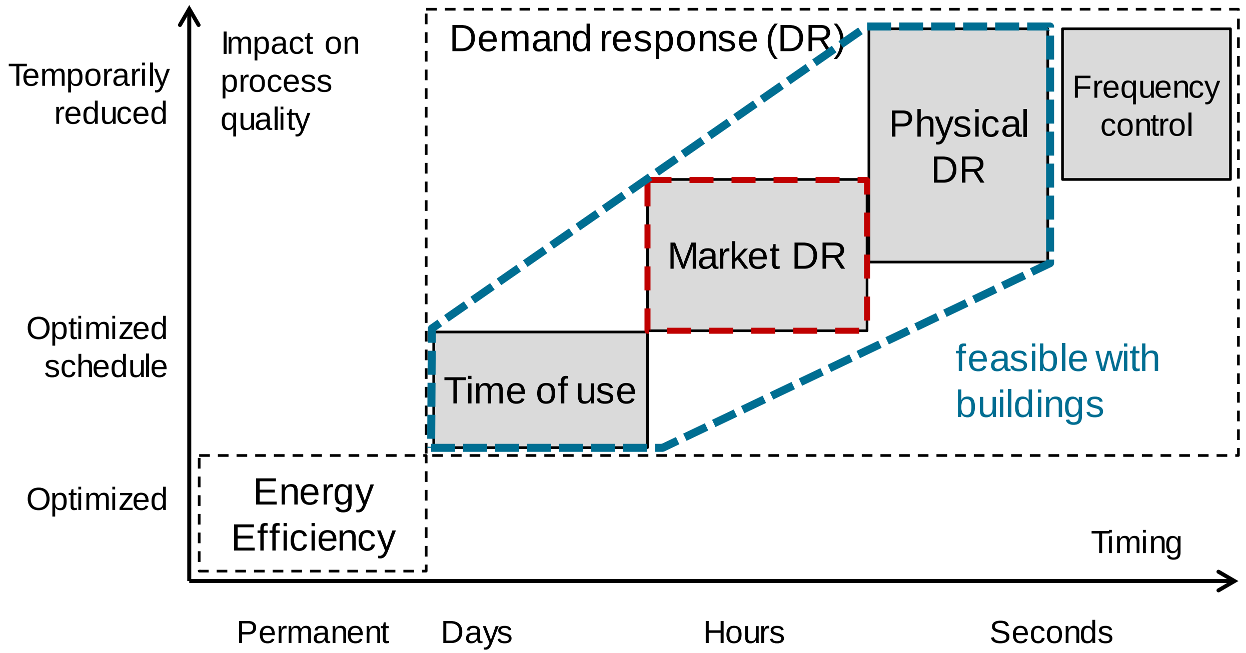
- Study about pathways to transform the energy systems by 2050
- parallel optimization for buildings, industry and transportation
- for heating technologies: large increase for heat pump systems predicted



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

Fraunhofer ISE

Evaluation of grid support

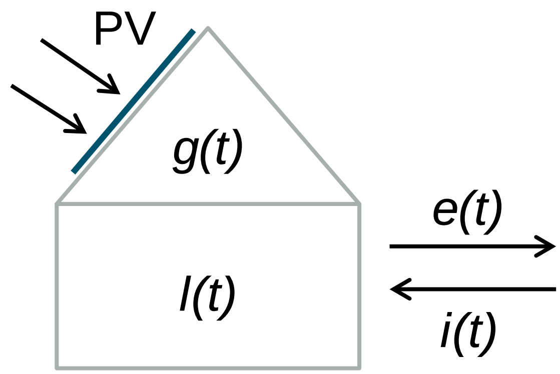
Self-consumption and autonomy[1]

- 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"



g(t)	generation
l(t)	load
e(t)	export
i(t)	import

Not reflected in self-consumption, autonomy:

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

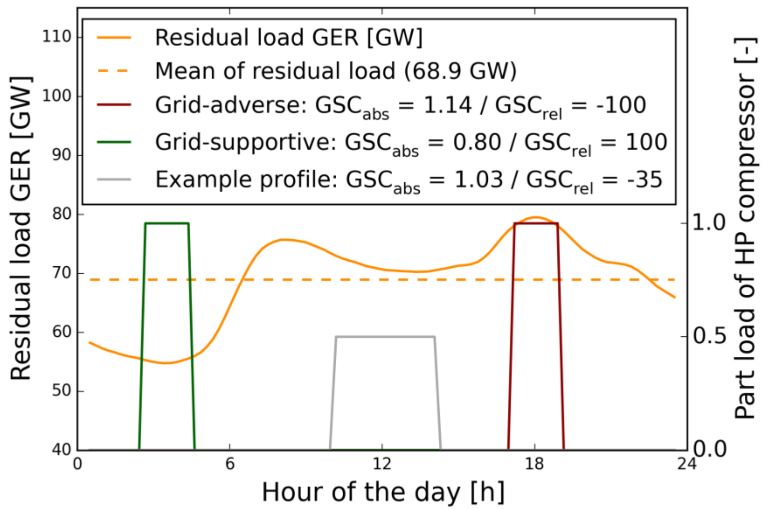
[1] Salom, J., et al., Analysis of load match and grid interaction indicators in net zero energy buildings with simulated and monitored data. Applied Energy, 2014. 136: p. 119-131.

