Future Grid Load of the Residential Building Sector

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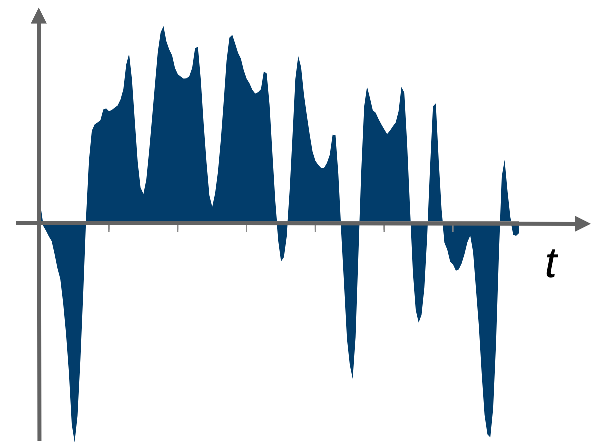
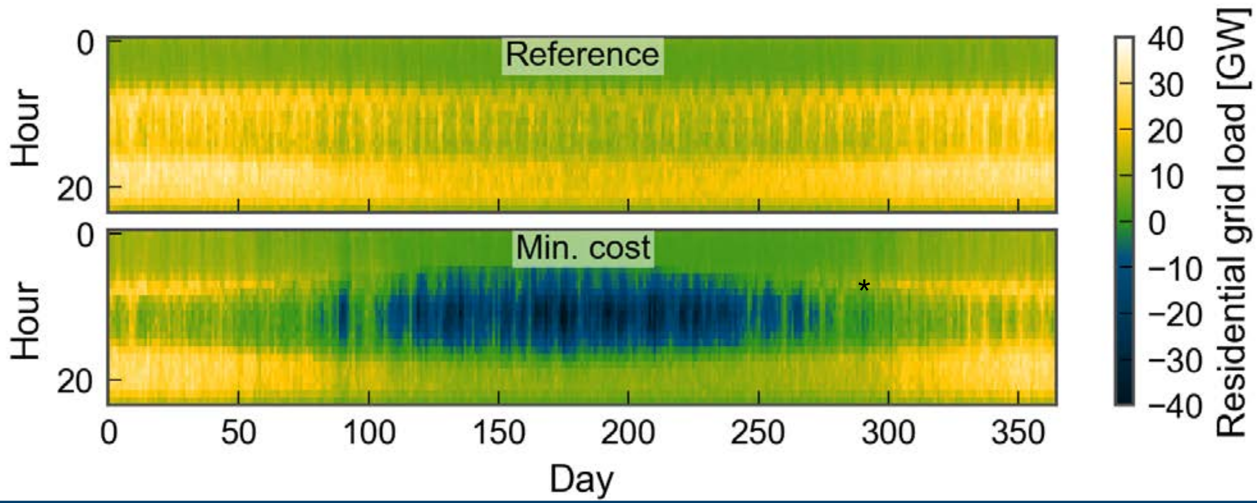


1. Motivation

Motivation - Change of the Residential Grid Load Until 2050[1]

Temporal



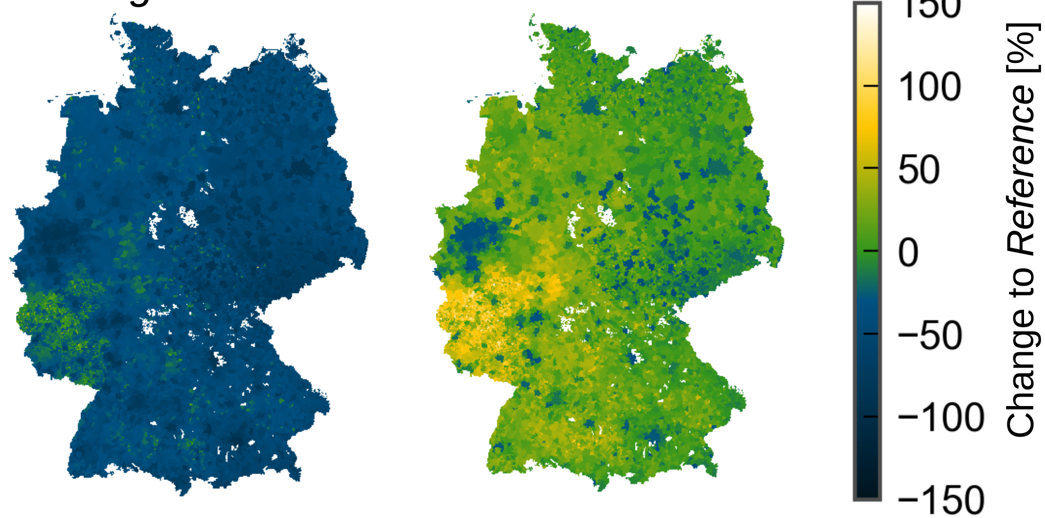
* Min Cost scenario case

Spatial

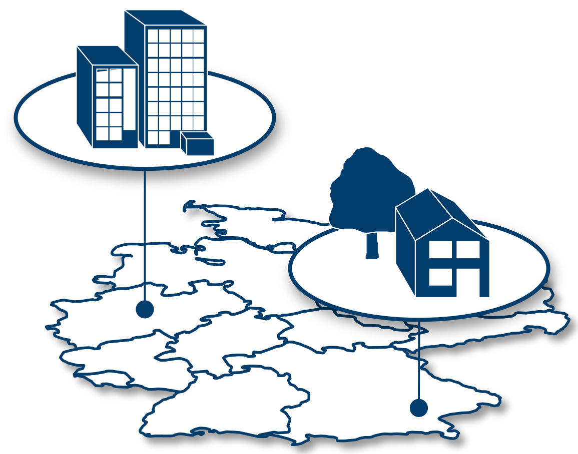
Reference **- 2013**
Cum. grid demand

Change of electricity load until 2050*

Cum. grid demand *Peak load*



[1] Kotzur, L., *Future Grid Load of the Residential Building Sector*, Thesis. 2018, RWTH Aachen.

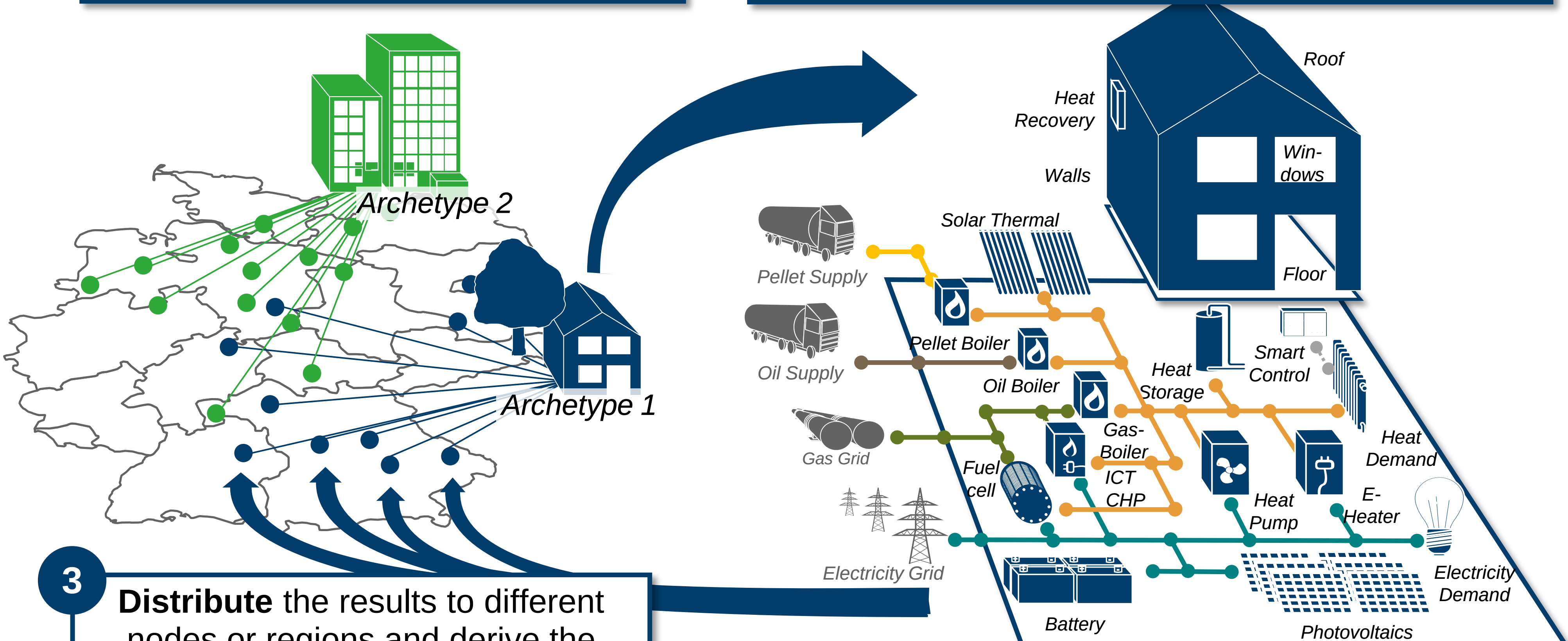


2. Methodology

Methodology – Overview

1 Aggregation of **200** spatially distributed **archetype buildings** from Census data on municipality level

2 Parallel optimization[1,2] to derive **cost minimal** choice of efficiency measures, as well as scaling and operation of supply technologies



3 **Distribute** the results to different nodes or regions and derive the change of energy demand

[1] Kotzur, L., et al., *Impact of different time series aggregation methods on optimal energy system design.* Renewable Energy, 2018. **117**: p. 474-487. **[2]** Kotzur, L., et al., *Time series aggregation for energy system design: Modeling seasonal storage.* Applied Energy, 2018. **213**: p. 123-135.

Methodology – Aggregation Algorithm

Problem

Indices
- $p \in P$ set of parameters
- $m \in M(P)$ expressions
- $n \in N$ nodes
- $b \in B$ archetype buildings

Constants
- $d_{n,m,p}$ parameter distribution
- w_p weighting of parameters

Variables
- $x_{b,n}$ occurrence of buildings in node
- $\delta_{b,m,p}$ parameter expression of building

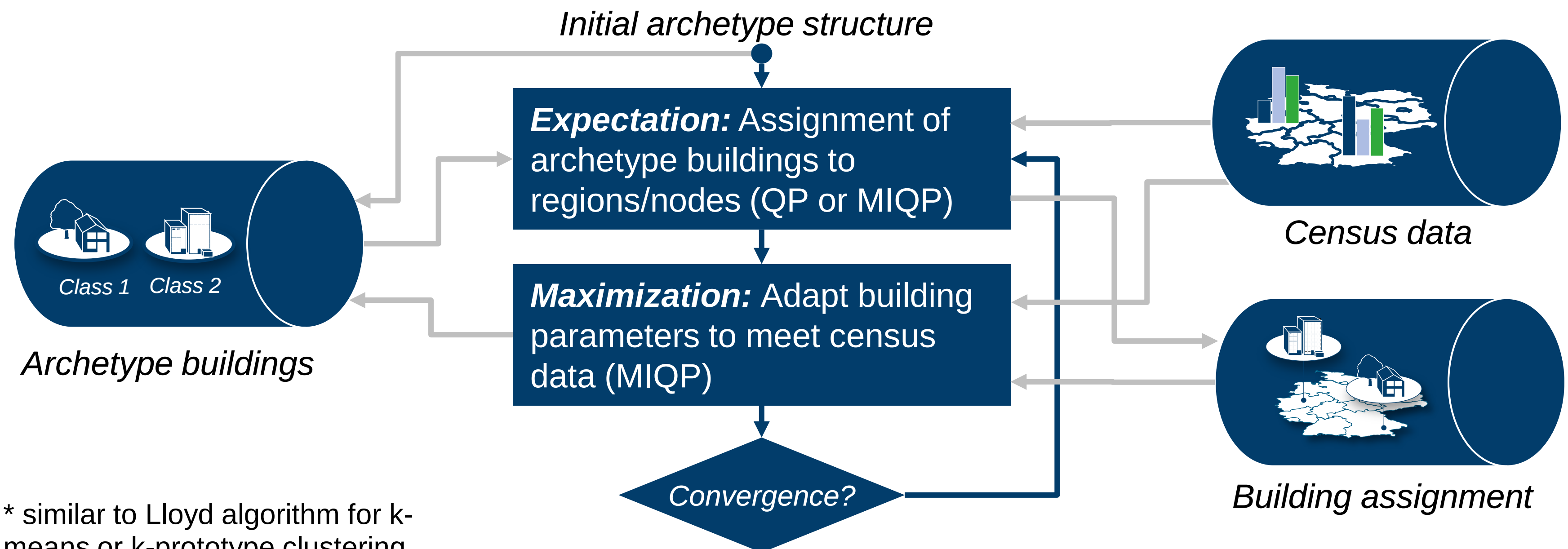
Building age, living area, … [1]

