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TradeRES
New Markets Design & Models for 100% Renewable Power Systems

Sector integration with residential heat pumps: The impact of building refurbishment and user behavior

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ENERDAY, Dresden, 30th September 2022

DLR

Motivation

Wärmepumpen

Pumpen gegen Putin

Zeit.de, Juli 1, 2022

German Heat Pump Boom To Do Without Russian Gas: Stiebel Eltron Invests 600 Million Euros

- 400 new green tech jobs in Lower Saxony, Germany

Businesswire, August 30, 2022

ENERGIEKRISE IN IMMOBILIEN

Wärmepumpen sind ein Schlüsselinstrument

Frankfurter Allgemeine Zeitung, August 26.2022

Erneuerbare Energien

Habeck will 500.000 Wärmepumpen jährlich

Tagesschau.de, June 29, 2022

Research questions

What is the influence of energetic **building refurbishment** on heat pumps' electricity demand?

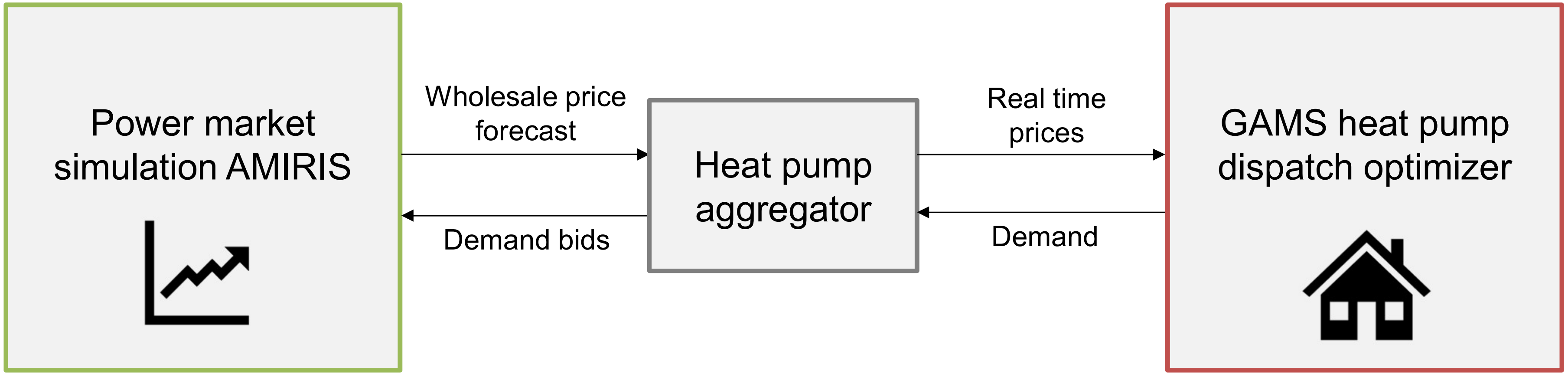
How does **user behavior** regarding comfort temperature settings affect electricity demand and cost for heat pumps, considering price-based **flexibility** provision?

How are **backup requirements** and **electricity generation** affected, taking into account building refurbishment and user flexibility?

What are **price impacts** of flexible heat pumps in Demand Response schemes?

