



4. Konferenz zur Norddeutschen Wärmeforschung

Conflicts in the roof

- system performance of PVT-HP systems combined with solar thermal areas for different climatic conditions in Germany

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Institute of Networked Energy Systems

Context - Coole Wärme



Modelling



Transfer



Application

- Investigate the **technical and economic potential of PVT+HP** systems
- Facilitate implementation of these systems through targeted dialogue with **industry partners on challenges and opportunities**
- **Goal: Design guidelines** for use in contexts with limited spatial or financial resources

Motivation and Goals

Process:

- Investigate the performance of PVT + HP systems (comparing to a baseline of air source heat pumps as typical system)

Focus:

- Roof as single heat source (e.g. small terraced houses)
- Brine cooled, open modules

The conflict: limited roof space

→ techno-economic optimization

- Advantages of additional **solar thermal use**
 - Increase the source temperature? (as compared to air)
 - better system efficiency?
 - influence of weather?: MUC, WÜRZBURG, HH
- Advantages of additional **PV-use**



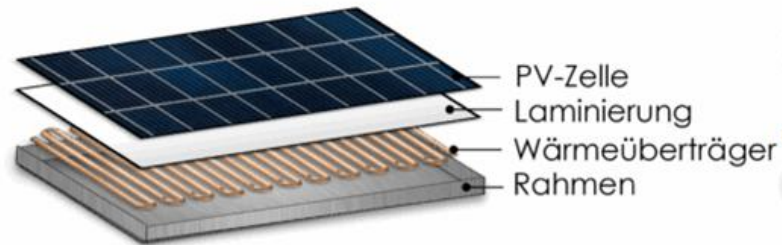
<https://www.pexels.com/de-de/foto/charmante-fachwerkhauser-in-quedlinburg-34270720/>

Collector Model

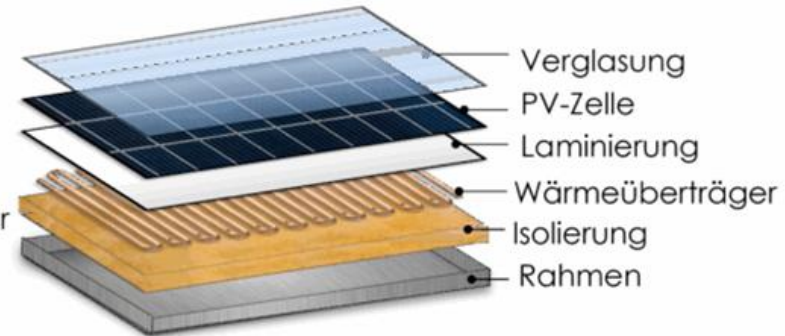
Offene Module

Geschlossene Module

Unabgedeckter PVT-Kollektor
(WISC)



Abgedeckter PVT-Kollektor



Grafik: C.A.R.M.E.N. e.V.

Sole-gekühlt

Luft-gekühlt

*WISC = wind and infrared sensitive collector

Collector Model

- MTRESS

- Mass-Flow based linear model
- Allows to optimise both, energy and temperature, in the same linear model

$$\dot{Q} = \rho c_p \dot{V} \times (T_{\text{flow}} - T_{\text{return}})$$

- Thermal collector as simplified linear model

$$\dot{Q} = \eta \times P_{\text{sol}}$$

$$\eta = \eta_0 - a_1 \frac{(T_{\text{out}} - T_a)}{G}$$



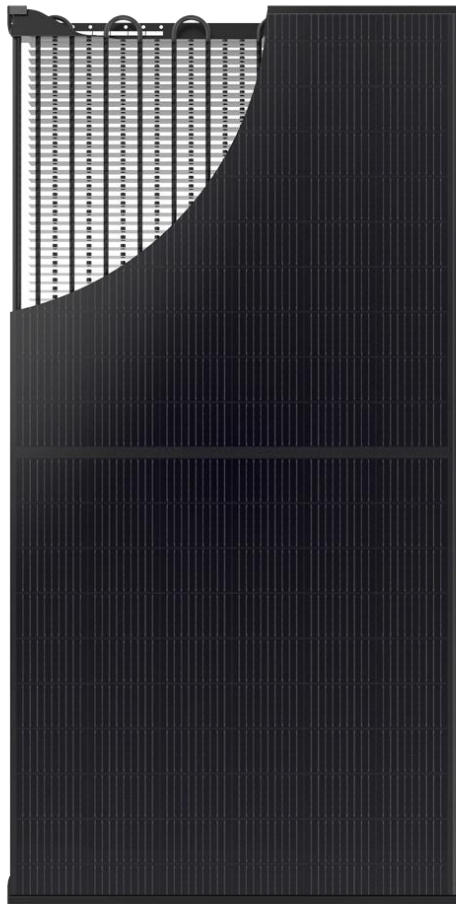
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Annex to Solar Keymark Certificate		Licence Number	011-752894 P
		Date issued	2025-01-14
		Issued by	DINCERTCO
Licence holder	Consolar Solare Energiesysteme	Country	Germany
Brand (optional)		Web	https://www.consolar.de
Street, Number	Gewerbestraße 7	E-mail	anfragen@consolar.de
Postcode, City	D-79529 Lörrach	Tel	+49 (0)69 7409328-0
Collector Type		WISC (Wind and/or infrared sensitive collector)	