Minimize the error between data[1] and archetype buildings

$$\min_{x,\delta} \sum_{n \in N} \sum_{p \in P} w_p \sum_{m \in M(p)} \left[d_{n,m,p} - \sum_{b \in B} x_{b,n} * \delta_{b,m,p} \right]^2$$

MINLP: Not solvable for municipalities

Solution*

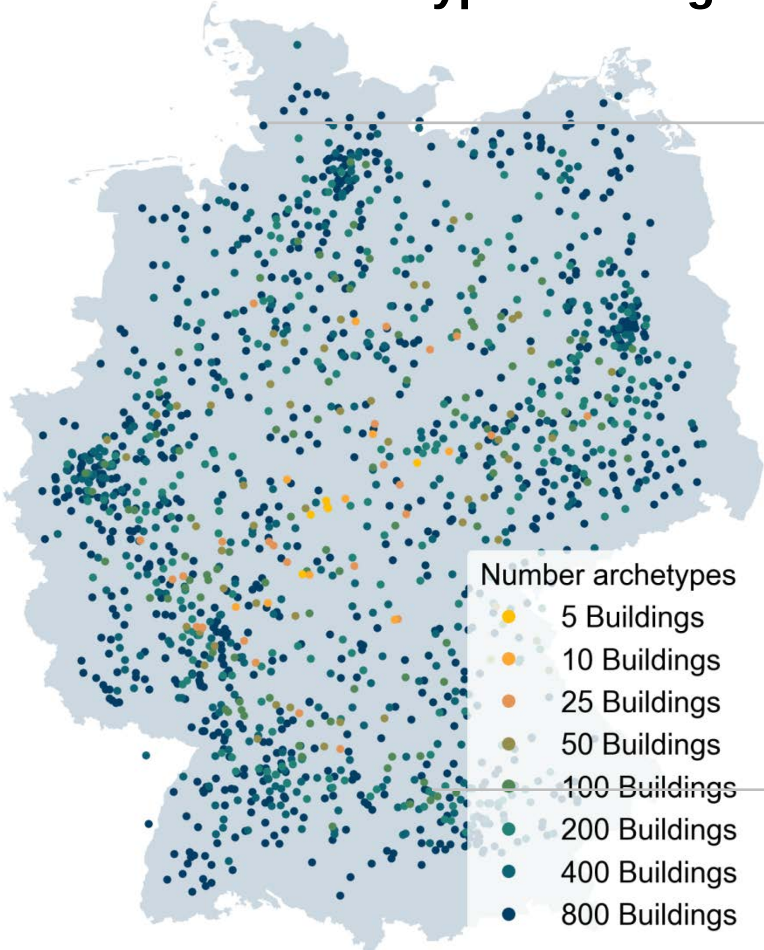


* similar to Lloyd algorithm for k-means or k-prototype clustering

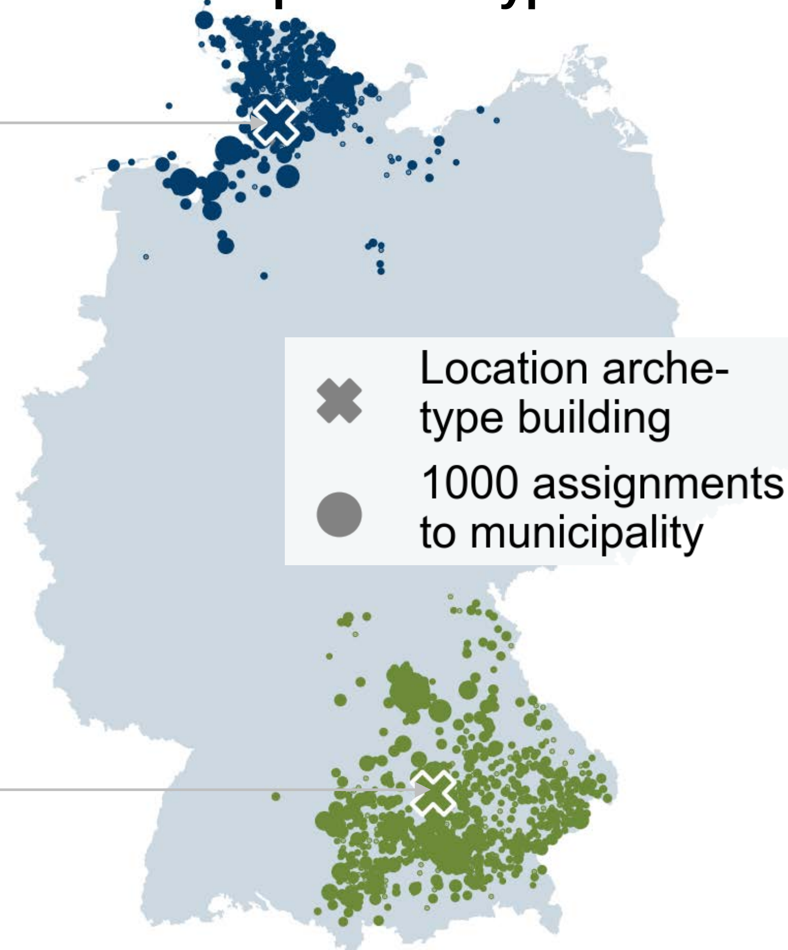
[1] Statistisches Bundesamt, *Zensus 2011*. 2016. https://www.zensus2011.de/DE/Home/home_node.html

Methodology - Plausibility of the Aggregated Archetypes

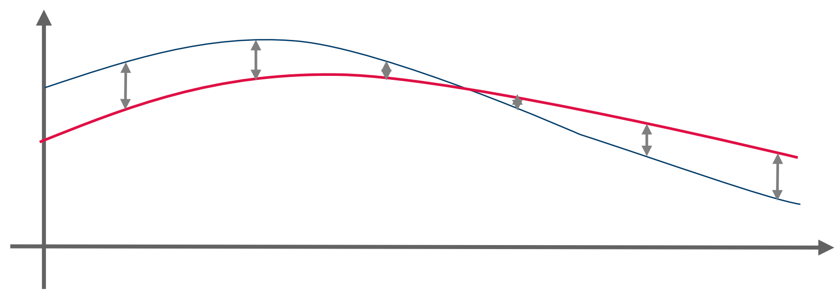
Resulting locations for a varying number of archetype buildings



Regional representation of two example archetypes*



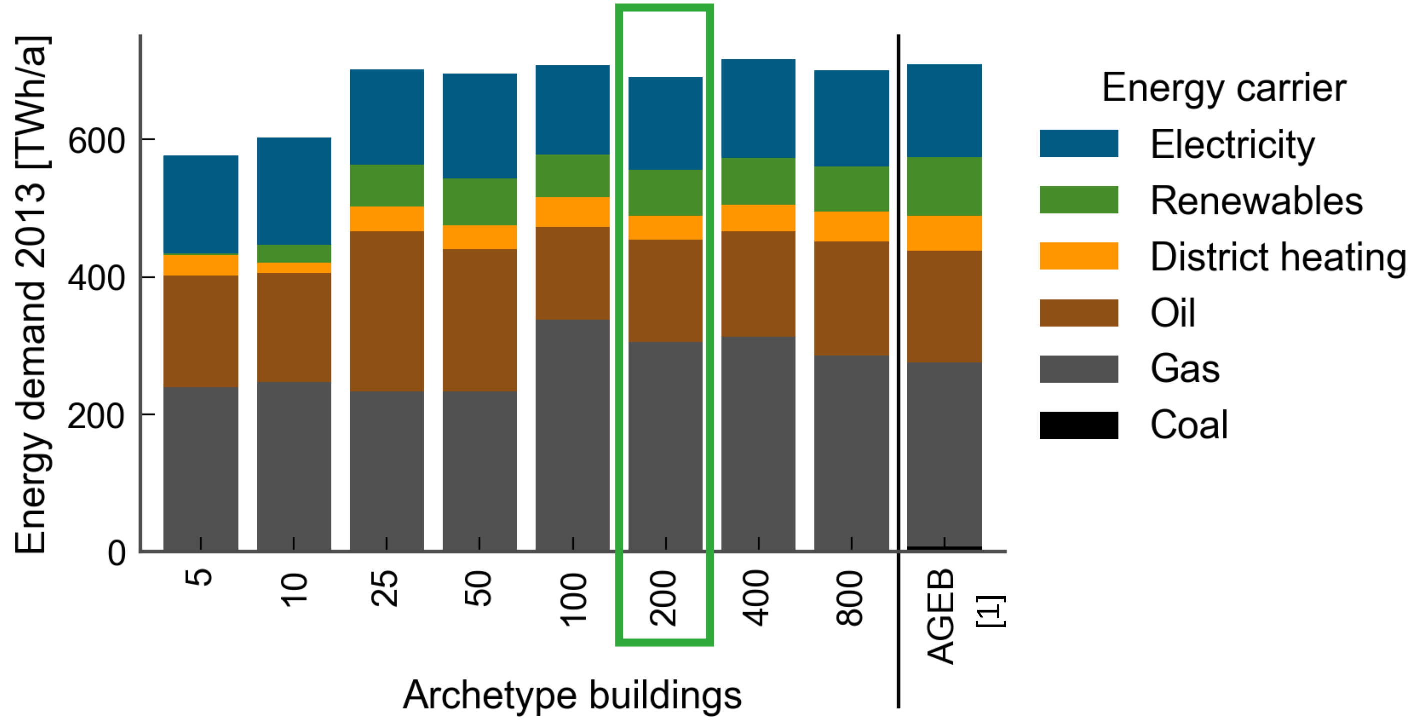
*example buildings are the most ***northern*** and ***southern*** archetype single family house with heat pump supply for the case of 800 archetype buildings

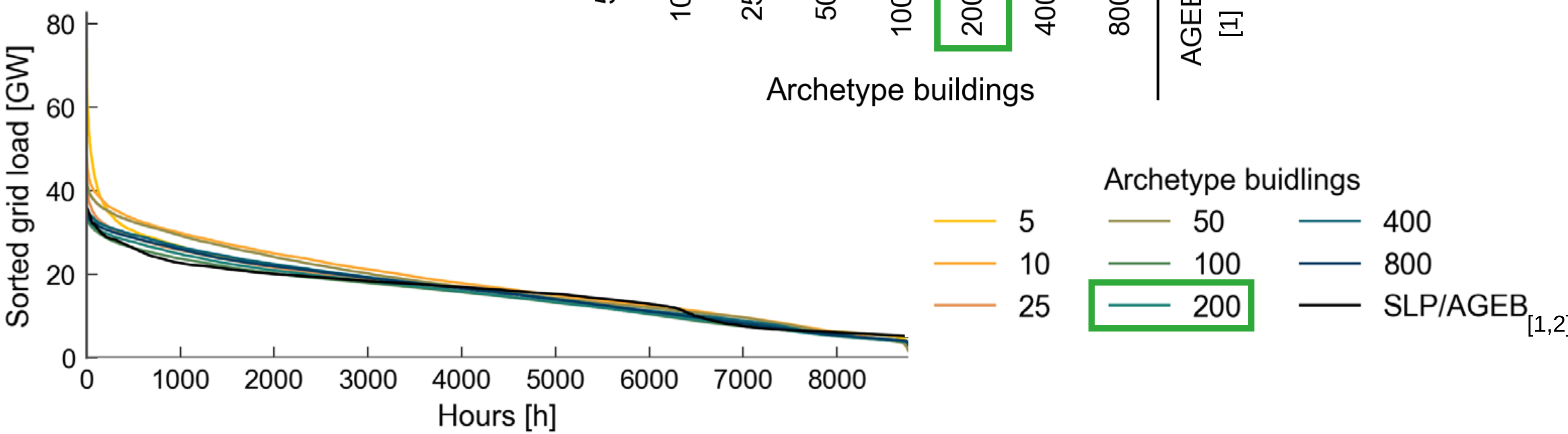


3. Validation

Validation – Variation of the Number of Archetype Buildings

- Existing supply system choice
- Optimized scale and operation
- Current refurbishment status





[1] AGEB, *Auswertungstabellen zur Energiebilanz Deutschland 1990 bis 2016*. 2017.

