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Household specific self-consumption of photovoltaic-based power generation

A comprehensive parametric study to increase the reliability of energy consulting.

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Agenda

1. Introduction
2. Scope
3. Methodology
   a. Stochastic occupant behavior modeling
   b. Building simulation & parametric study
4. Results
   a. Occupant behavior model
   b. Evaluation of PV self-consumption and self-sufficiency
5. Conclusion and outlook

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Introduction

- Private households cause a substantial share of GHG emissions in Germany
- Energy performance certificates (EPC) consider building related power generation
- PV self-consumption and self-sufficiency have a major impact on the overall profitability and acceptance of PV systems

Scope

- Developing a robust method for the **realistic** estimation of PV self-consumption and self-sufficiency
- Expanding the EPC balancing of only HVAC-related power consumption to **households total power consumption**
- Establishing an **easy-to-use approach** for practitioners and building owners

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Methodology – Occupant behavior

- Stochastic occupant behavior model peaktime

- Differentiation of households by employment status

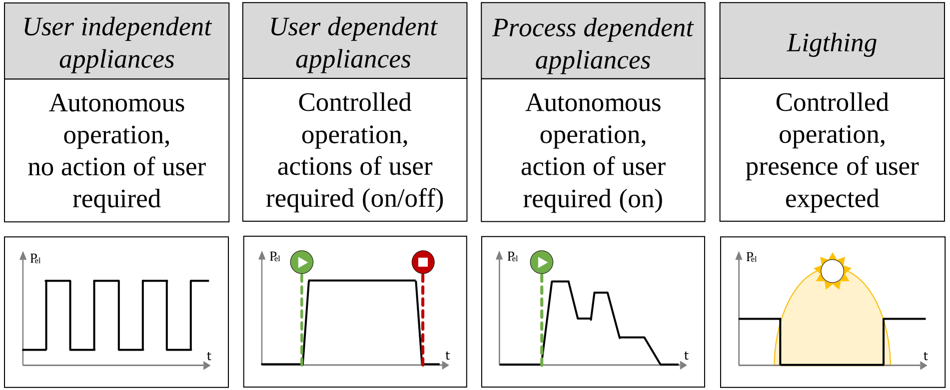

Figure 1: Categories of electrical household appliances (Wörner, P. 2020).

HH group	No. of HH members	Share of HH type in Germany
1 Employed, all adults full-time	1 or 2 pers., families	28,2 %
2 Retired	1 or 2 pers.	27,7 %
3 Employed, at least 1 adult part-time	2 pers., families	13,1 %
4 Unemployed, at least 1 adult	1 or 2 pers., families	23,2 %

Table 1: Characteristics of the defined household (HH) groups.

Methodology – Building Simulation & parametric study

- Equa IDA ICE 4.8 ‘scripting’
- Archetype single-family house with air-to-water heat-pump
- Varying parameters for
  - Energy performance level
  - Presence of occupants*
  - Internal gains from domestic appliances*
  - Domestic hot water demand*
  - Zone temperature set point
  - Location (test reference year climate)
  - Orientation
  - Size / annual yield of PV system
- Power balance and analysis in R (in 5 min. resolution)

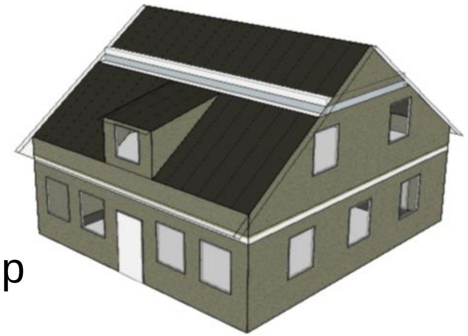

Figure 2: 3D building Model

No. of floors	2
Floor area	90 m²
Slope of roof	35°
Roof area	2 x 48 m²

Table 2: Parameters of the archetype building

*peaktime profiles

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Results - Occupant behavior model

- 100 profiles per group
- Annual electricity demand increases by household size
- Mean presence at home of household members scatters among groups and sizes