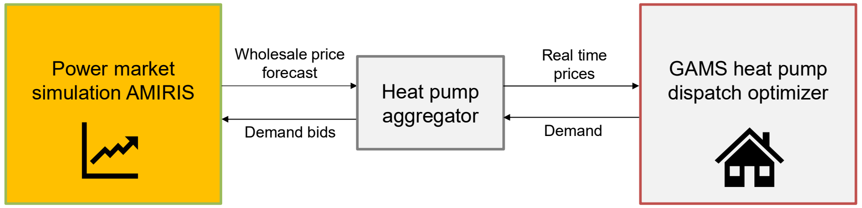
Methods

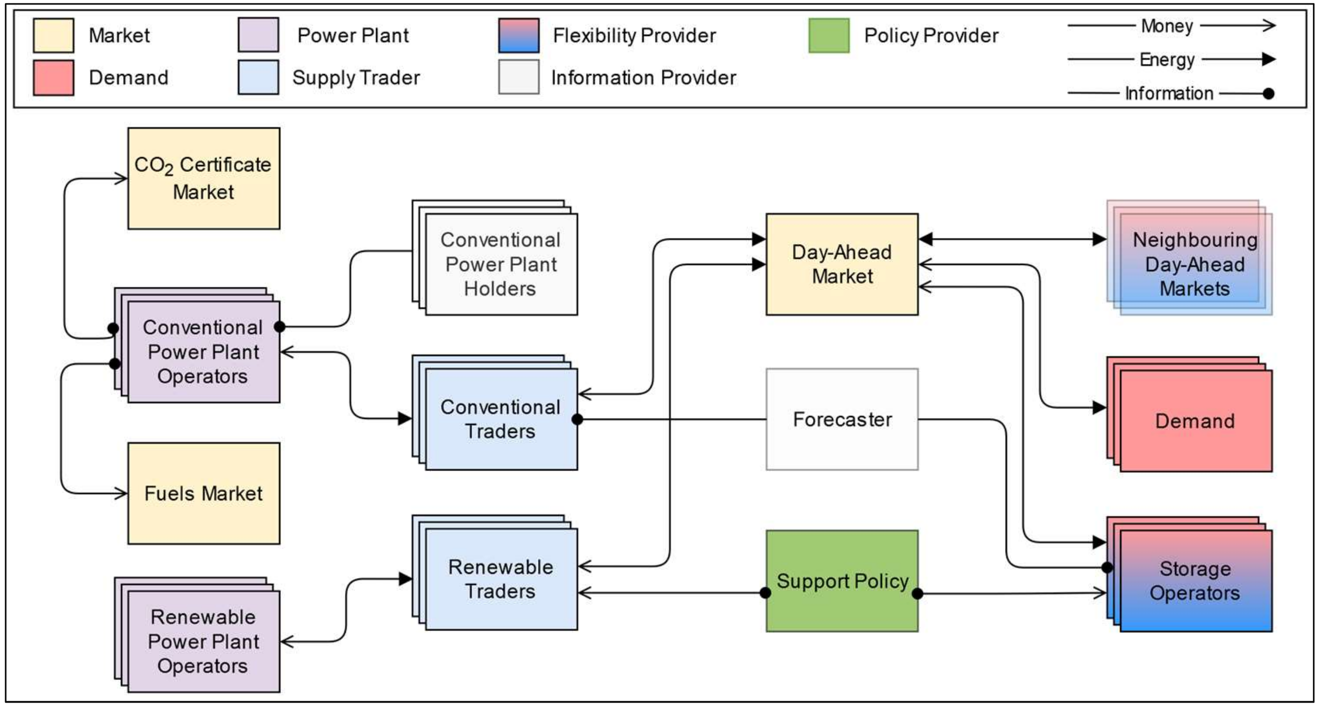
Coupling power market simulation model to heat pump dispatch optimization model



AMIRIS

Agent-based market model for the investigation of renewable and integrated energy systems

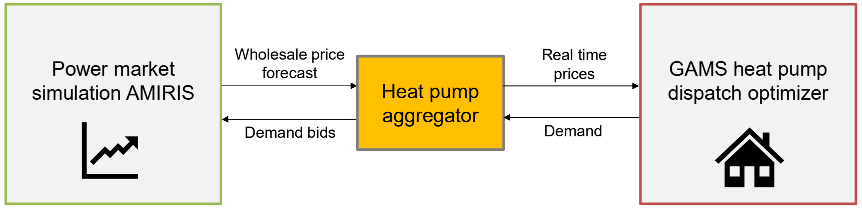




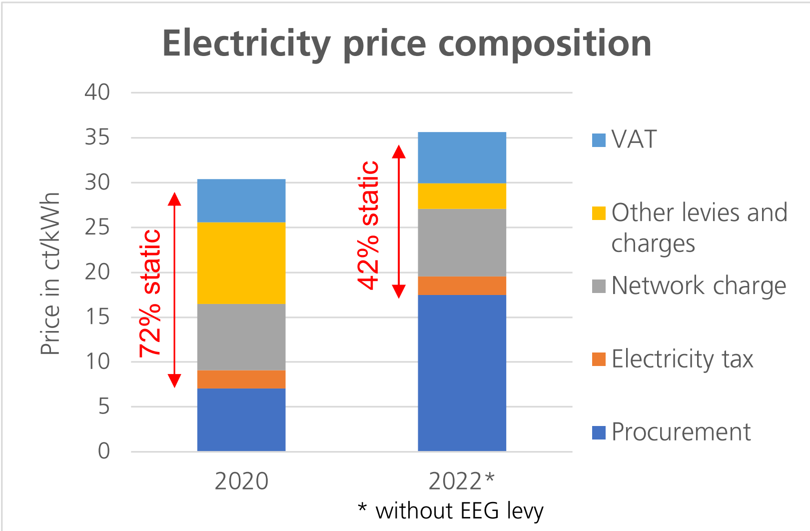
- Agent-based model to simulate German day-ahead electricity market
- Considers business-oriented decisions of power plants and flexibility operators
- Endogenous merit-order model