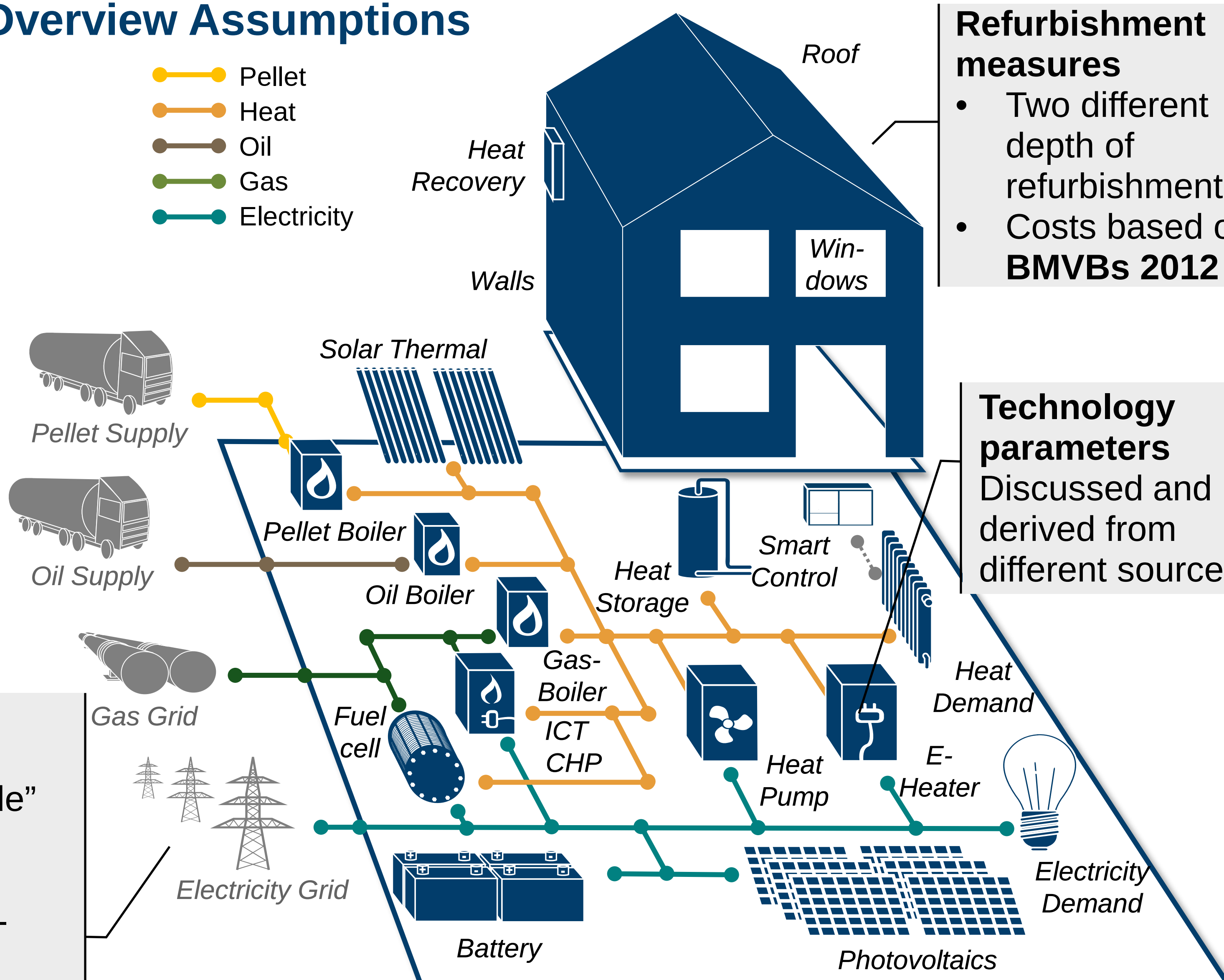
[2] BDEW, *Standardlastprofile (SLP)*. 2011, Bundesverband der Energie- und Wasserwirtschaft.

4. *Min Cost* Scenario in 2050

2050 *Min Cost* – Overview Assumptions

- Sole optimization of annualized cost
- Interest rate 3%
- Invest reduction assumed for photovoltaics, batteries and fuel cells
- Variable discrete heat supply temperature levels for optimized heat pump performance

Resource prices
Based on “Energie-effizienzstrategie Gebäude” **[BMWi2015]** and “Entwicklung der Energiemärkte – Energie-referenz-prognose“ **[EWI, Prognos, GWS 2014]**

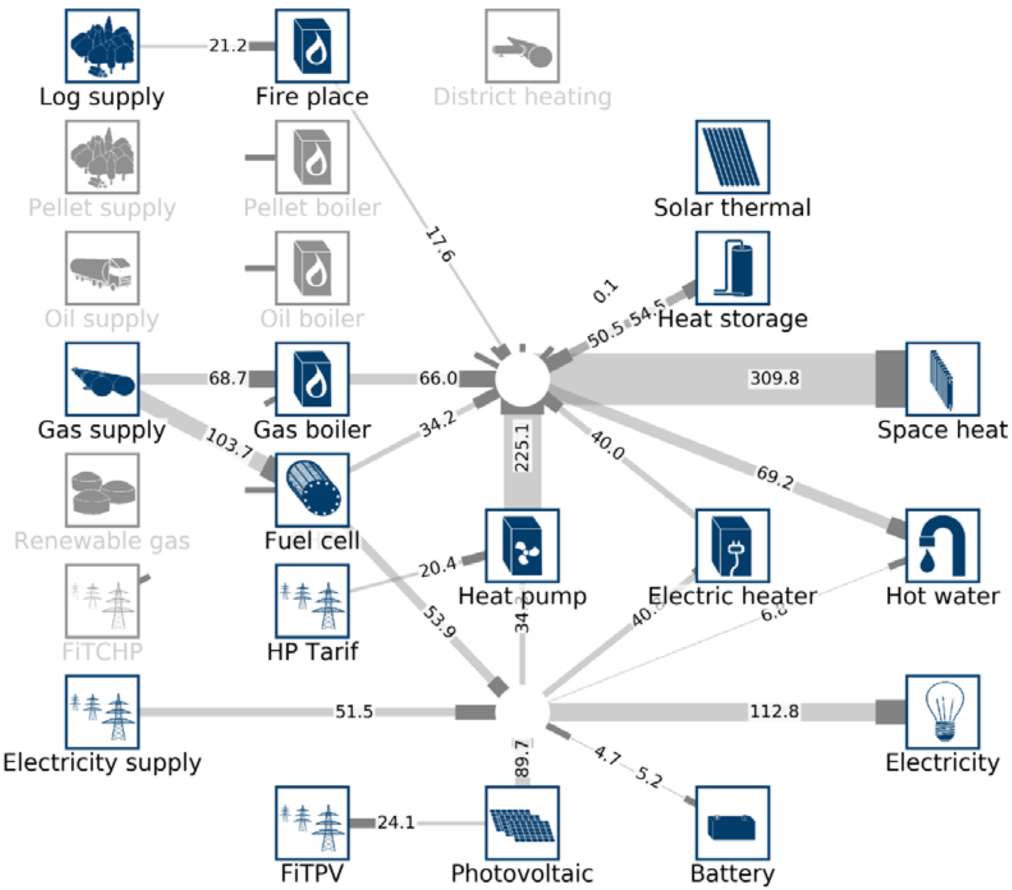


Refurbishment measures
- Two different depth of refurbishment
- Costs based on **BMVBs 2012**

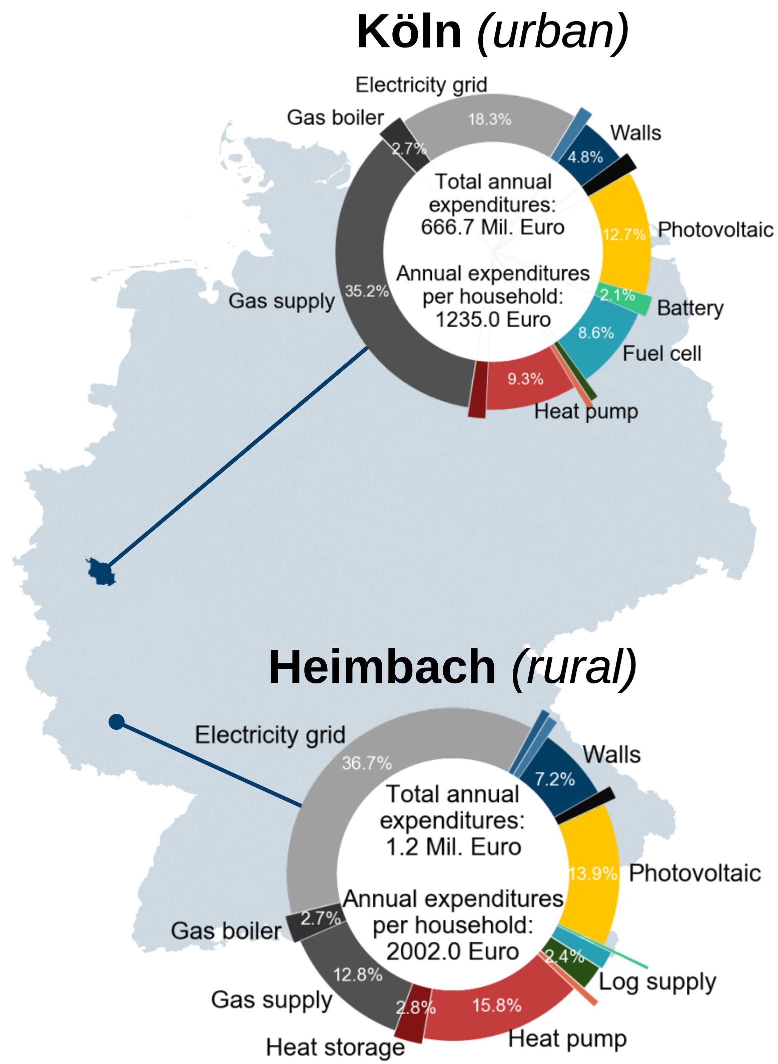
Technology parameters
Discussed and derived from different sources