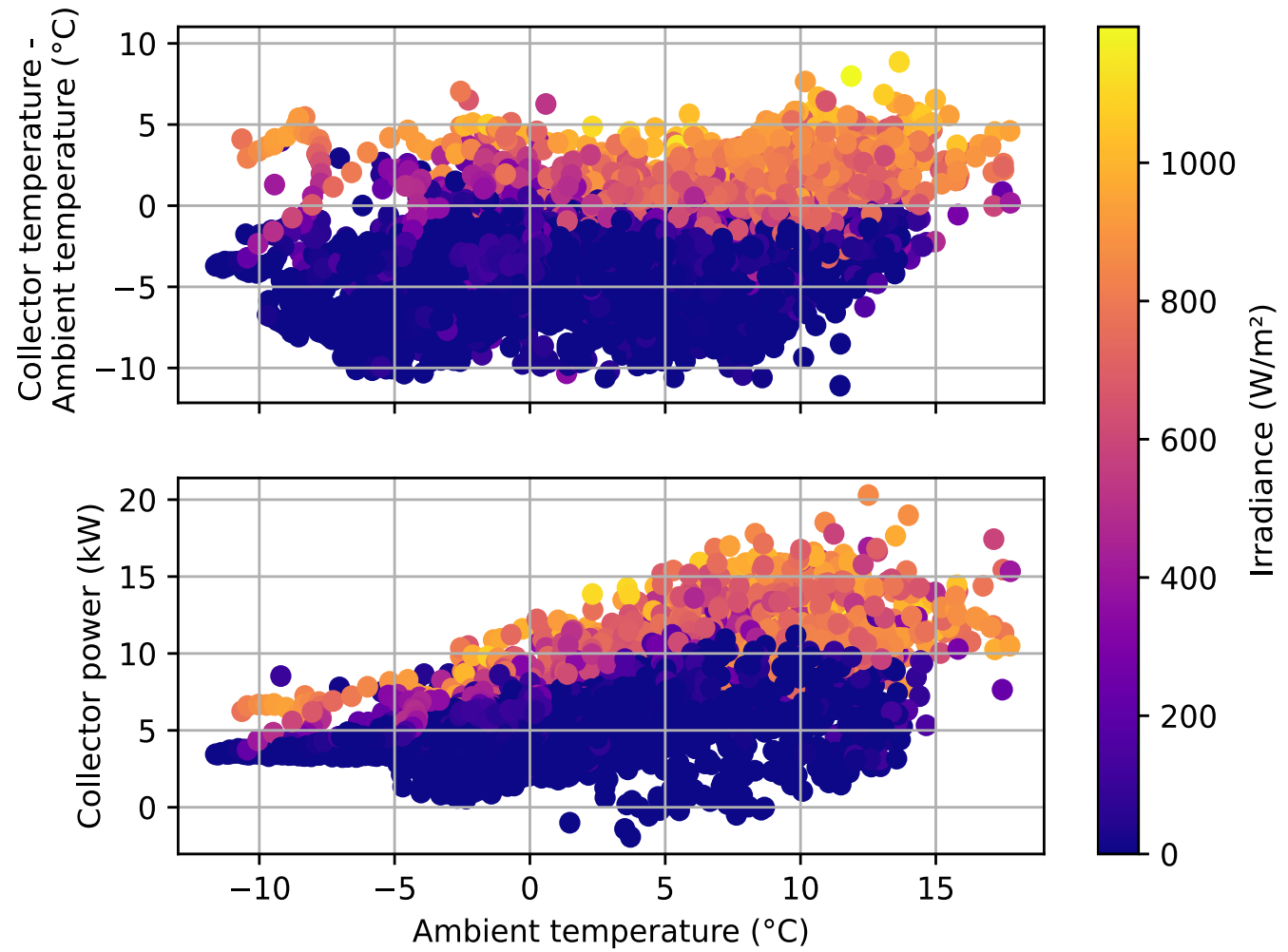
Data required for CDR (EU) No 811/2013 - Reference Area A_{sol}		Data required for CDR (EU) No 812/2013 - Reference Area A_{sol}	
Collector efficiency (η_{col})	-92%	Zero-loss efficiency (η_0)	0.38
Remark: Collector efficiency (η_{col}) is defined in CDR (EU) No 811/2013 as collector efficiency of the solar collector at a temperature difference between the solar collector and the surrounding air of 40 K and a global solar irradiance of 1000 W/m², expressed in % and rounded to the nearest integer. Deviating from the regulation η_{col} is based on reference area (A_{sol}) which is aperture area for values according to EN 12975-2 or gross area for ISO 9806:2017.		First-order coefficient (a_1)	32.56 W/(m ² K)
		Second-order coefficient (a_2)	0.000 W/(m ² K ²)
		Incidence angle modifier IAM (50°)	0.97
		Remark: The data given in this section are related to collector reference area (A_{sol}) which is aperture area for values according to EN 12975-2 or gross area for ISO 9806. Consistent data sets for either aperture or gross area can be used in calculations like in the regulation 811 and 812 and simulation programs.	
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[https://solarkeymark.eu/database/]