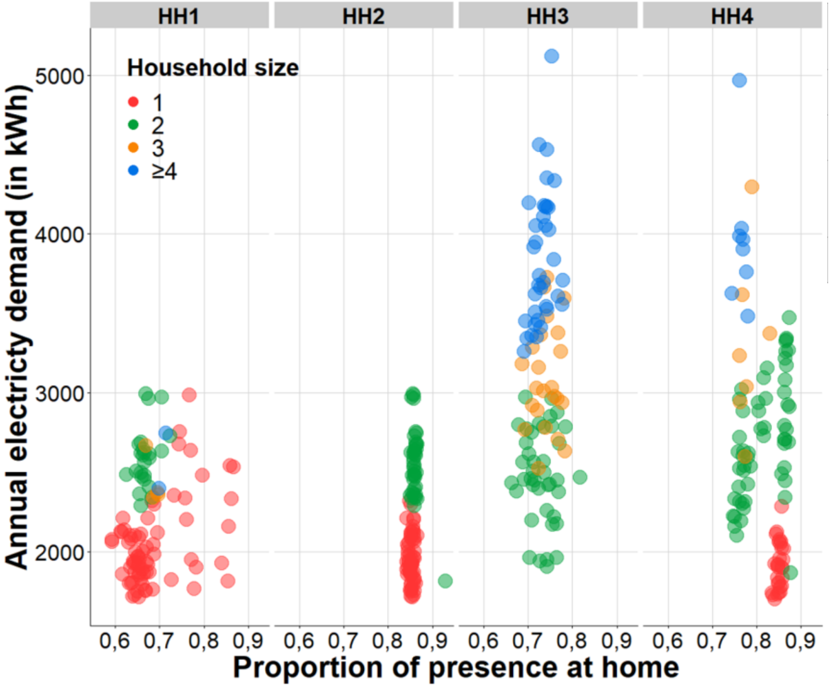


Figure 3: Evaluation of synthetic peaktime *load profiles.*

Results - Evaluation of PV self-consumption and self-sufficiency

- 2/3 of all simulations conducted for the location Potsdam (n = 9.600)
- Annual PV yields from 2.000 to 20.000 kWh/a in 2.000 kWh/a intervals

→ already ca. 100k data points

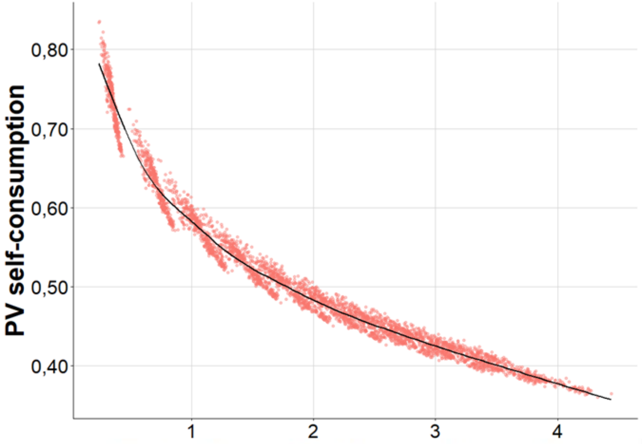
Location / TRY 2015	Orientation	Refurbished building			New building					
					GEG			KFW40		
		Temperature set point (°C - 3 K)								
		20	21	22	20	21	22	20	21	22
Potsdam	0°	X	X	X	X	X	X	X	X	X
	45°	X			X	X	X	X		
	90°	X			X	X	X	X		
	135°	X			X	X	X	X		

In addition, certain parameter sets were simulated for the Locations Mannheim and Garmisch-Partenkirchen.

Table 3: Description of the variants already simulated.

Results - Evaluation of PV self-consumption and self-sufficiency

- Preliminary results for a single parameter set



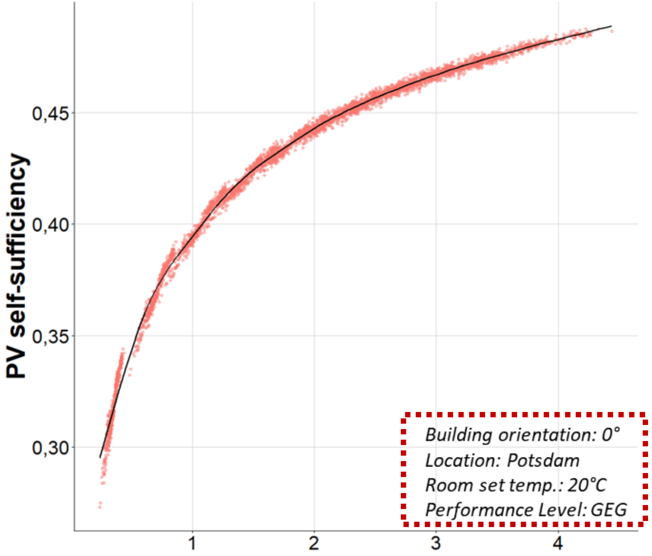


Figure 4: PV self-consumption (left) and self-sufficiency (top) as a function of ratio of annual PV generation and total electricity demand. (n = 4.000)