2050 *Min Cost* – Aggregated Energy Flows and Regional Annual Cost

Total annual energy flows in TWh/a

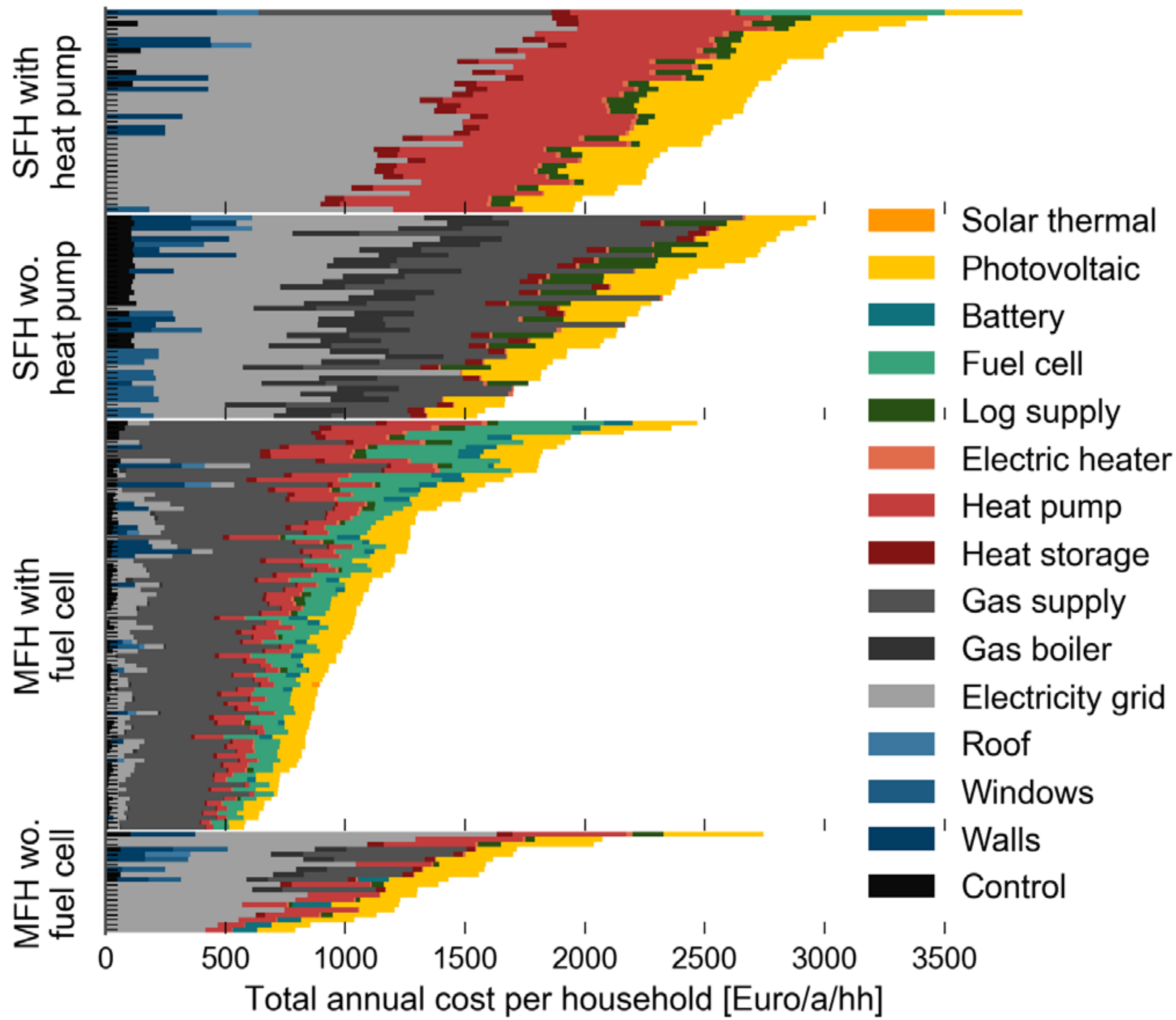


Regional annual expenditures in Euro/a



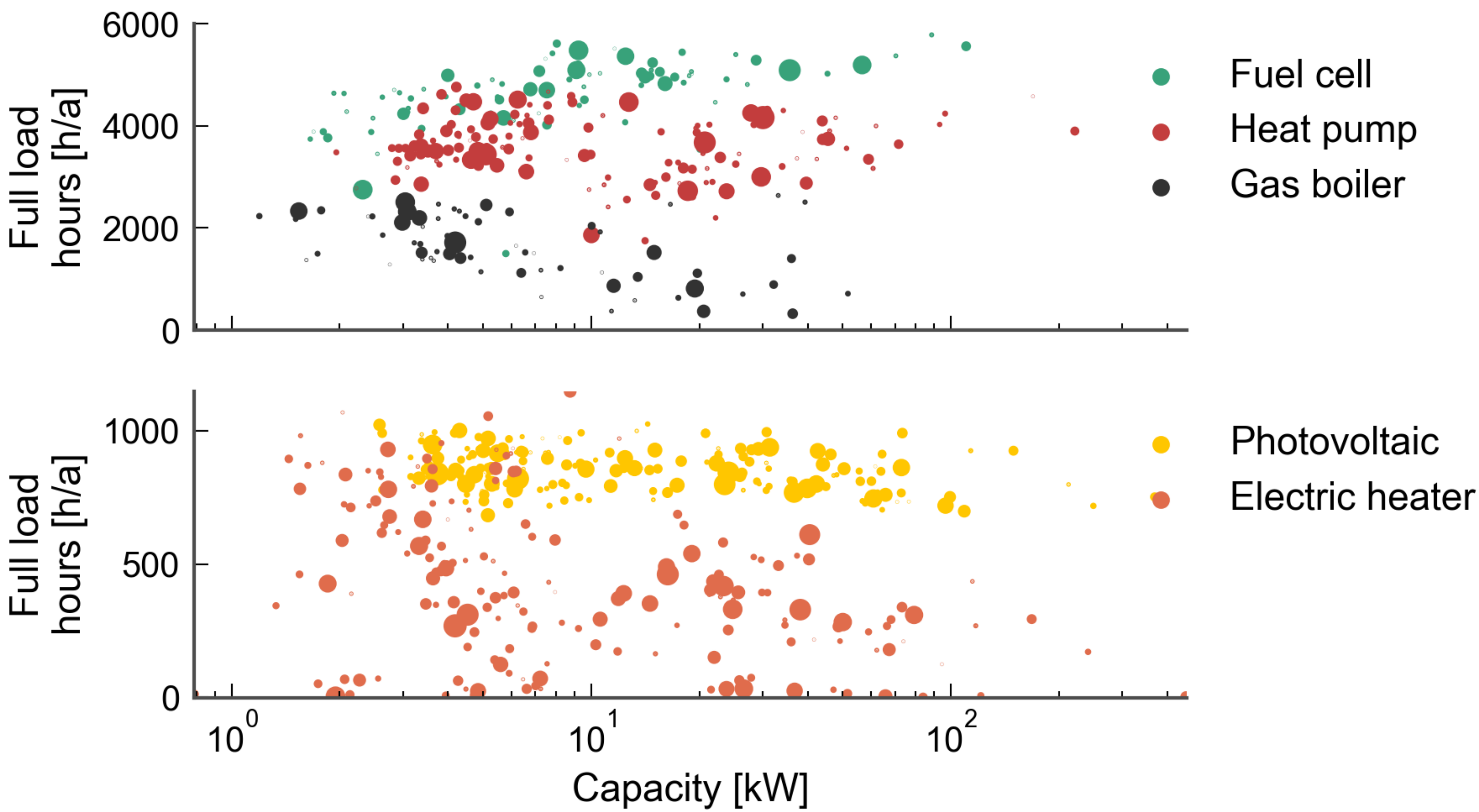
GHG-footprints and energy prices based on “Energiereferenzprognose“;
(1) footprint of 122 g-CO_2-eq/kWh; (2) only energy related investment cost;

2050 *Min Cost* – Annual Cost per Household for the Different Archetypes



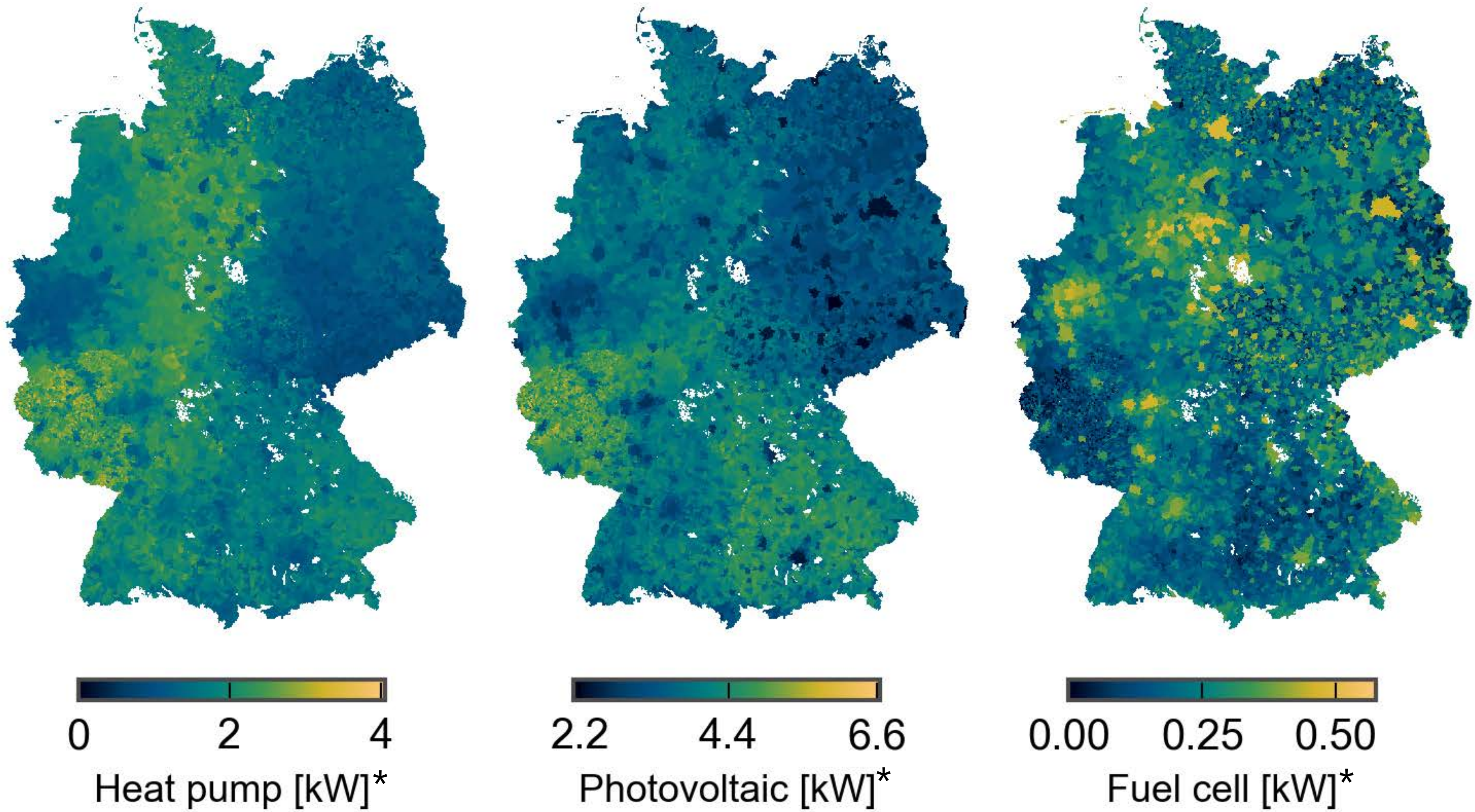
*hh = household, SFH = Single Family House, MFH = Multi Family House