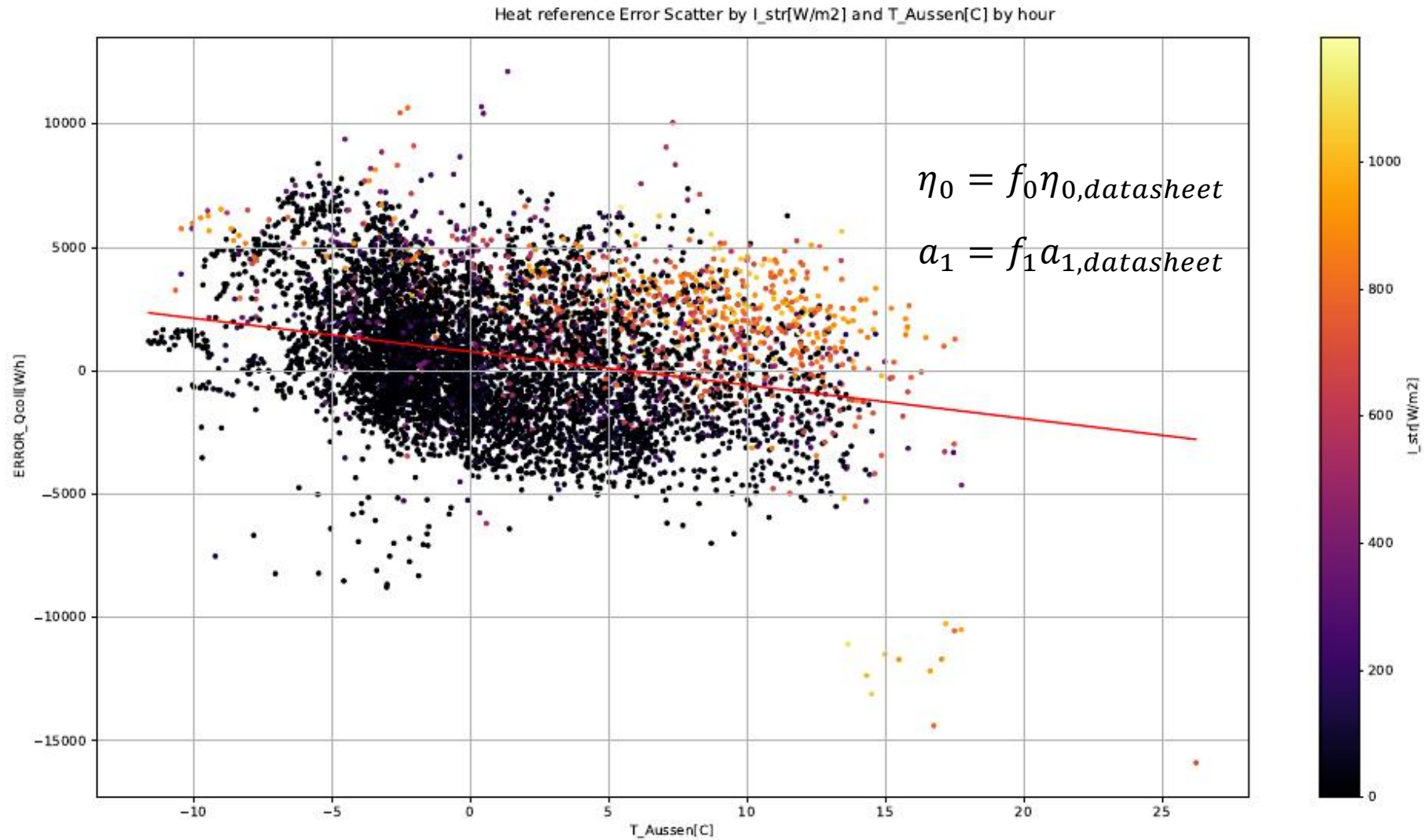
Collector Model



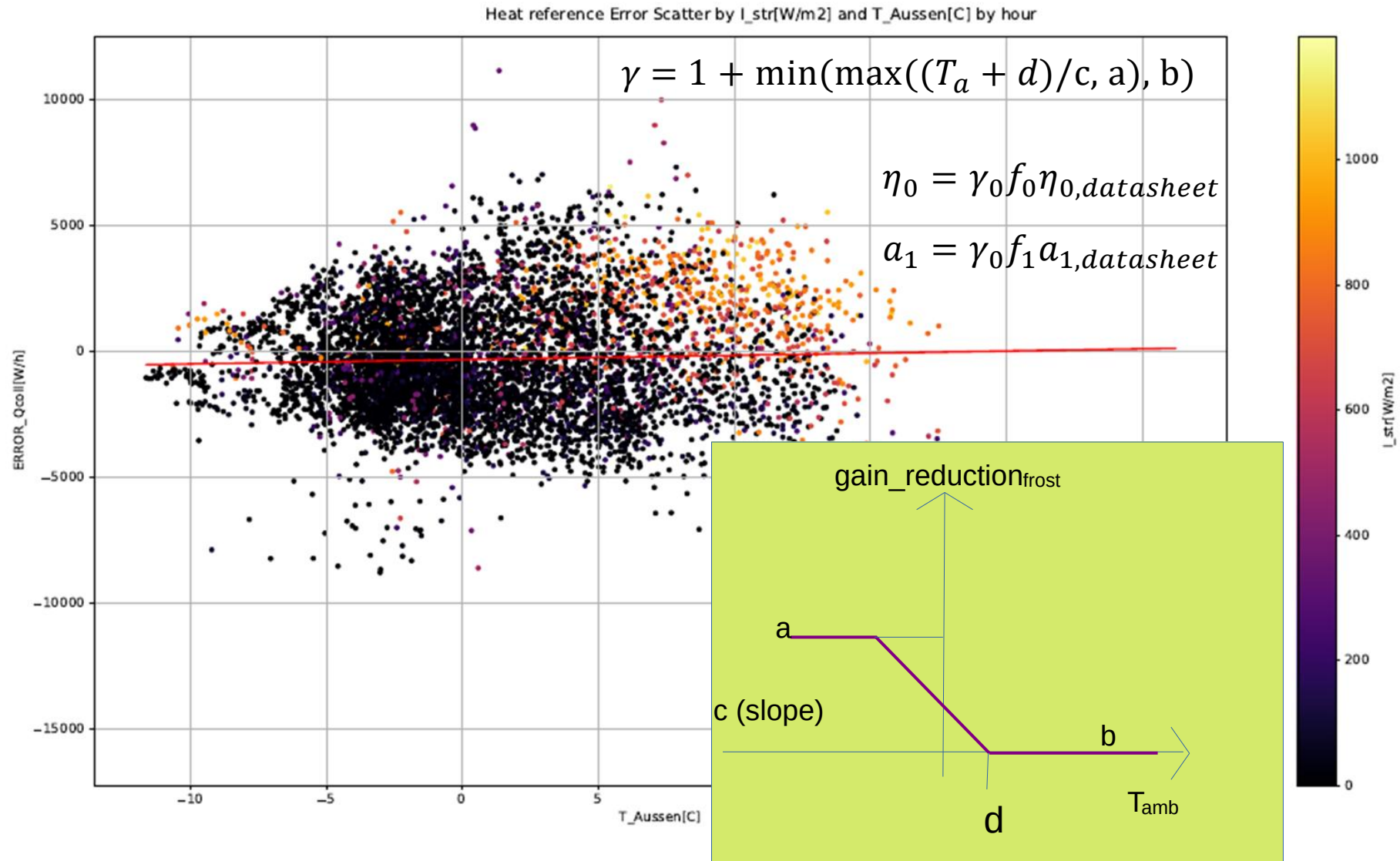
[consolar.de]



Collector Model



Collector Model



Collector Model

- MTRESS

- Mass-Flow based linear model
- Allows to optimise both, energy and temperature, at the same time

$$\dot{Q} = \eta \times P_{\text{sol}}$$