Evaluation of grid support
Established metrics

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

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

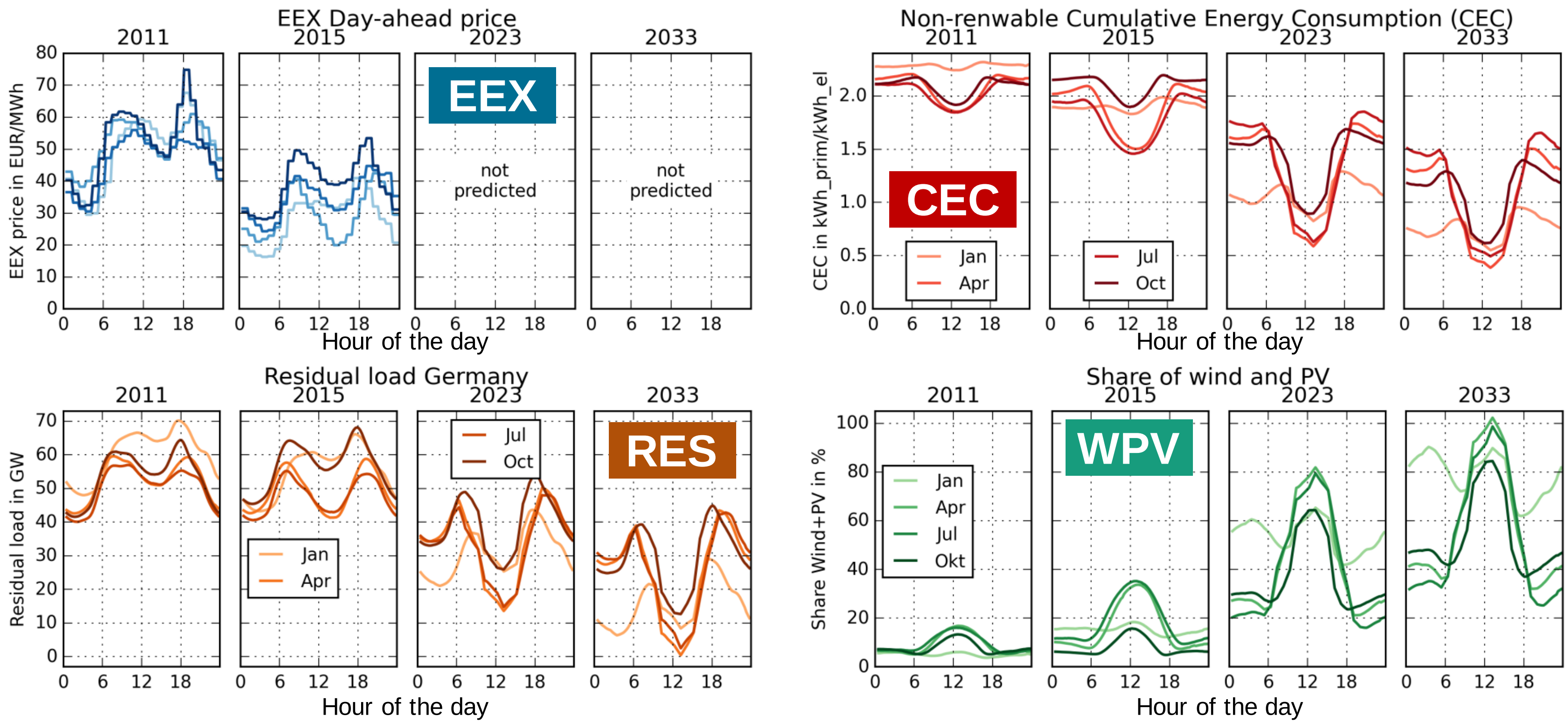
GSC_{abs}	**1.14**	**1.03**	0.97		**0.8**
GSC_{rel}	**-100**	**-35**	0	50	**100**