2050 *Min Cost* – Operation and Scale of the Main Residential Supply Technologies



*bubble size represents for the total occurance number of the archetype

2050 *Min Cost* - Spatial Distribution of Key Technology Installations



*per household

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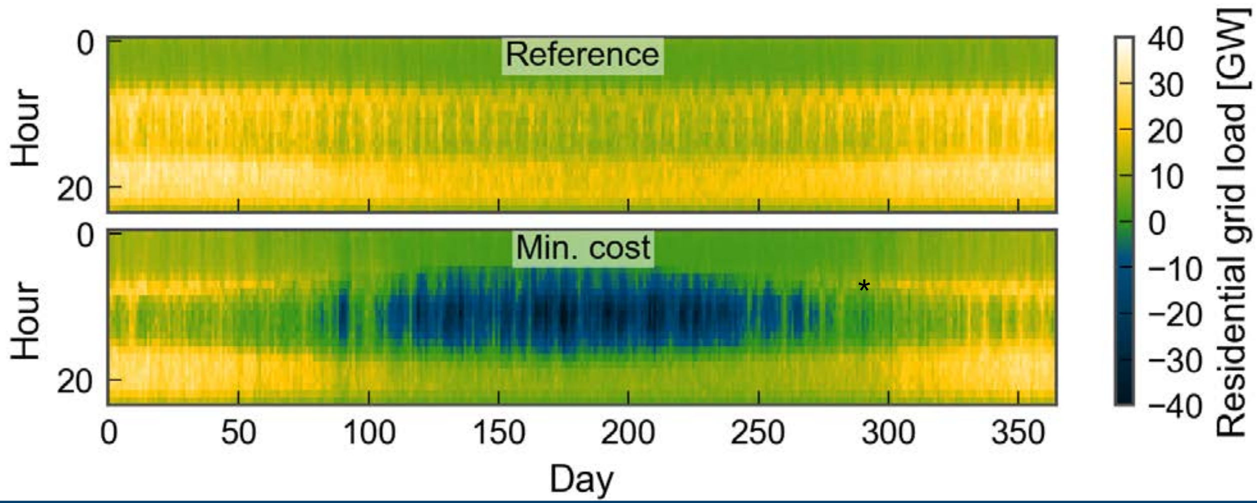
2050 *Min Cost* – Resulting Change of the Residential Grid Load

Temporal



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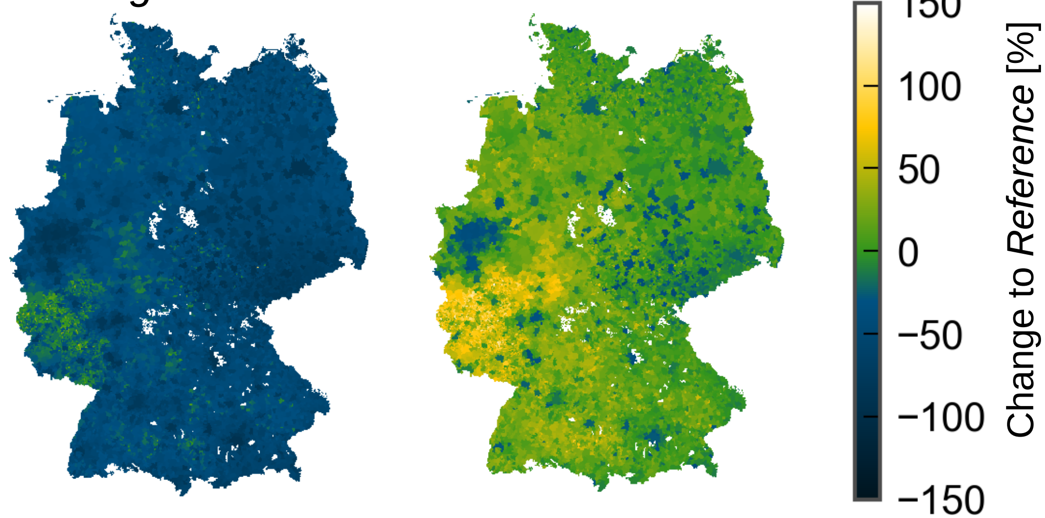
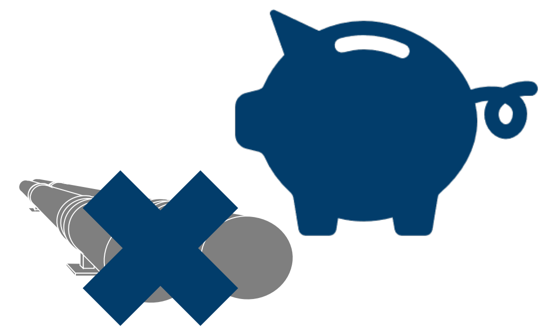
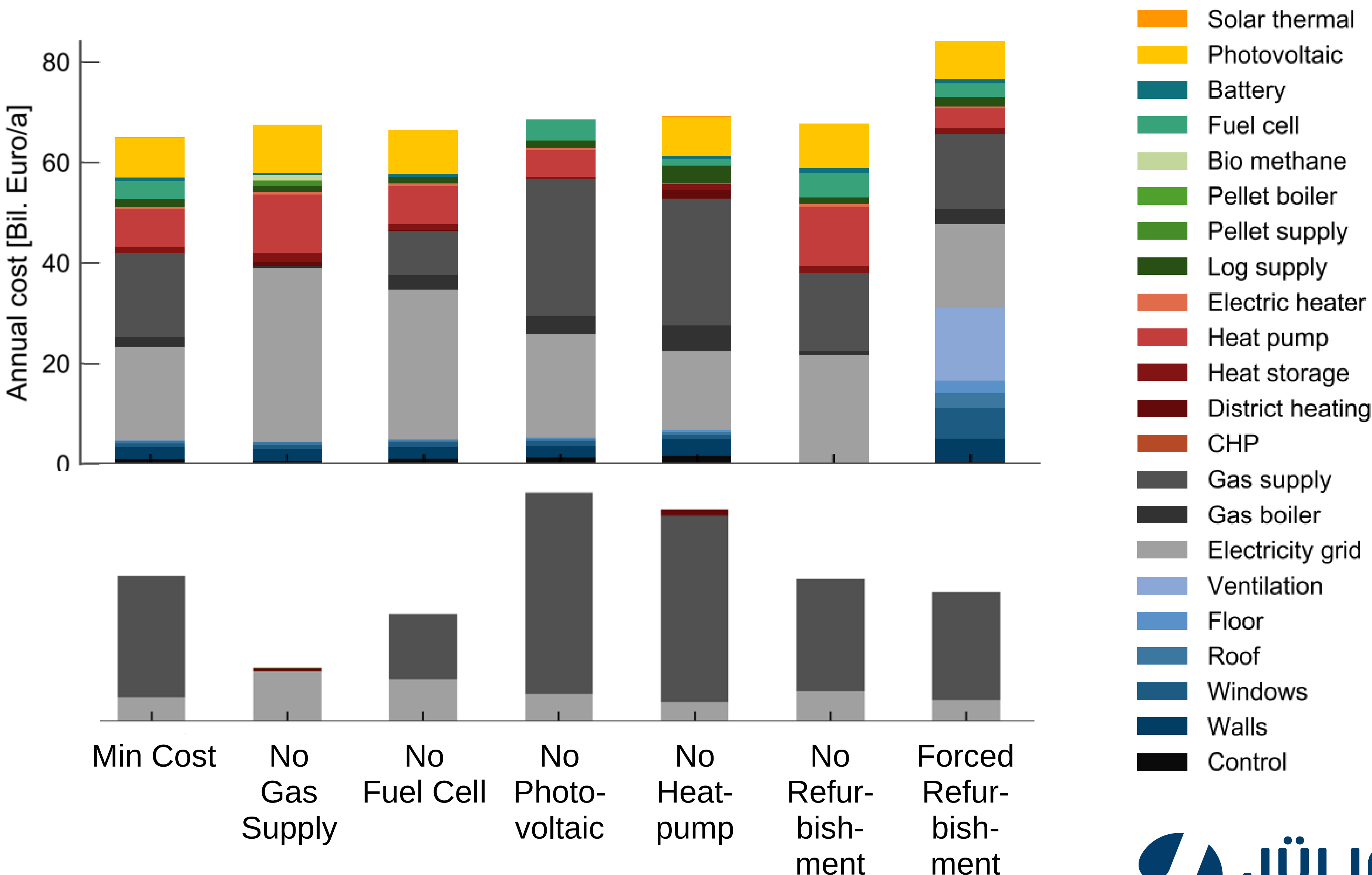




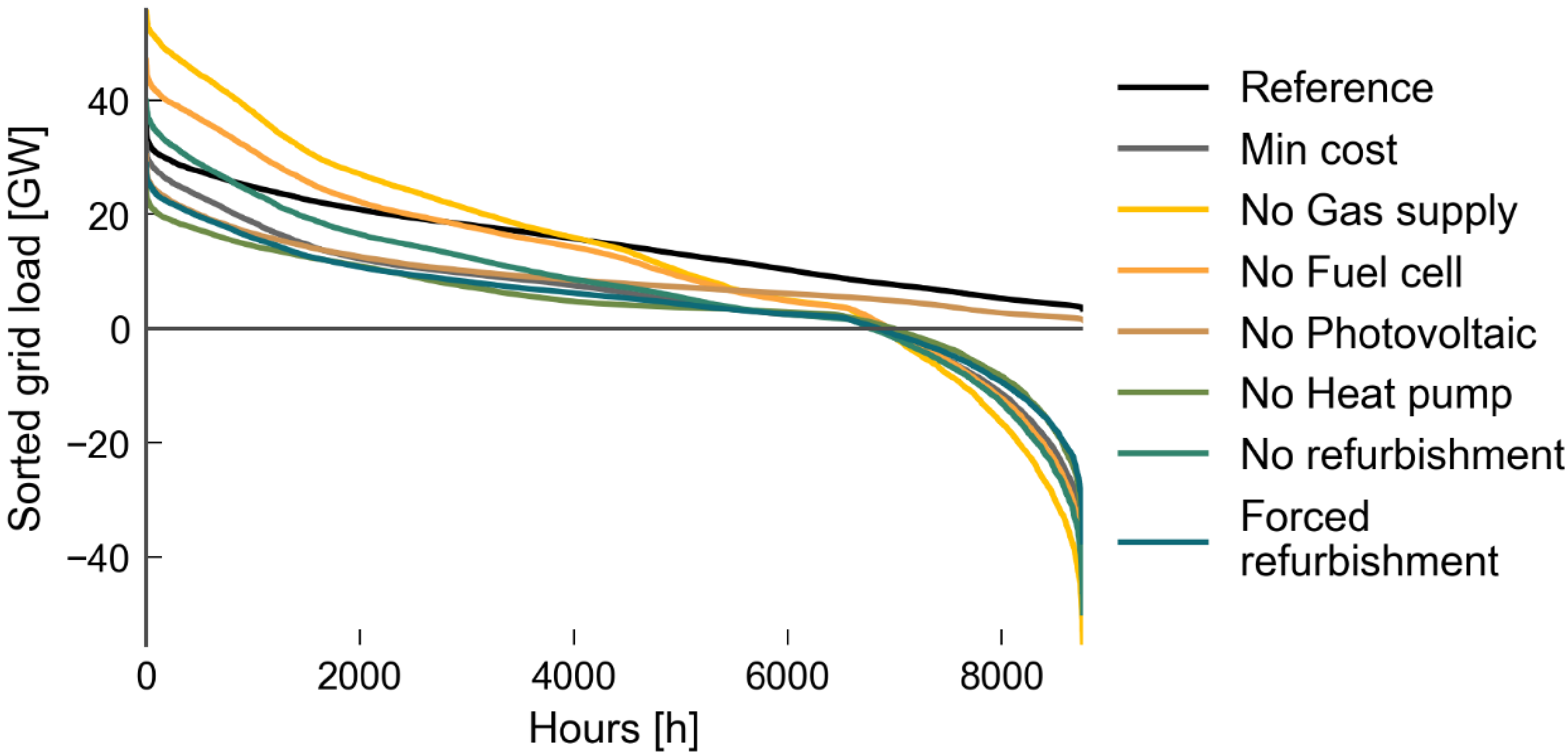
5. *Min Cost* Scenario in 2050

Value Of Analysis

2050 *Min Cost Value Of* analysis - Total Annual Cost and GHG-footprint



2050 *Min Cost Value Of* Analysis - Sorted Grid Load



6. Conclusion

Conclusions

- *Heat pumps and photovoltaics are the central technologies* for a GHG neutral building stock and will increase the seasonal variation of the residential load
  - 90 TWh/a of photovoltaic electricity can be self-consumed
- Refurbishment measures are expensive and only chosen in case the building is in the cosmetic refurbishment cycle wherefore *space heat demand just decreases by 30 %*
  - Most chosen efficiency option is the occupancy controller
- *Fuel cells can compensate the seasonal variation* in a transient phase with their flexible and efficient co-generation
  - A GHG neutral fuel would further allow the operation as renewable backup generator
  - Enforcing economic effects between fuel cells and heat pumps are observable
- *Rural areas are more critical regarding a changing electricity* load than the urban areas since the balancing co-generation units are not cost efficient in small scales