$$\eta = \gamma_0 \eta_0 - \gamma_1 a_1 \frac{(T_{\text{out}} - T_a)}{G}$$

- Thermal collector as simplified linear model

$$\gamma = 1 + \min(\max((T_a + d)/c, a), b)$$

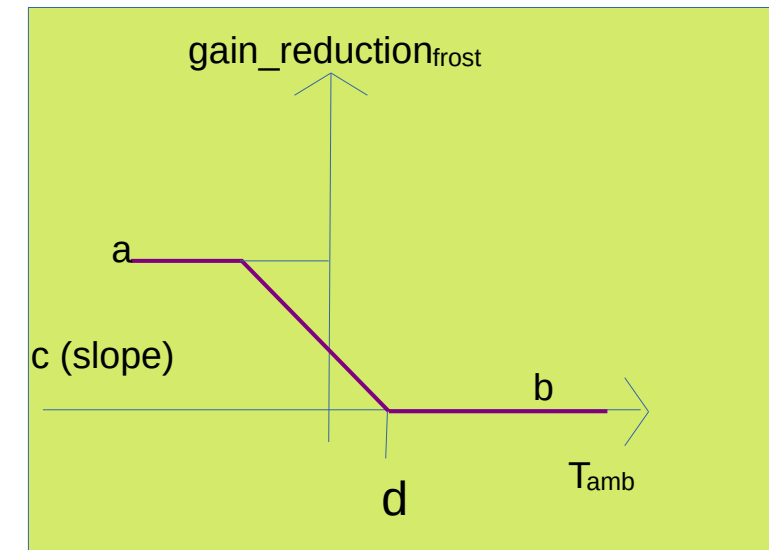
- Adjustment with calibration factors γ_0 und γ_1 to fit measurements from a real system