Most grid-adverse
Power consumption in hours with highest residual load

Grid-optimal
Power consumption in hours with lowest residual load

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

Fraunhofer ISE

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

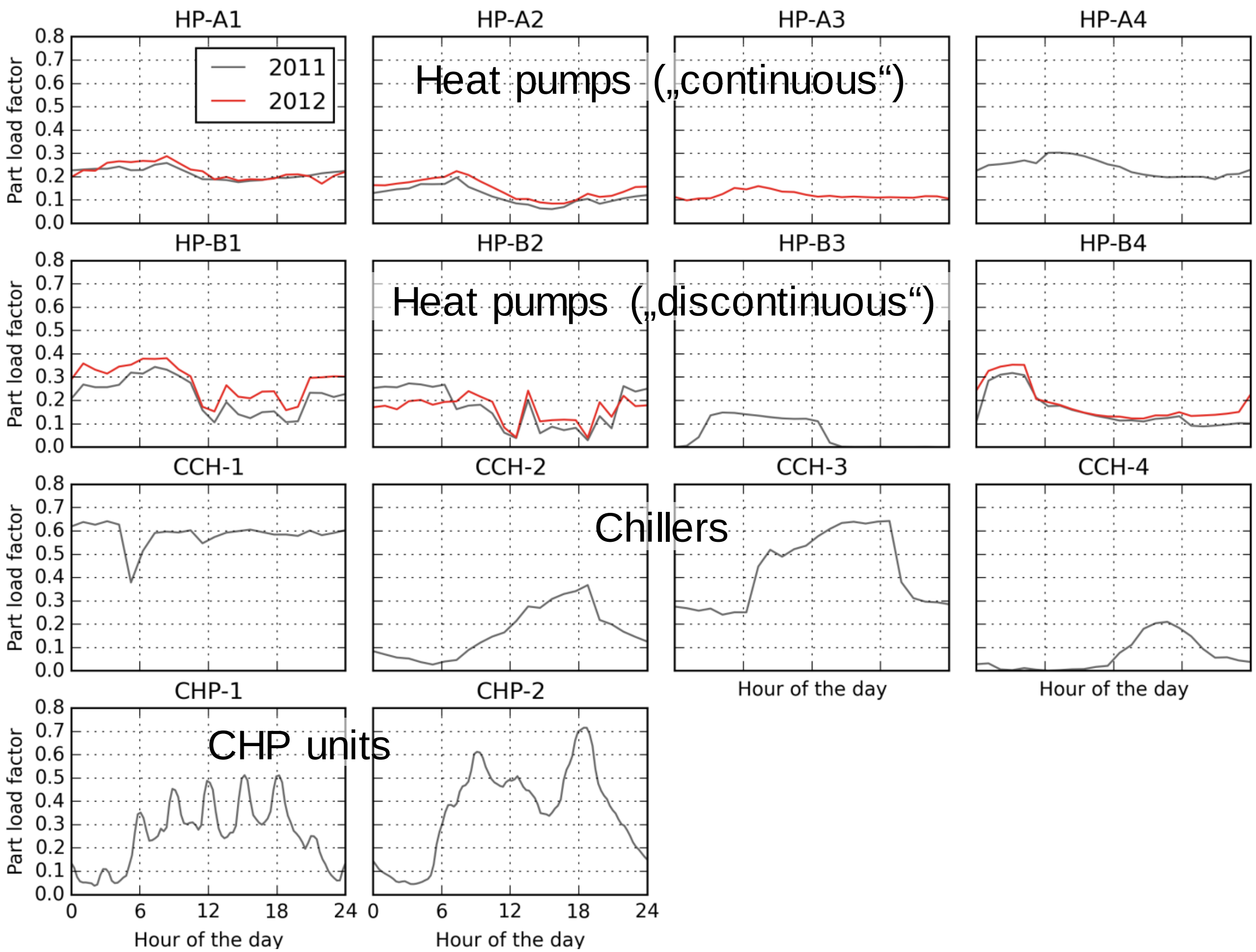
Evaluated field monitoring data

- 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

Photos: enob.info

Grid support of present-day installations

Operation analysis (offices and multi-family buildings)