Open source available at https://gitlab.com/dlr-ve/esy/amiris

Heat pump aggregator

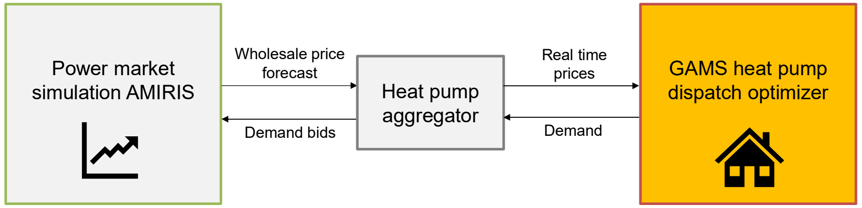


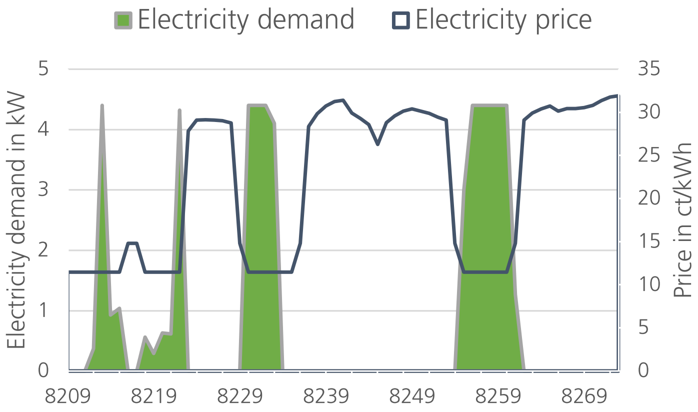
- Generates real time electricity prices based on
  - wholesale price forecast (*incorporates aggregated demand of inflexible heat pumps)*
  - regulatory price components
- Bids with heat pumps' aggregated demand on the exchange
- Real time price structure:
  - variable: wholesale price + related VAT
  - static: (electricity tax + levies + charges) * VAT