http://hdl.handle.net/2128/21115

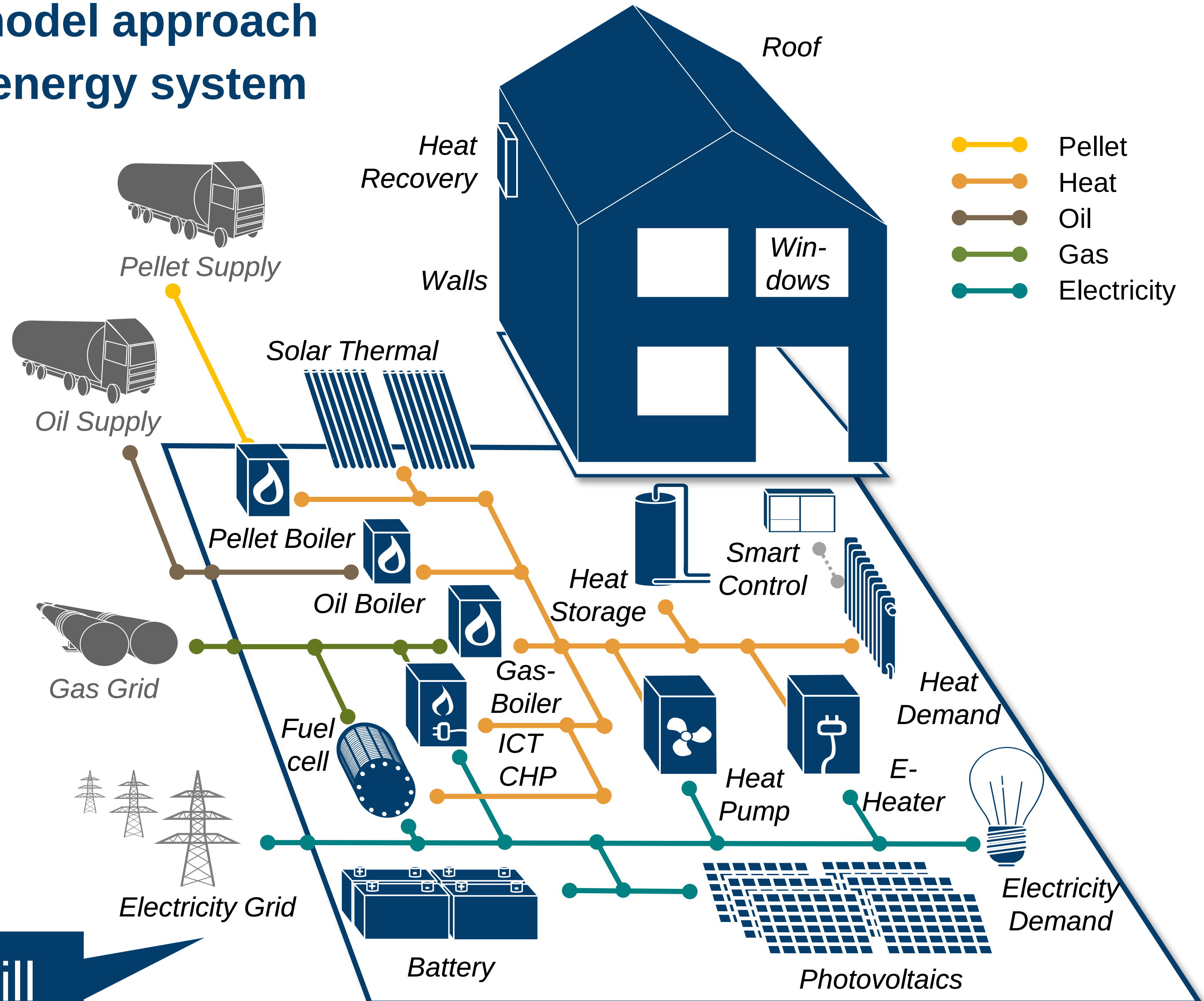
Thank you for the attention!

Danke für Ihre Aufmerksamkeit!

Single
Building Optimization

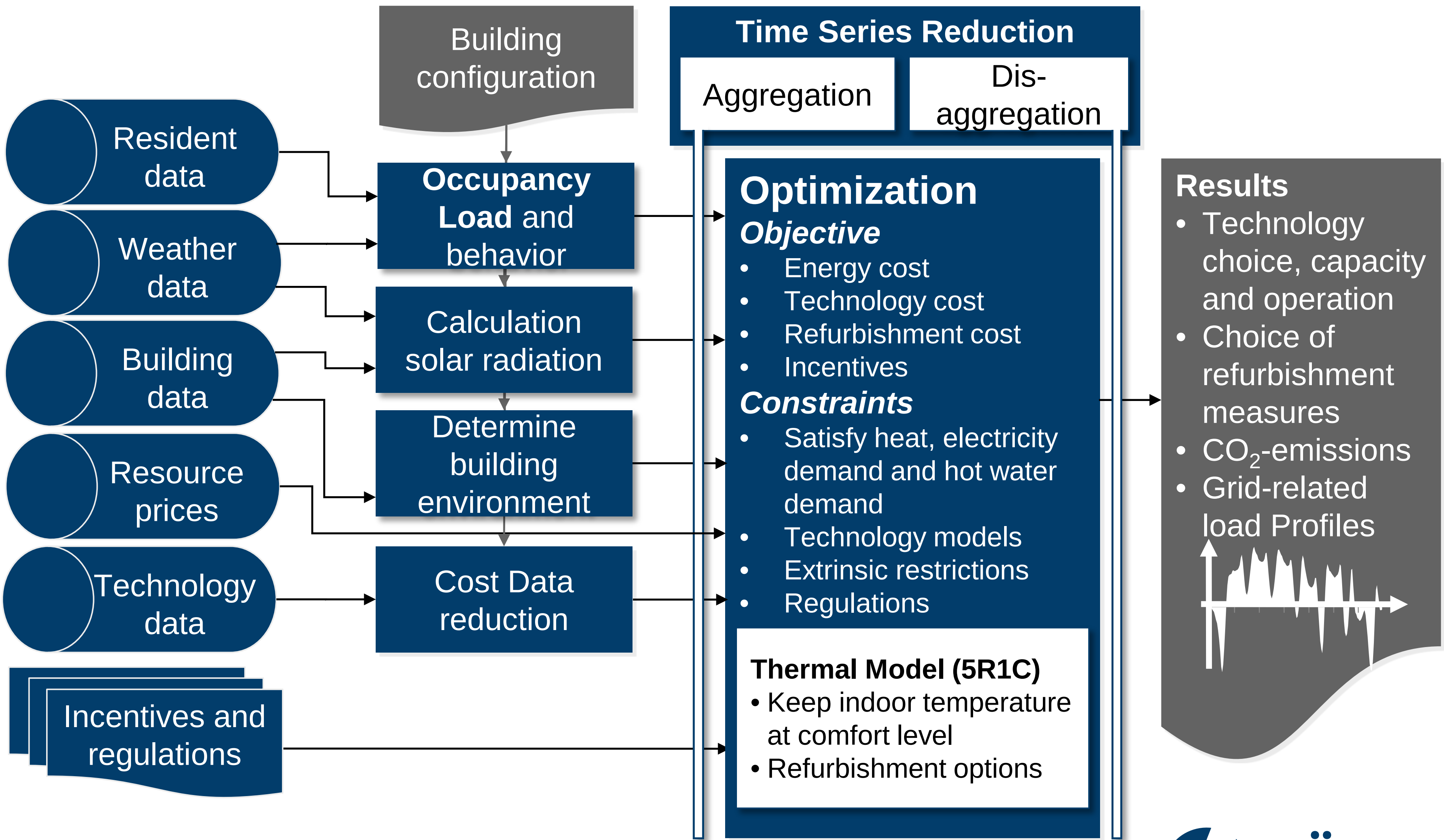
Super-structure and model approach of the single building energy system

- ***Linear*** system ***operation*** model
- ***Discrete choice*** if a measure is chosen, and ***continuous scaling***
- ***Two level*** approach to determine optimal energy system design:
  1. Determine ***structure*** of with ***time series aggregation*** (small MILP)
  2. Derive exact ***scaling and operation*** with the ***full time series*** (LP)



Objective: How will the grid load change?