HP operation follows heating load

Steady profile

Cut-off times, night setback, operation time programs

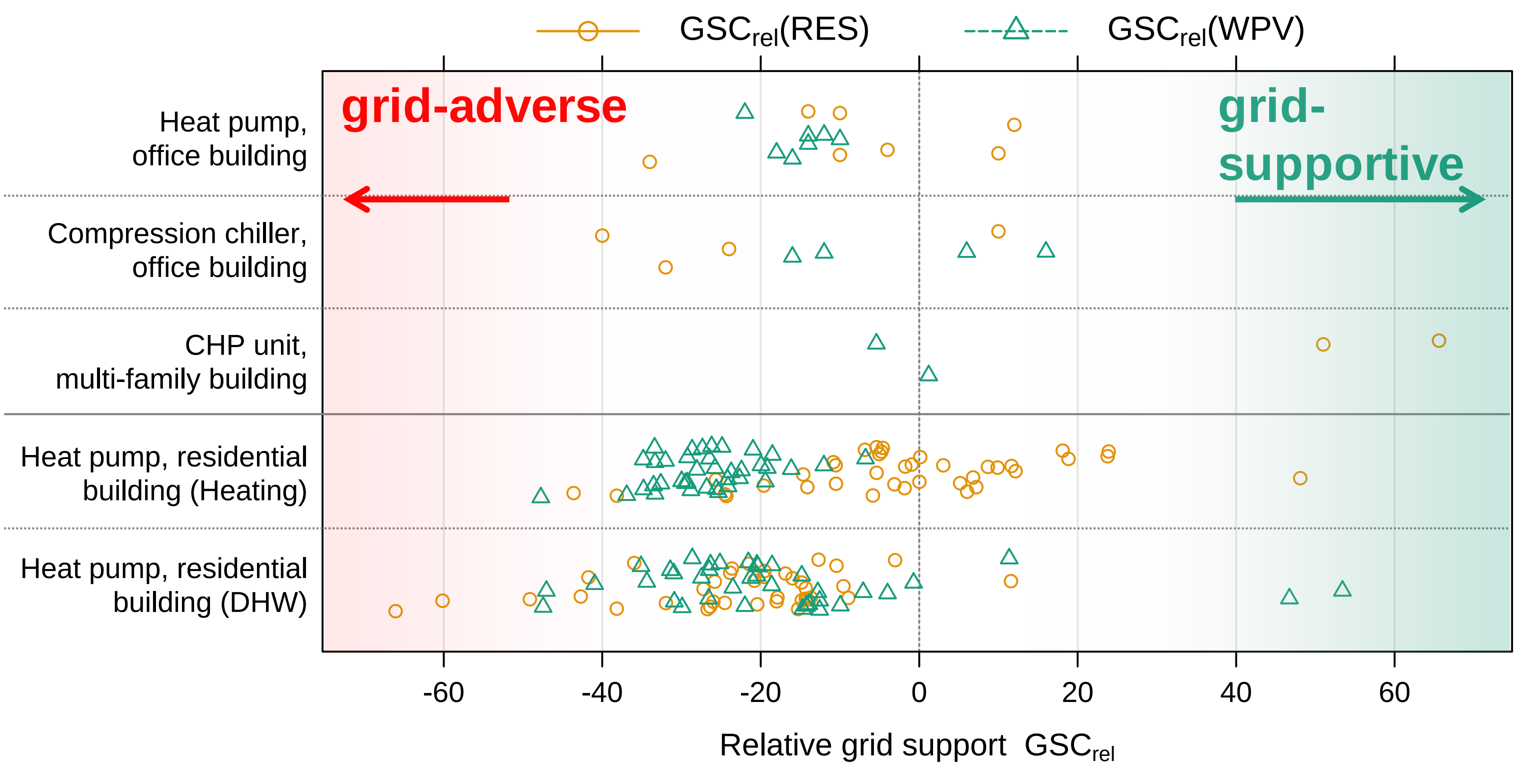
Individual profiles

Thermal load type shapes operation profile

Model-predictive controllers follow EEX market signal

Grid support of present-day installations

Annual GSC_{rel}



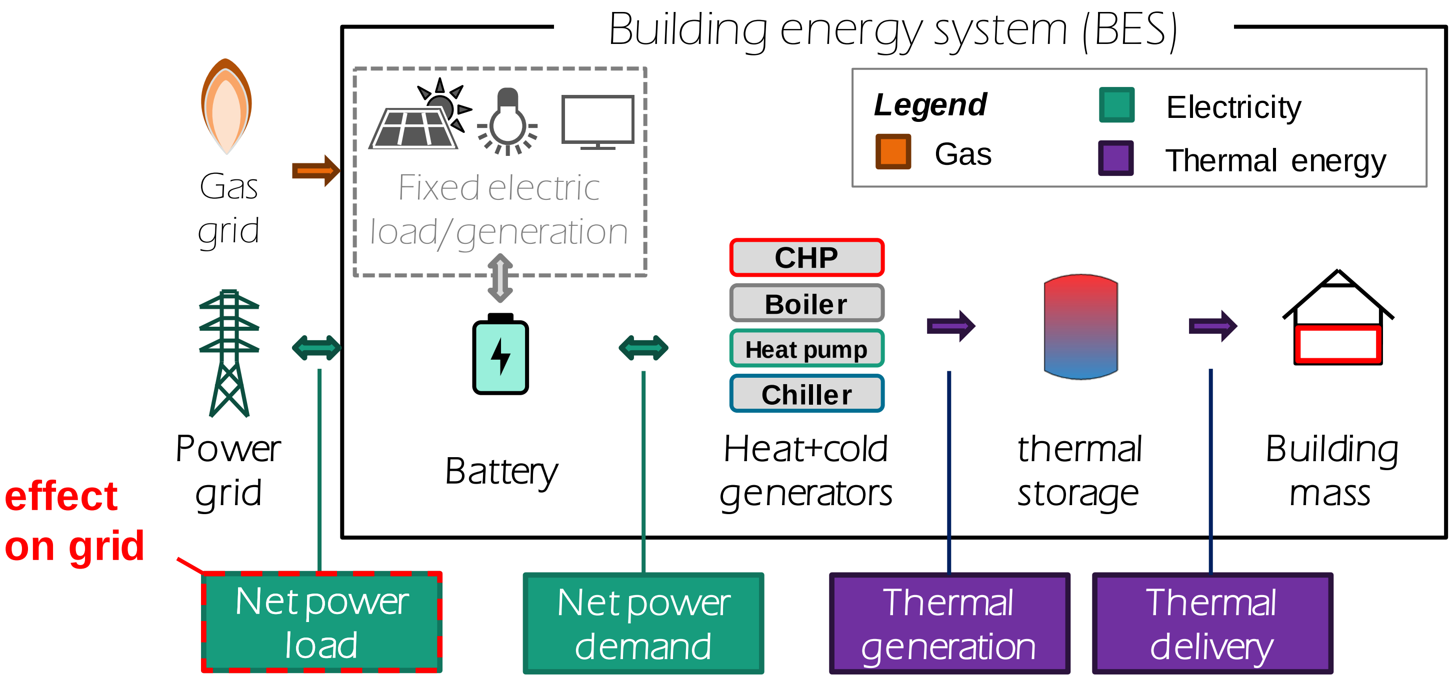
- Most installations „grid-neutral“ or moderately „grid-adverse“
- High grid support is achievable in present-day buildings
- Success factors: thermal load profile and implemented control strategy