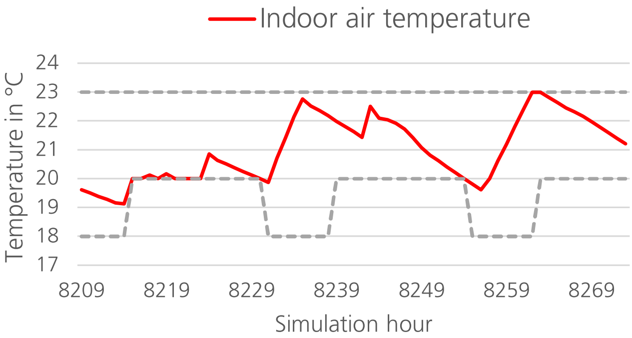


Adapted from *https://www.verivox.de/strom/themen/strompreiszusammensetzung/*

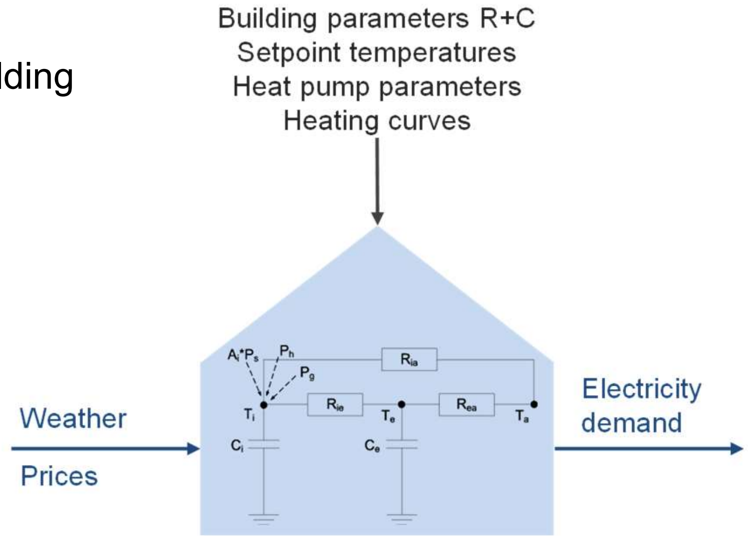
GAMS heat pump dispatch optimizer







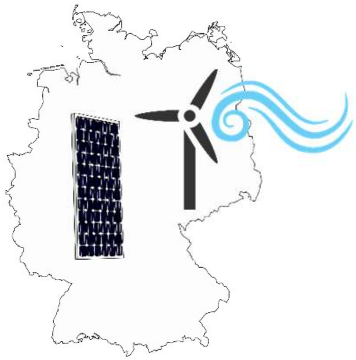
- Minimizes operating cost of heat pumps from micro-economic perspective
- Flexibility from buildings' thermal mass provided by varying indoor temperature within given boundaries (→ user setting)
- Electricity demand calculated bottom-up by reduced-order thermodynamic models of building archetypes[1)]



1) E. Sperber, U. Frey, V. Bertsch: *Reduced-order models for assessing demand response with heat pumps – Insights from the German energy system*, Energy & Buildings vol. 223, 2020

Case study setup

75% market penetration in single family houses ≥ 1958
= 6.4 M heat pumps



Germany 2030,
~ 80% RES share

Basic scenario data

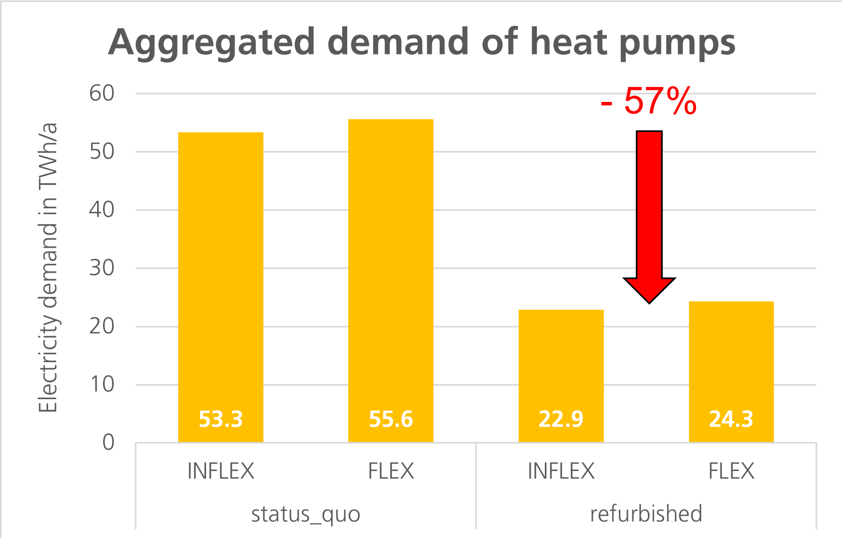
- Heat pump technology:
  70% air/water, 30% brine/water
- 8 building types according to German building typology
- Power plants:
  - Wind: 145 GW
  - PV: 215 GW
  - Gas: 100 GW
- "Traditional" electricity demand:
  530 TWh/a | 85 GW_p
- CO_2 price = 100 €/t
- RES support: fixed market premium
- Fixed levies, charges and taxes
  = 12.5 ct/kWh
  = 2/3 of average retail price
- Weather year 2019
- No storage besides building thermal mass, no further flexibilities
- No grid constraints