Single building parameterization and optimization



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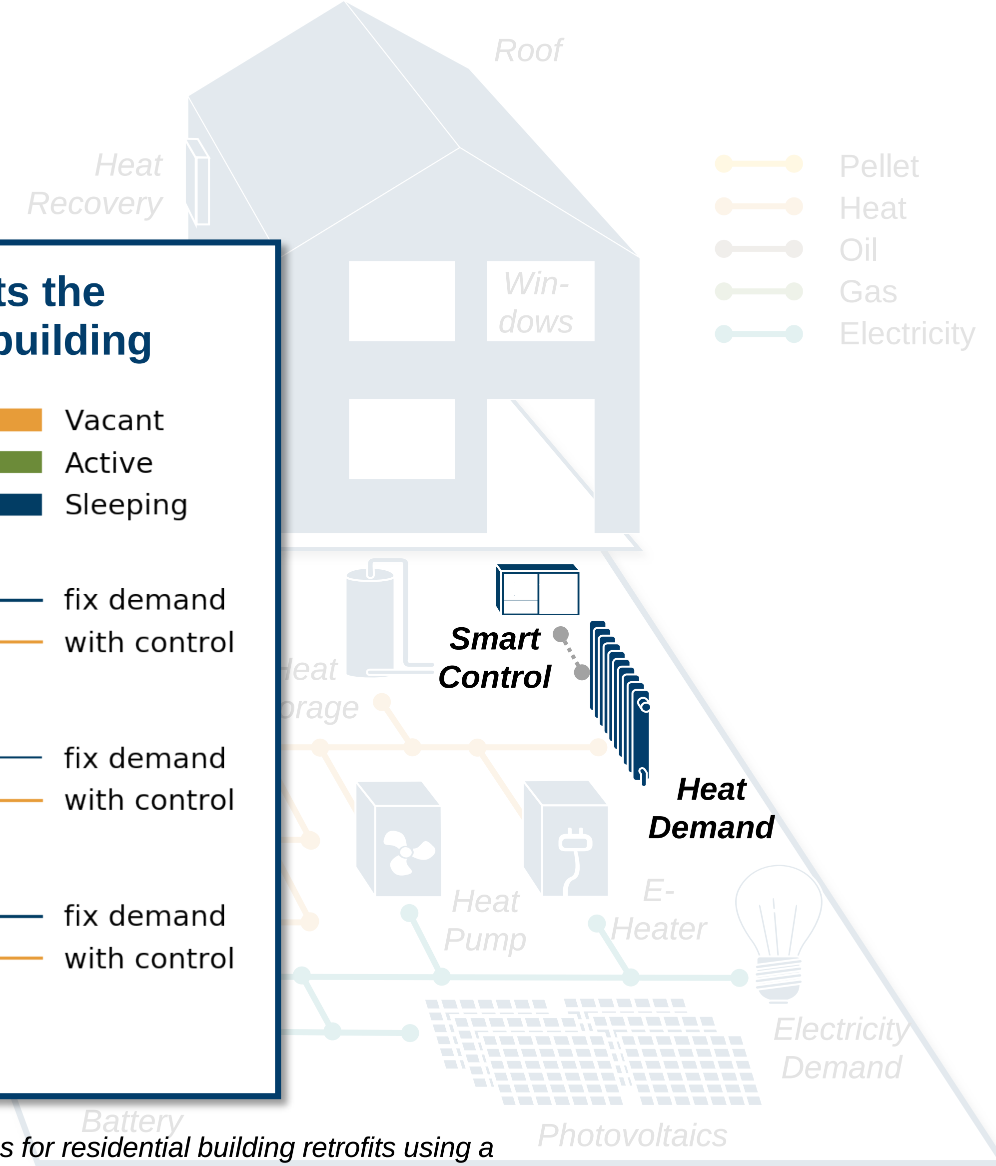
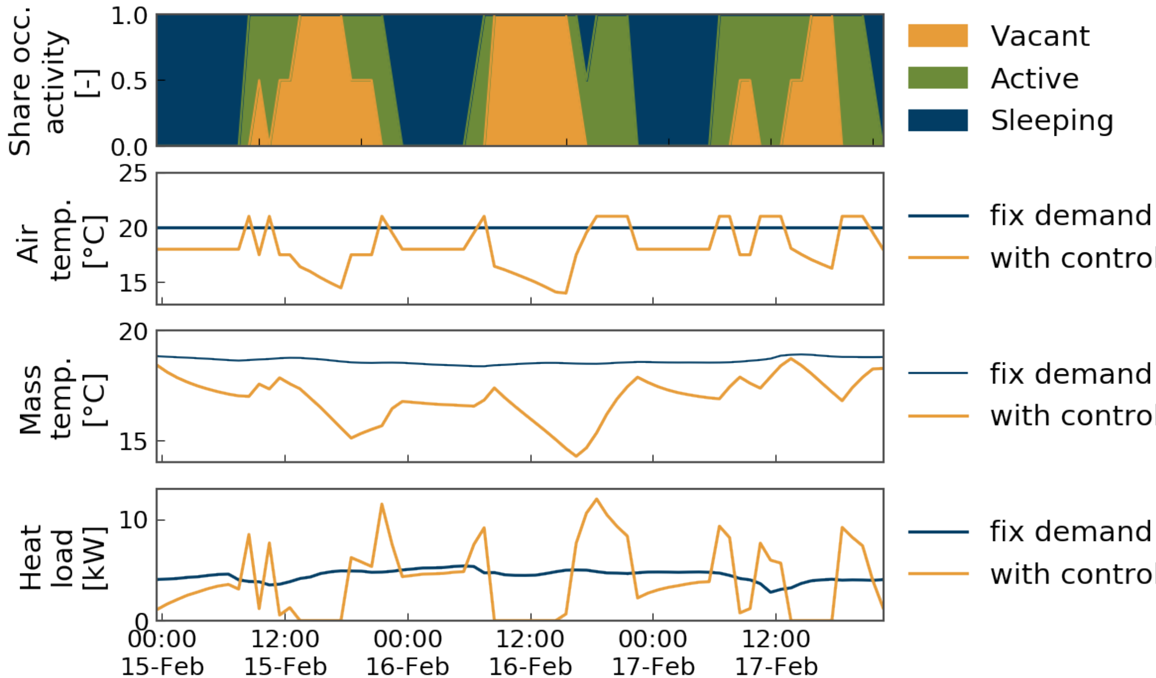
Super-Structure and Model Approach of the Single Building Energy System



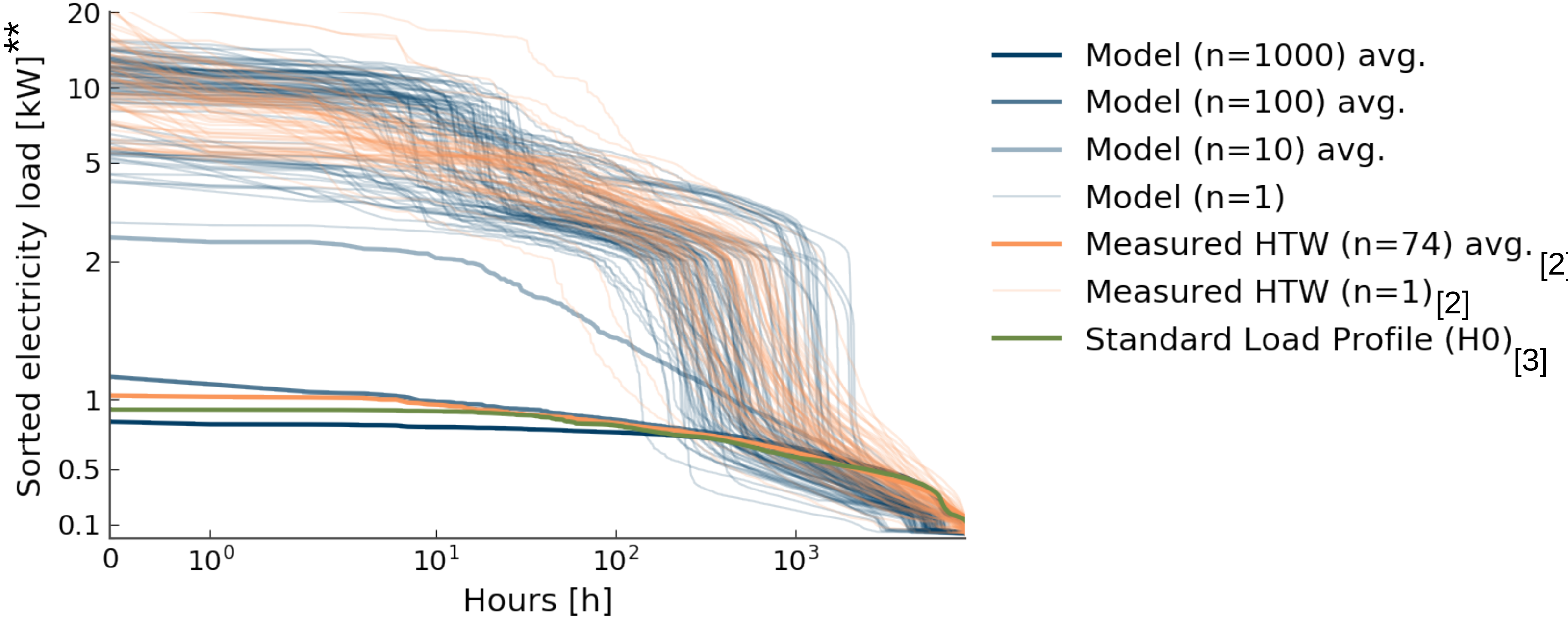
Integrated heat demand model[1] which respects the occupancy activity[2] and thermal mass of the building



[1] Schütz, T., et al., *Optimal design of energy conversion units and envelopes for residential building retrofits using a comprehensive MILP model.* Applied Energy, 2017. **185**: p. 1-15.1.

[2] Richardson, I., M. Thomson, and D. Infield, *A high-resolution domestic building occupancy model for energy demand simulations.* Energy and Buildings, 2008. **40**(8): p. 1560-1566.

The Markov-Chain based electricity demand model* is able to cover the load fluctuation on different aggregation levels



* based on [1], implemented to Python for parallelization, data updated to fit German load profiles
** normalized to a typical household demand with 3500 kWh/a

[1] Richardson, I., M. Thomson, D. Infield and C. Clifford (2010). "Domestic electricity use: A high-resolution energy demand model." Energy and Buildings **42**(10): 1878-1887.

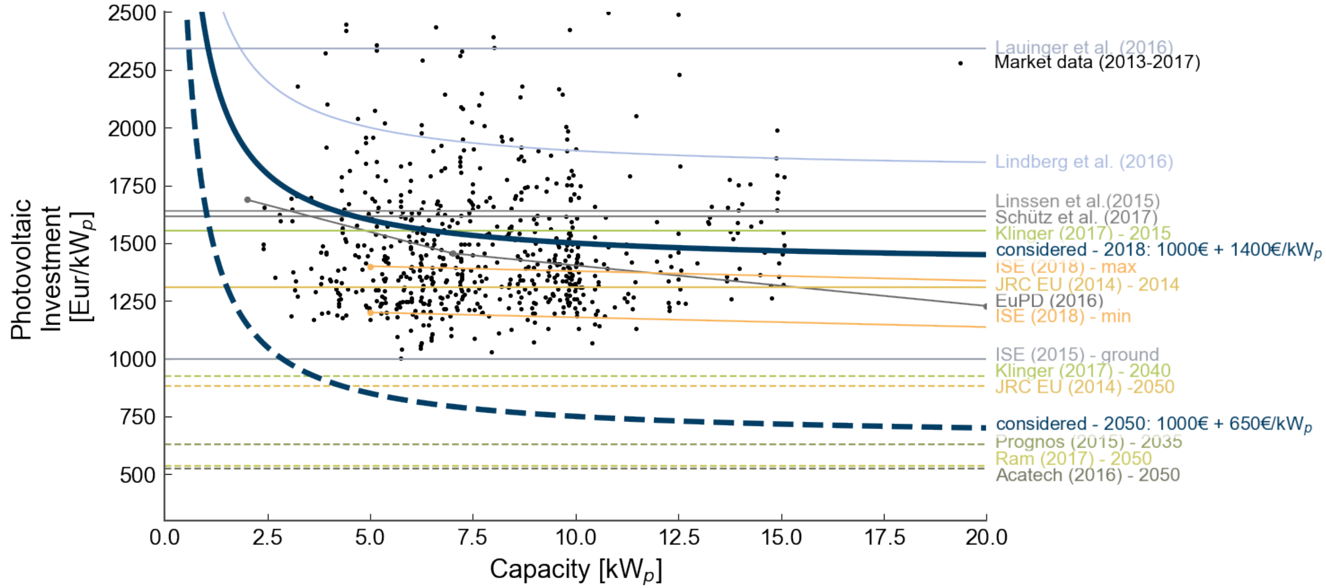
[2] BDEW, *Standardlastprofile (SLP)*. 2011, Bundesverband der Energie- und Wasserwirtschaft.