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



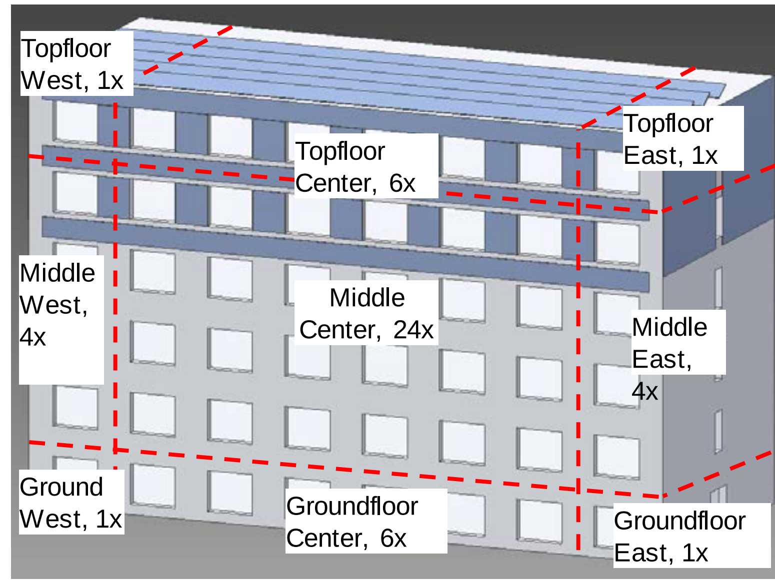
- **Battery storage**: creates a delay between power load and power demand
- **Fuel switch**: changes relation of thermal generation and power demand
- **Thermal storage**: creates a delay between thermal generation and delivery
- **Building mass**: manipulates trajectory of thermal energy delivery

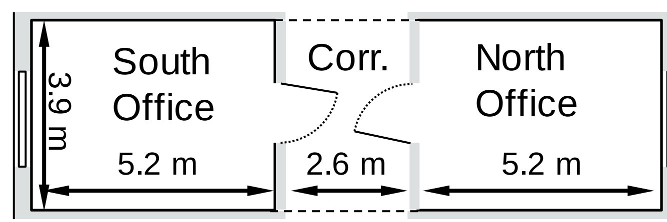
source: Konstantin Klein: „Quantifying the energy flexibility of building energy systems
Evaluation of grid-supportive concepts for space heating and cooling in non-residential buildings"; Dissertation, Freiburg 2017