	No Calibration	Model Calibration	+ Frost Calibration
R2	-1.18	-0.135	0.19
PBIAS	34.08	9.73	-4.86
cv(RMSE)	0.59	0.43	0.36

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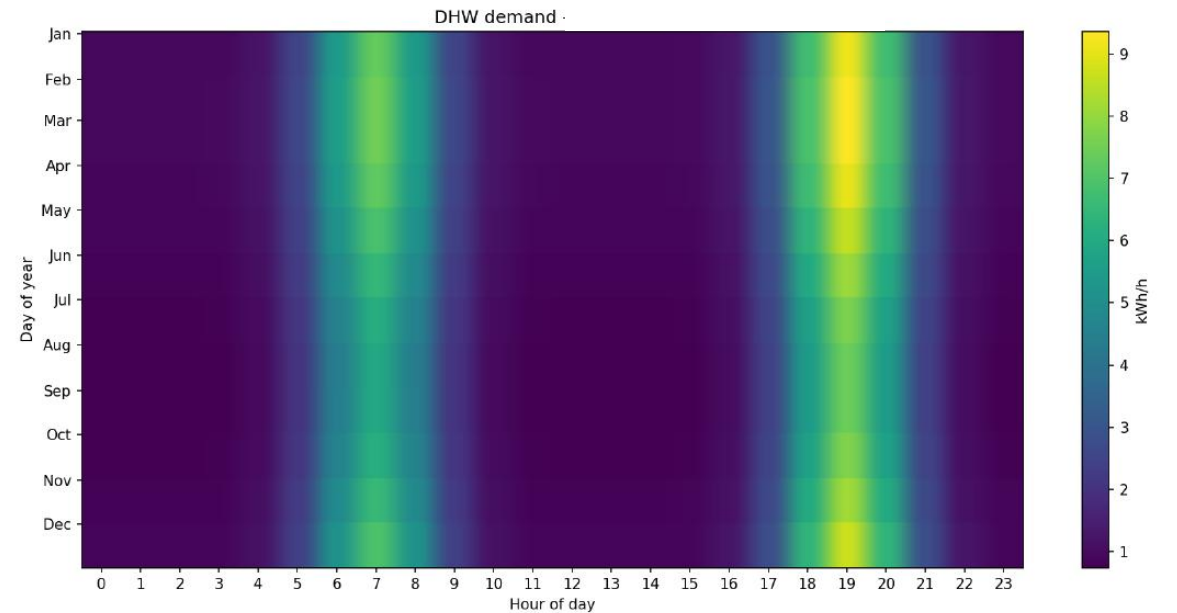
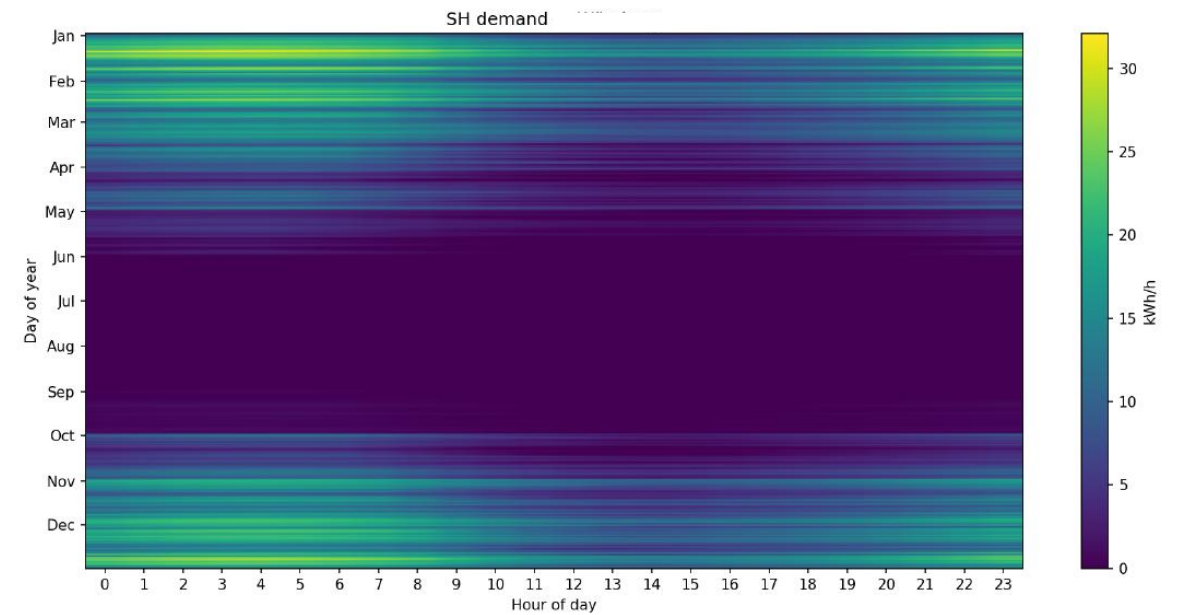
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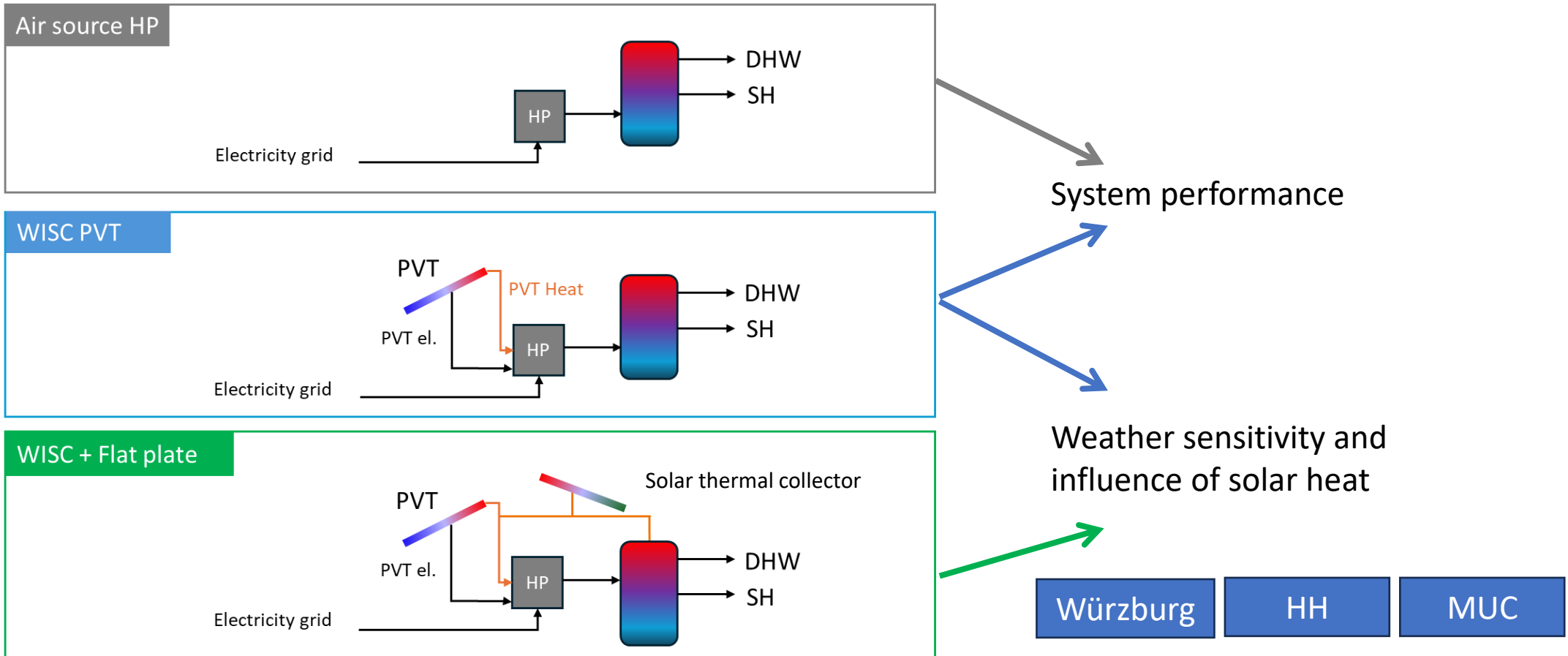