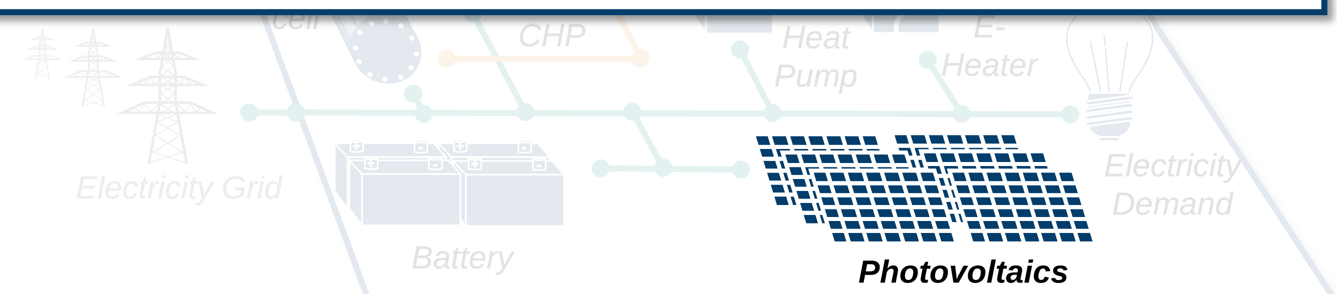
[3] Tjaden, T., J. Bergner, J. Weniger and V. Quaschning (2015). "Repraesentative elektrische Lastprofile fuer Wohngebaeude in Deutschland auf 1-sekuendiger Datenbasis."

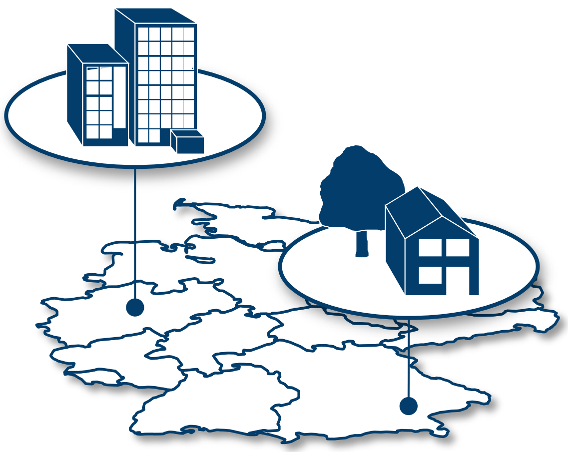
Super-Structure and Model Approach of the Single Building E…

- ***Linear*** system ***operation*** model
- ***Discrete choice*** if a ***technology*** or efficiency measure is chosen, and ***continuous scaling*** of the technology
- ***Two level*** approach to determine optimal energy system design:
  1. Determine ***structure*** of energy system together with ***time series aggregation*** (small MILP)
  2. Derive exact ***scaling and operation*** with the ***full time series*** (LP)

Cost modeling with binary decision and continuous scaling variable allows the integration of simplified economy of scale

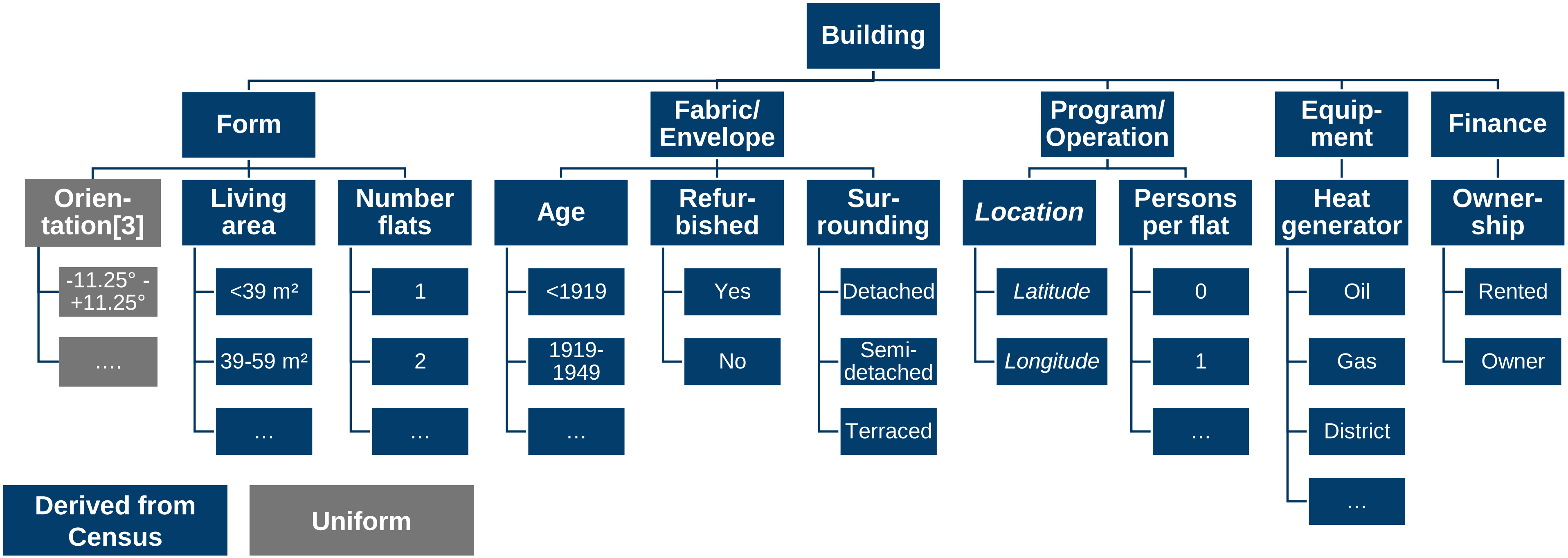






Aggregation of Archetype Buildings

Categorization of building characteristics[1,2] relevant for the energy performance on municipality level



The goal is to find a ***sufficient number*** of archetype buildings to ***represent*** all buildings, while minimizing their number in order keep ***computation load small***

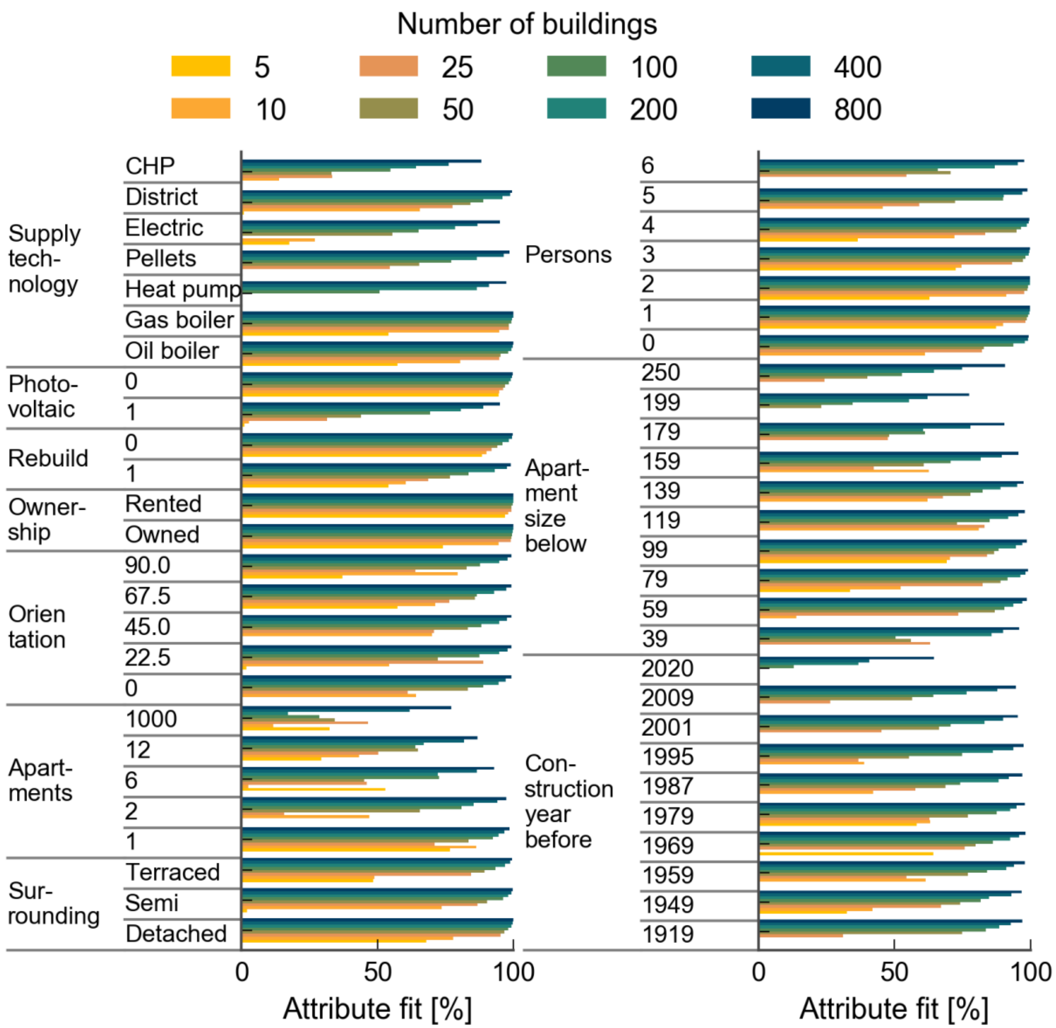
[1] Torcellini, P., et al. *DOE commercial building benchmark models*. in *ACEEE summer study on energy efficiency in buildings*. 2008.

[2] Corgnati, S.P., et al., *Reference buildings for cost optimal analysis: Method of definition and application.* Applied Energy, 2013. **102**: p. 983-993.

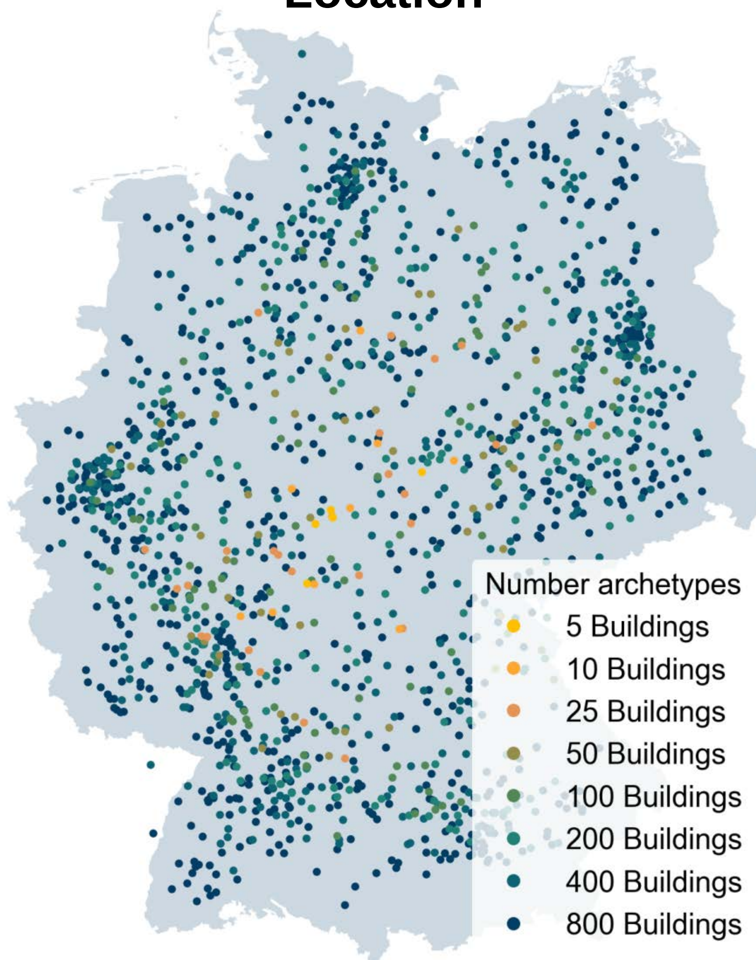
[3] Mainzer, K., et al., *A high-resolution determination of the technical potential for residential-roof-mounted photovoltaic systems in Germany.* Solar Energy, 2014. **105**: p. 715-731.

Impact of the number of archetype buildings on the spatial resolution and the representation of the categorical attributes

Categorical attribute fit



Location



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