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

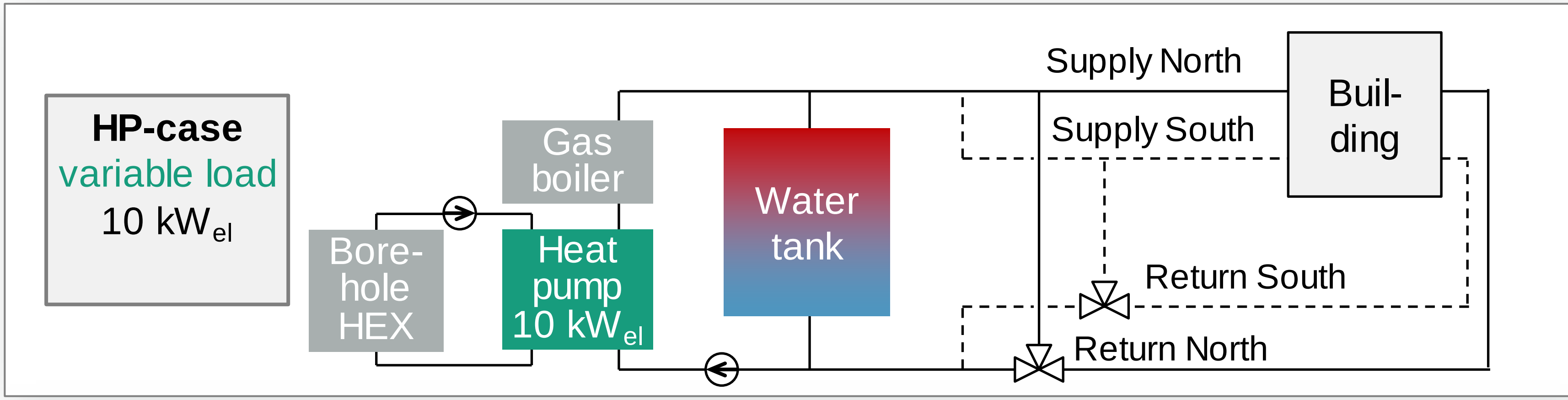


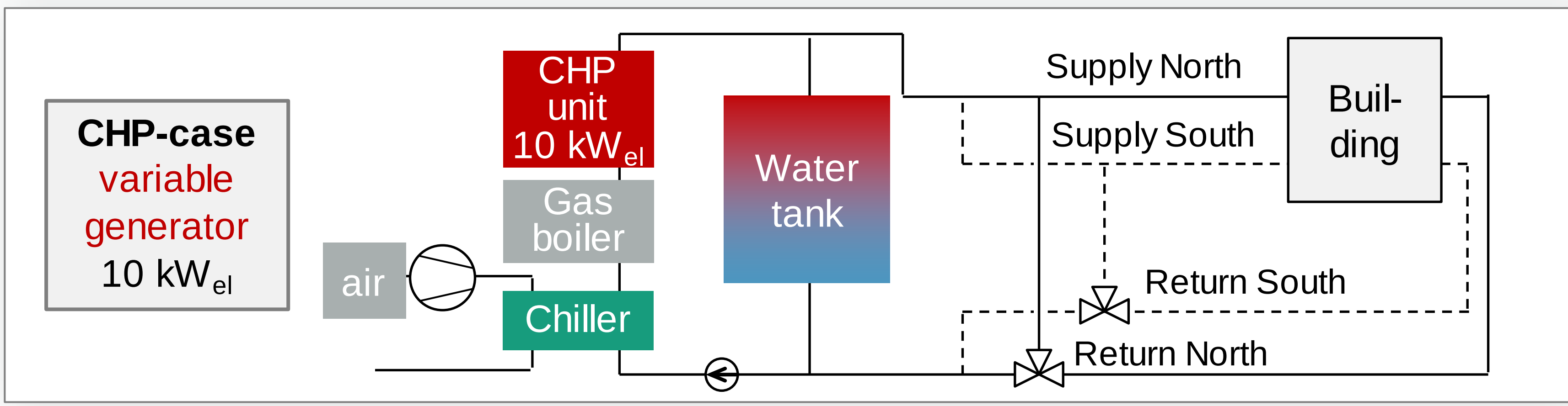


Fraunhofer ISE

Case study of grid-support potential

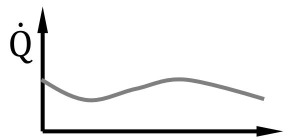
simulation study: heat supply

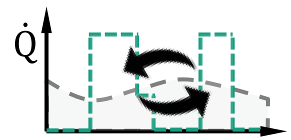


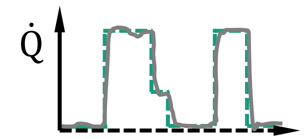


Case study of grid-support potential

Simulation workflow and hybrid control concept







	I Reference simulation	II Load shifting	III Simulation with load shifting
Model	Complete thermo-hydraulic system	Simplified models	Complete thermo-hydraulic system
Language	Modelica	Python	Modelica
Control	Low level control, no input signal	High-level control algorithms	Low level control with input signal
Significance	Reference case: no load shifting	Determination of input signals	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)

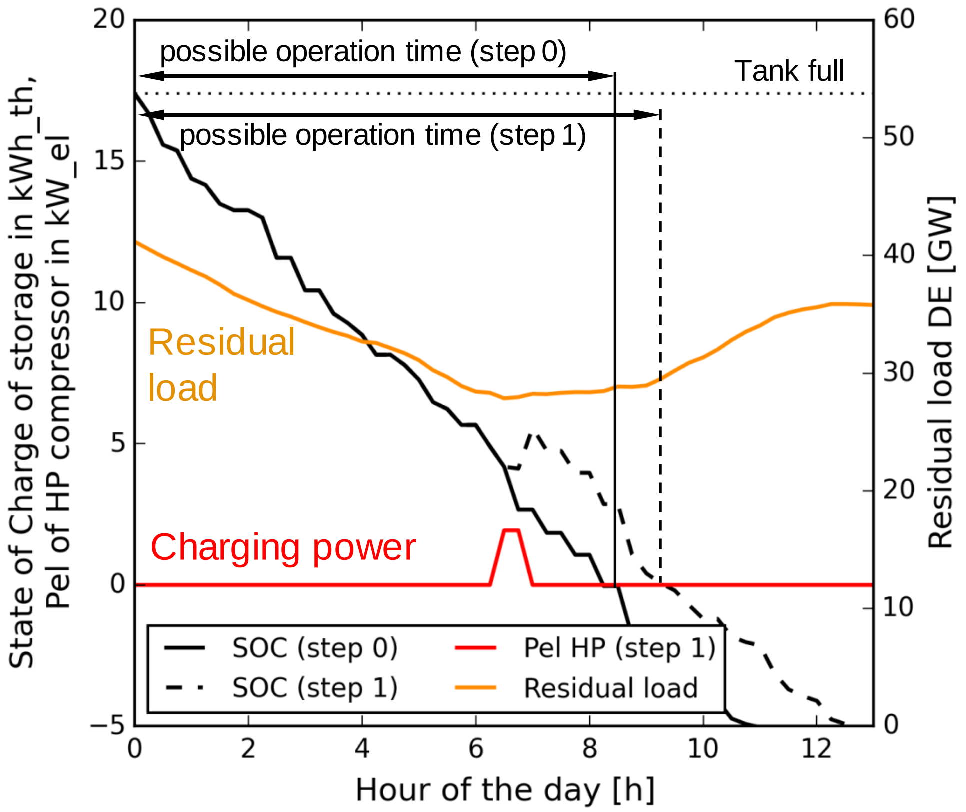
Fraunhofer ISE

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. Interation 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