Demand Models

- VDI-profiles (demandlib implementation)
 - SH: 54400 kWh/a
 - DHW: 22000 kWh/a
- Heat pump, thermal power limit: 34 kW
- No electricity demand



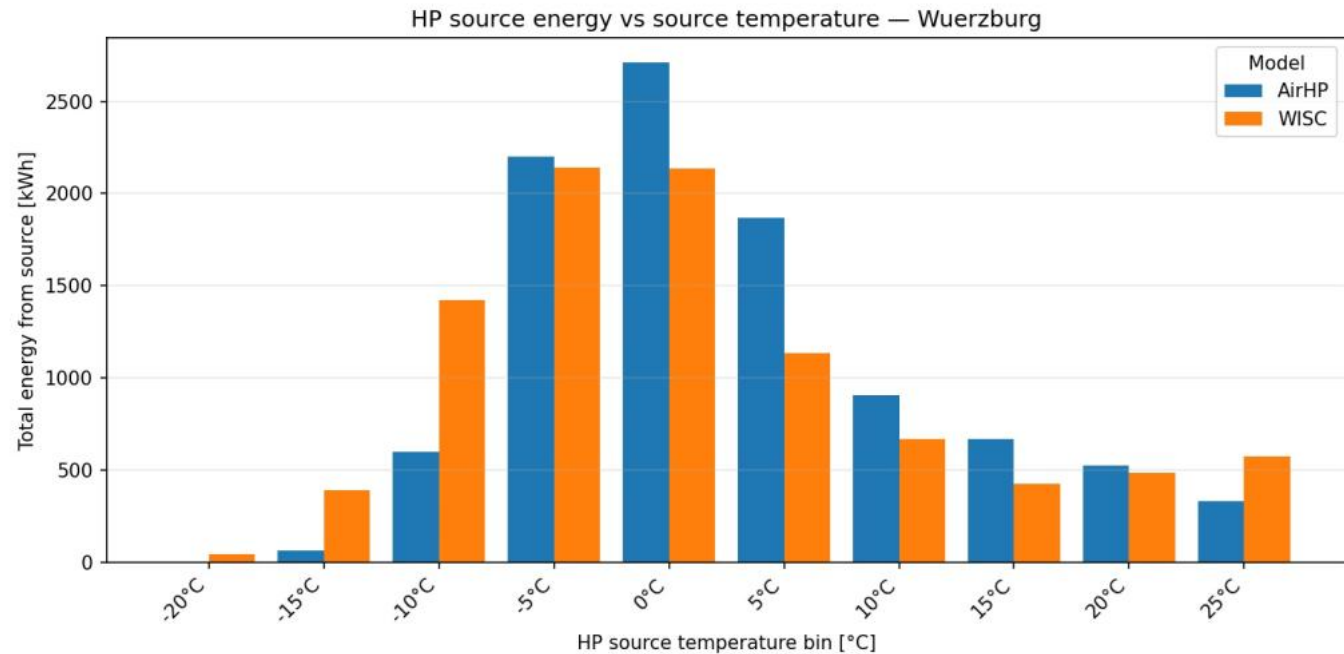
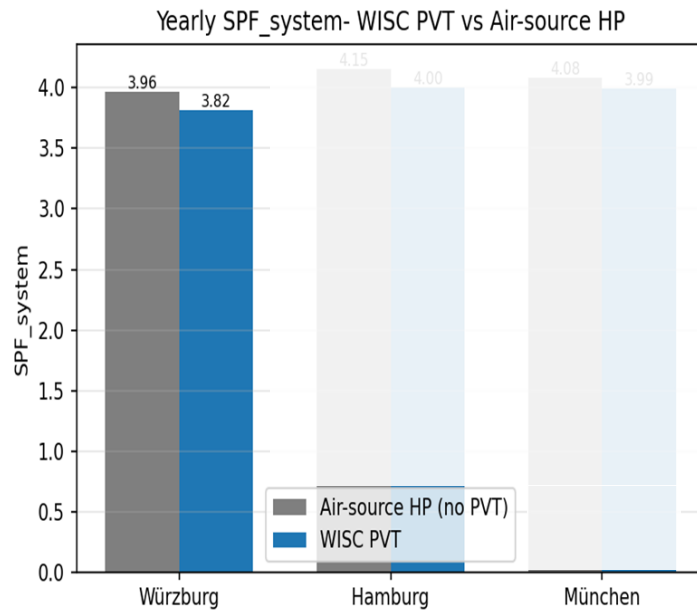
System performance and solar thermal



System performance and solar thermal

Models using the same COP values $1/\eta(T)$ for both heat pumps (air and brine)

- PVT as single source is possible
- Decreases the source temperature for most of the demand (winter)
- Same trend observed for the three investigated weather conditions