Results - Evaluation of PV self-consumption and self-sufficiency

- Large discrepancies in PV self-consumption between household groups and due to household size

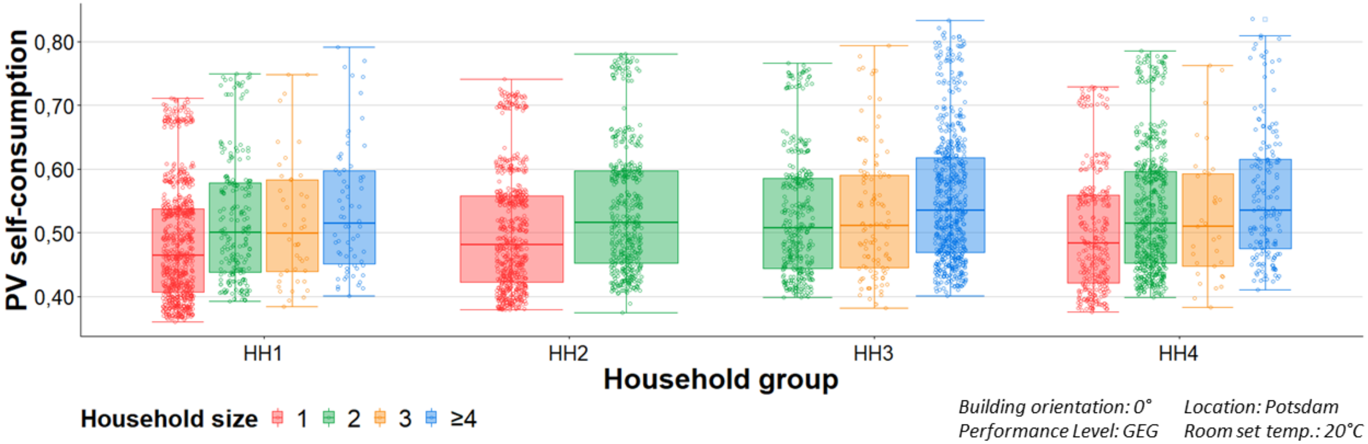


Figure 5: Dependency of self-consumption on household group and size. (n = 4.000)

Results - Evaluation of PV self-consumption and self-sufficiency

- A graphical method is derived for a household specific estimation of PV self-consumption and self-sufficiency
- Confidence intervals show the most probable range (+/- σ = 68%)

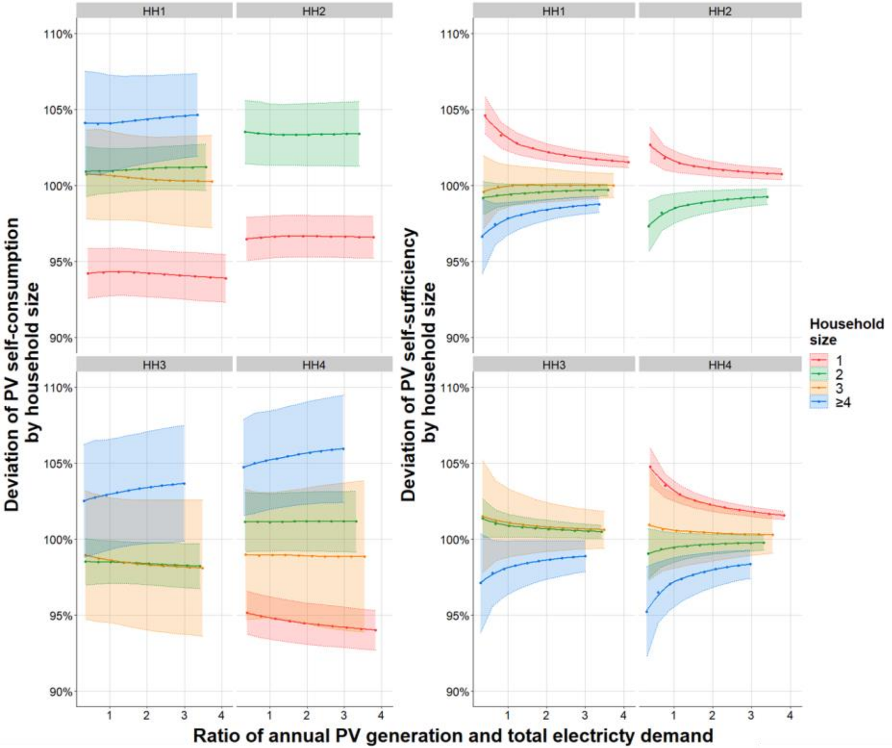
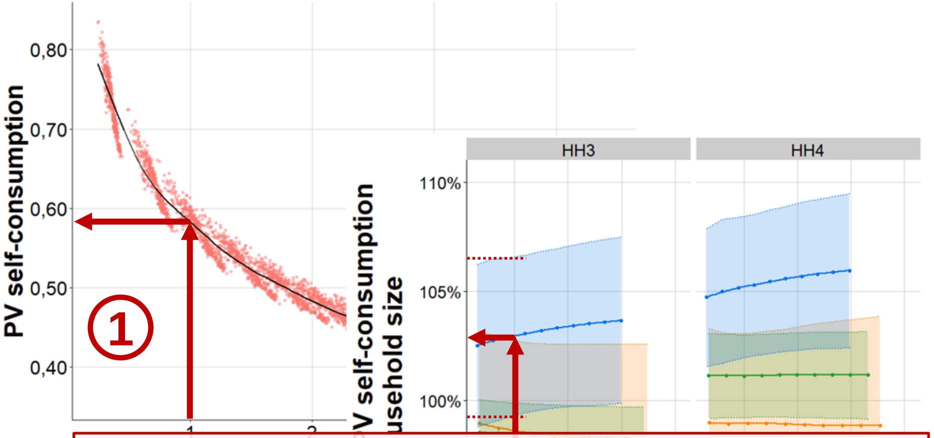