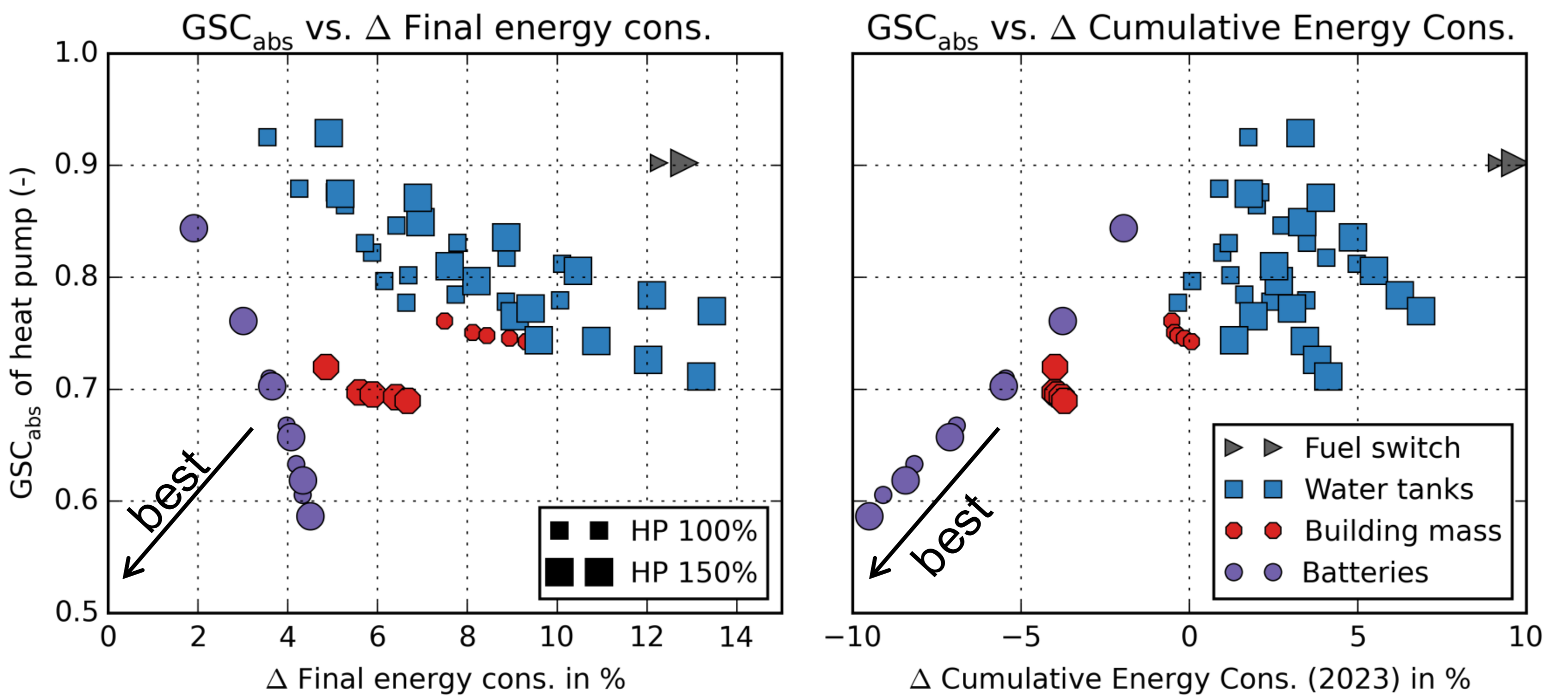


Fraunhofer ISE

Case study of grid-support potential

Results of parameter variations - HP case

HP-case

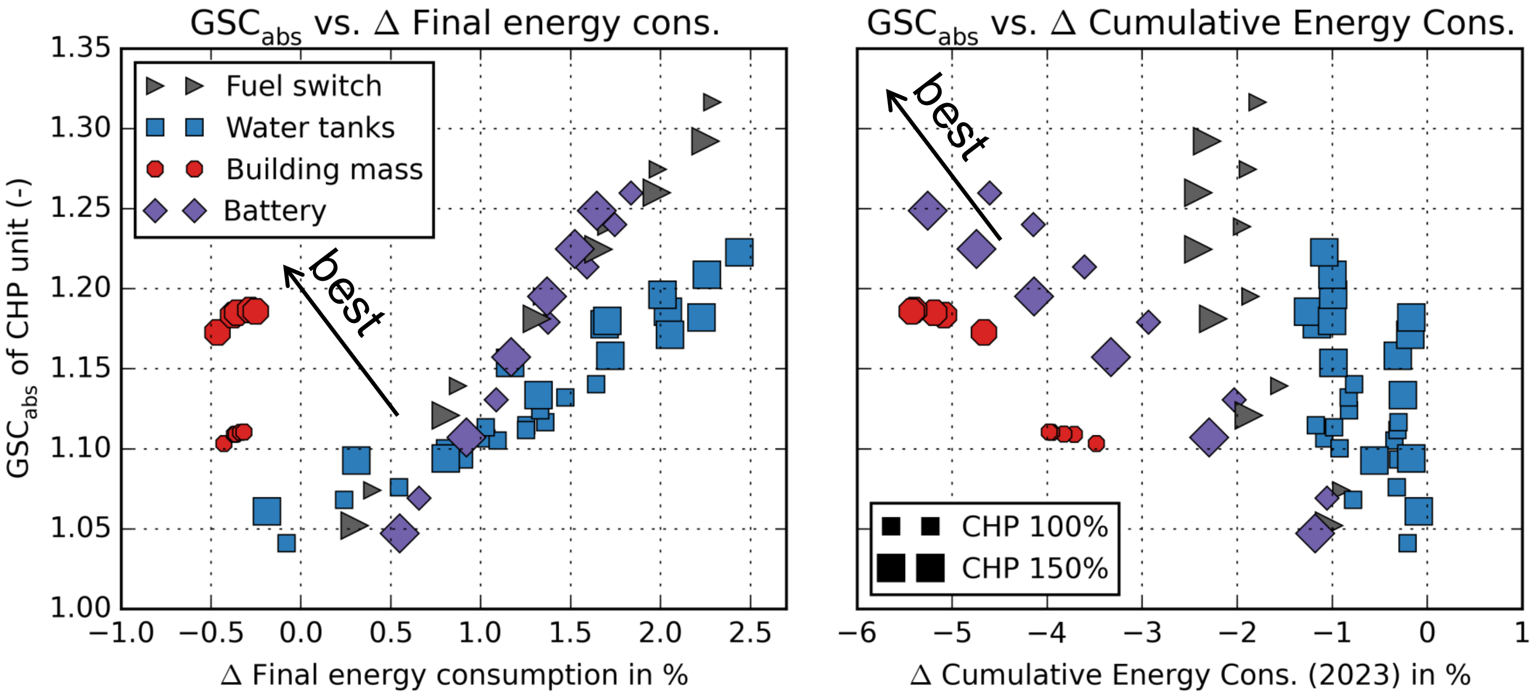


- **Fuel switch**: ineffective (regarding grid support) and (energy) inefficient
- **Water tanks**: somewhat effective but relatively inefficient
- **Building mass**: both effective and efficient
- **Batteries**: most effective <u>and</u> most efficient

Case study of grid-support potential

Results of parameter variations - CHP case