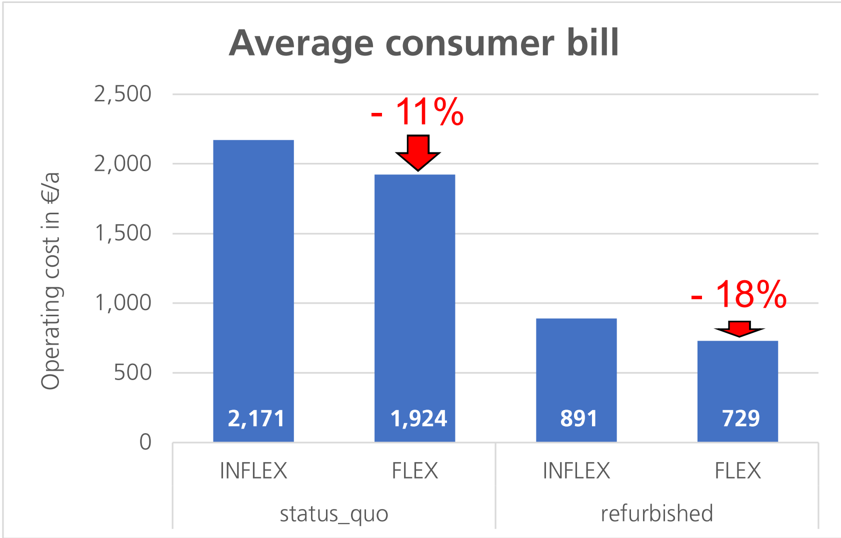
Scenario variations:

Building refurbishment level	
status_quo	No subsequent energetic refurbishment 65 GW_{el}
refurbished	Energetic refurbishment according to legal standard 32 GW_{el}

Heat pump user settings	
INFLEX	Inflexible operation 20 - 20.5°C
FLEX	Flexible operation 20 - 23°C

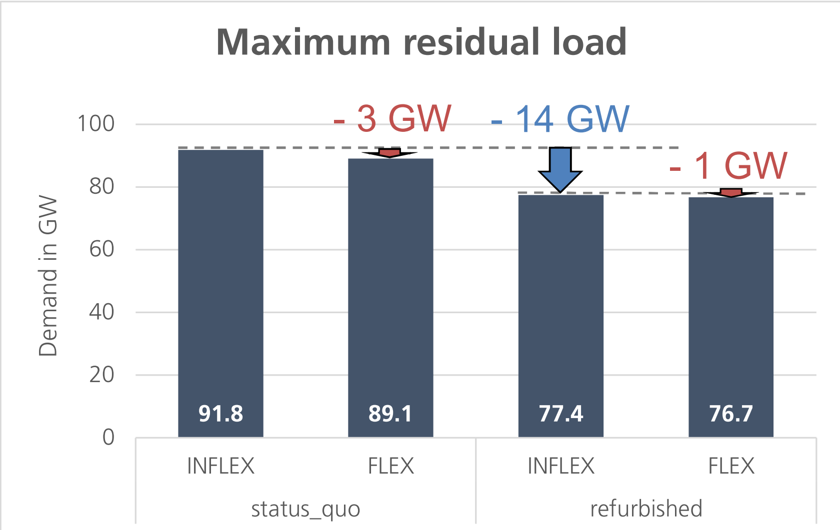
Building perspective

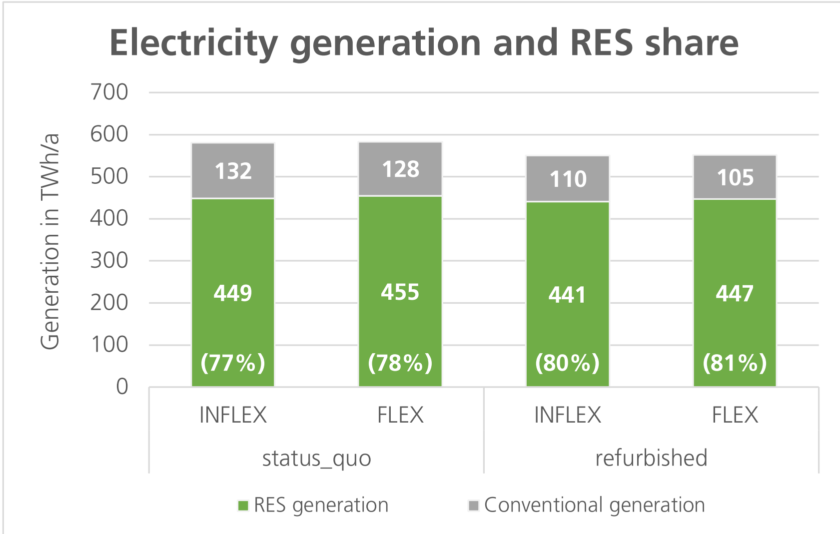




- Refurbishment: drastic demand and cost reduction
- Flexibility: slightly higher demand pays off