Figure 6: Deviations of mean PV self-consumption and self-sufficiency for household groups and sizes.

Results - Evaluation of PV self-consumption and self-sufficiency

- Example
  - 4 persons HH size ≥4
  - One adult full-time employed HH3
  - El. demand & production
    - EPC relevant: ca. 3.500 kWh/a
    - Total: ca. 7.800 kWh/a
    - PV generation: ca. 8.000 kWh/a

  Generation-Demand-Ratio → 1



Estimated PV self-consumption

58 % ∗ 103 % = 59,7 % (+/- 2,3 %)

→ ca. 4.800 kWh/a (+/- 185 kWh/a)

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Conclusion and Outlook

- The study results can help to minimize risk and support decision makers
- The parametric study will be extended
  - Additional archetype buildings
  - Other heating systems and controls
  - Locations
  - Domestic cooling
  - District scale energy systems
- A more detailed statistical analysis is to be done
- Simulation data can be coupled with further data/profiles
  - Dynamic CO_2-emissions of public electricity supply
  - Non-spatial & spatial building stock models

Literature & Acknowledgement

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Wörner, P. (2020). Einfluss des Nutzerverhaltens auf den Stromverbrauch in Wohngebäuden – Entwicklung eines komplexen Simulationsmodells für energetische Analysen. Dissertation. Institute of Concrete and Masonry Structrues, Technical University of Darmstadt. Darmstadt (Germany).

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Questions and Comments

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Backup

Component	Energy performance level		
	Refurbished building	New building	
		GEG	KfW40
Roof	0,41	0,15	0,10
External walls	0,23	0,17	0,12
External floor	0,34	0,17	0,12
Windows	1,3	1,1	0,70
Doors	1,3	1,3	0,80
Thermal bridges	Δ = 0,1	Δ = 0,05	Δ = 0,02

Table B-1: U-values of the building models in W/(m²K).

Parameter	Description	Range / resolution
Presence of occupants	100 profiles per HH group, given as a fraction of present members of the household	[0, 1] 5 minutes
Internal gains from domestic electricity demand	100 profiles per HH group, normalized by the maximum power demand	[0, 1] 5 minutes
Domestic hot water demand	100 profiles per HH group	[0, 36,7 kW] 5 minutes
Zone temperature set point	Schedule of constant room temperature with a nightly setback between 11 pm and 6 am	20 °C - 3 K 21 °C - 3 K 22 °C - 3 K
Location and climate file	TRY 2015 data for locations as defined in VDI 4655 (2019)	Potsdam; Mannheim; Garmisch-Partenkirchen
Orientation	Default roof ridge direction is north to south, counting direction is counter-clockwise	0°; 45°; 90°; 135°

Table B-2: Description of input parameters for the parametric study.