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

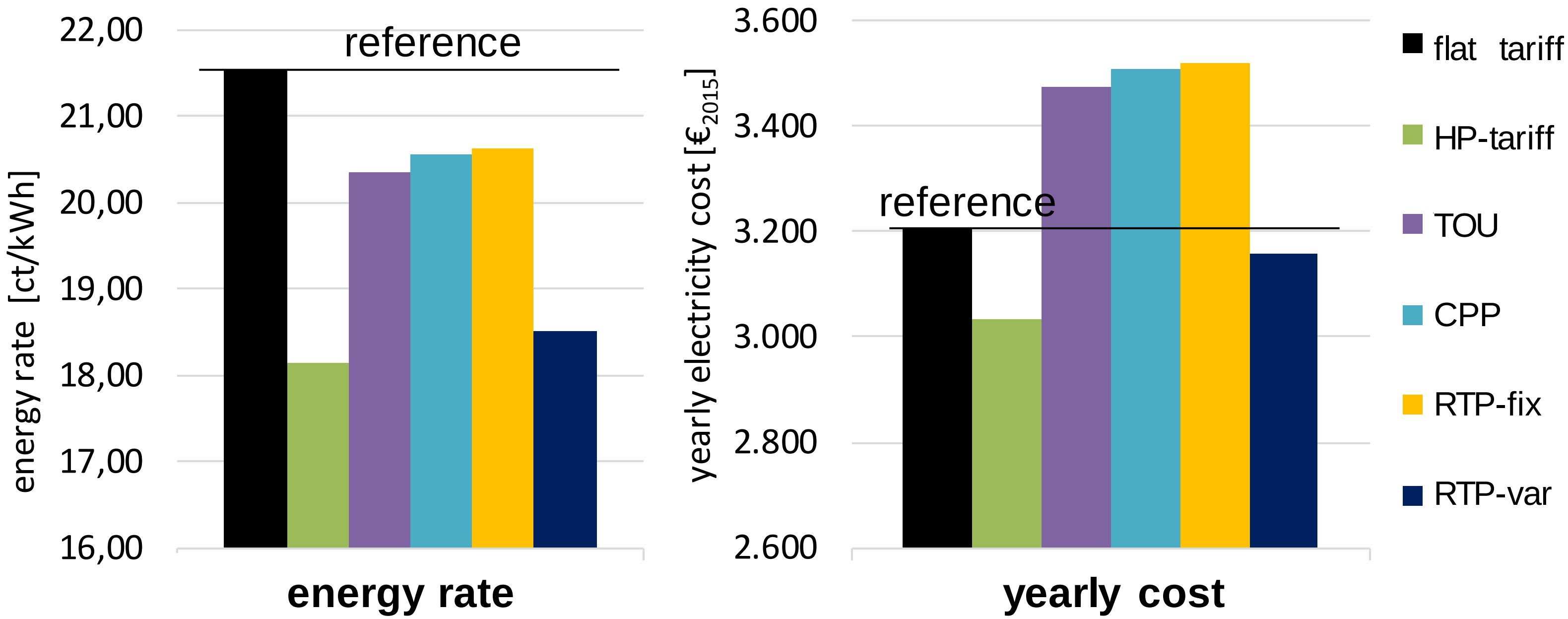
advantages and limitations

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

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

Fraunhofer ISE

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

Fraunhofer ISE

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"

iea Energy Technology Network EBC Annex 67

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

Fraunhofer ISE

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