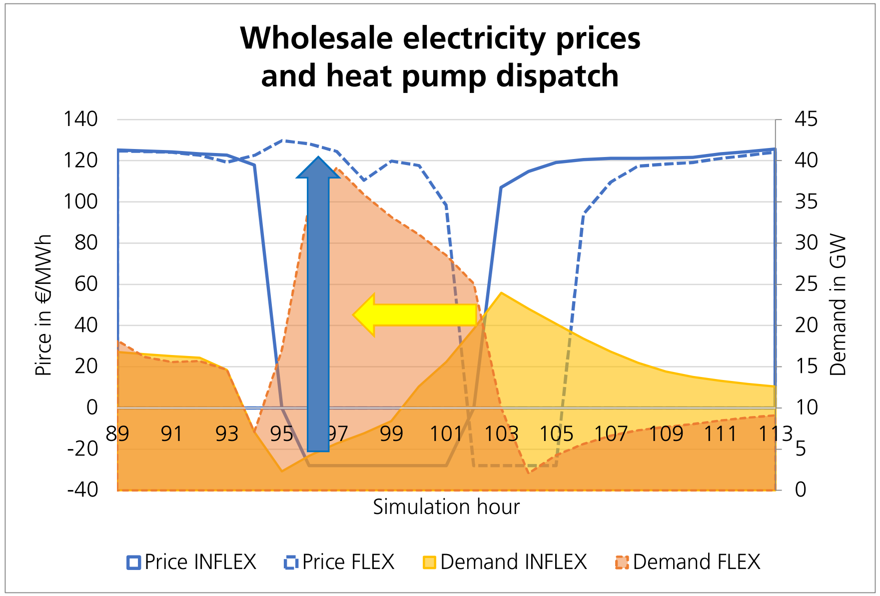
Power market perspective



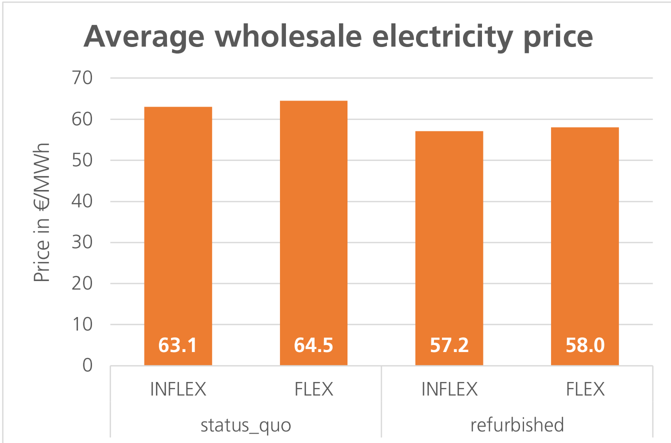


- Flexibility: slightly lower backup requirements and RES curtailment
- Refurbishment is key

The avalanche effect



- All flexible heat pumps receive the same price signal
  - ➢ Herding behavior
  - ➢ New price peaks and valleys → „avalanche effect“ [1,2]
- After all:
  - ➢ No new critical peaks
  - ➢ Average wholesale price hardly affected



1) M. Kühnbach, J. Stute, A.L. Klingler, *Impacts of avalanche effects of price-optimized electric vehicle charging - Does demand response make it worse?* Energy Strategy Reviews vo. 34, 2021
2) S. Gottwalt et al., *Demand side management - A simulation of household behavior under variable prices*, Energy Policy, vol 39, 2011

Conclusion

- **Building refurbishment** prior to heat pump installation…
  - Significantly reduces heat pumps' electricity demand and consumer bill
  - Considerably cuts power system's residual load

- **Flexibility** by users…
  - Is easy on the wallet
  - Has only limited market potential
  - Triggers unwanted avalanche effects
    - Technical potential of buildings' thermal storage hardly exploited
    - Incentives probably not appropriate (static price components, no feedback included in price signal)

Thank you for your attention!

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