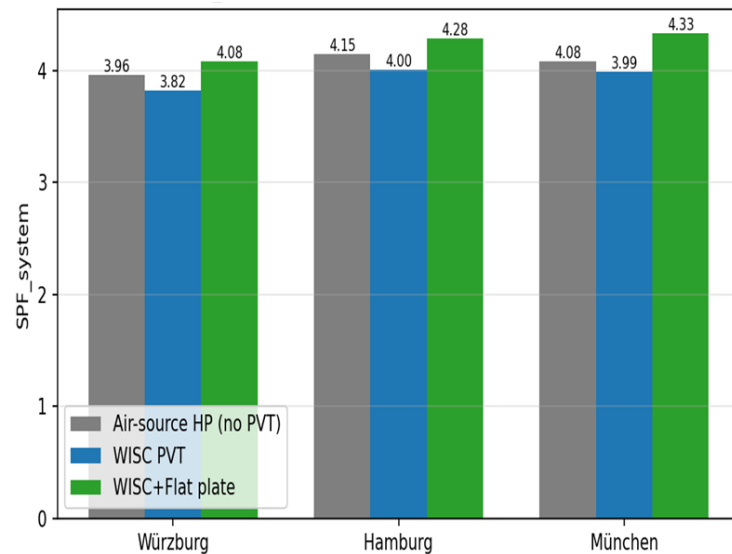


System performance and solar thermal

Using a **solar thermal area** increases the thermal system performance

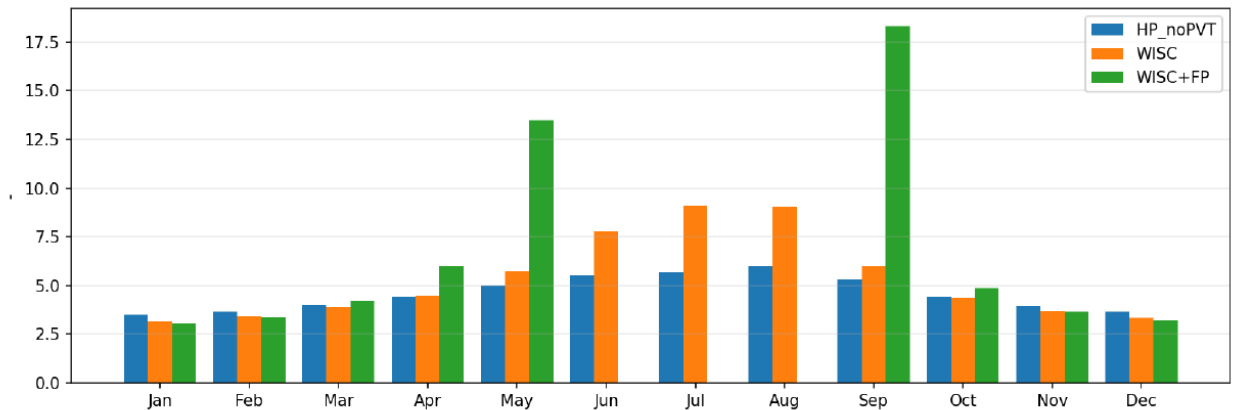
- Trend observed for all three weather conditions
- Mainly due to increased system thermal COP (SFP) in summer and spring/fall

System thermal COP- annual values



Würzburg

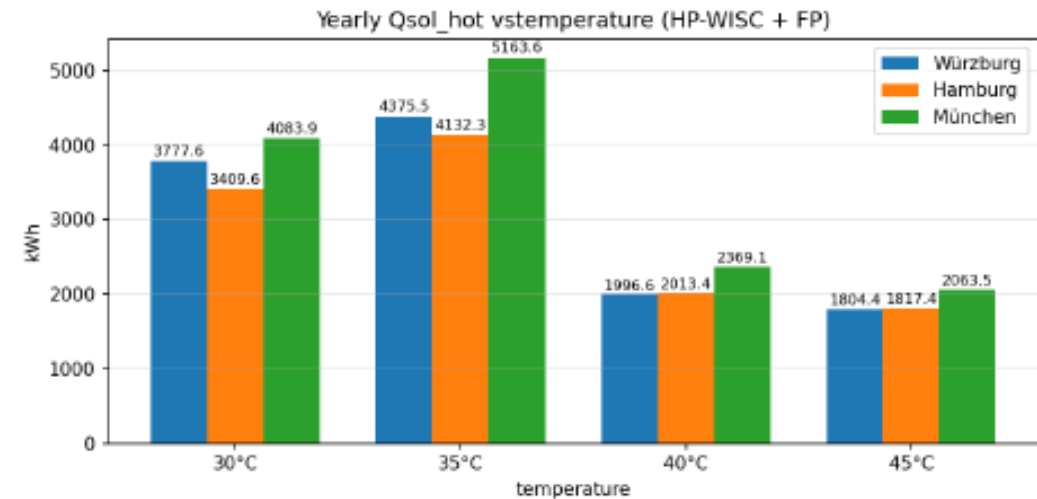
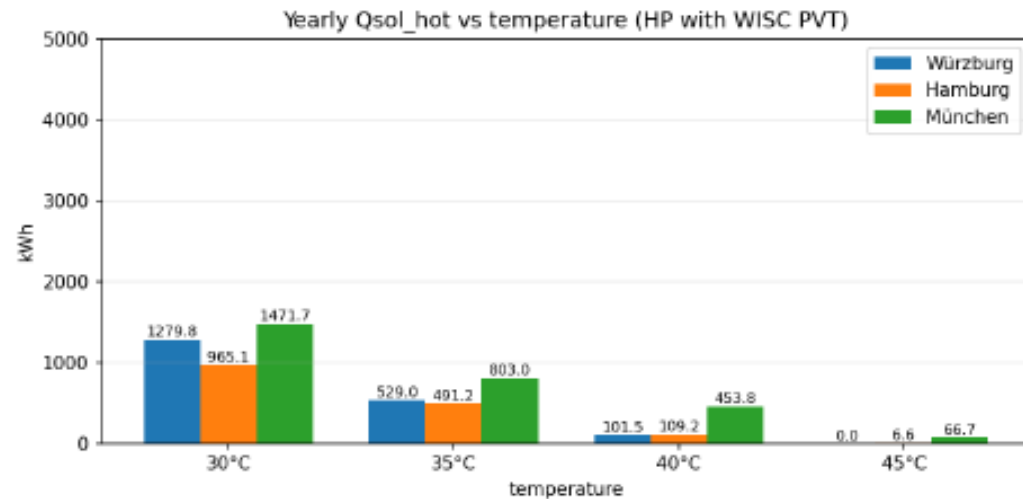
System thermal COP- monthly values



System performance and solar thermal

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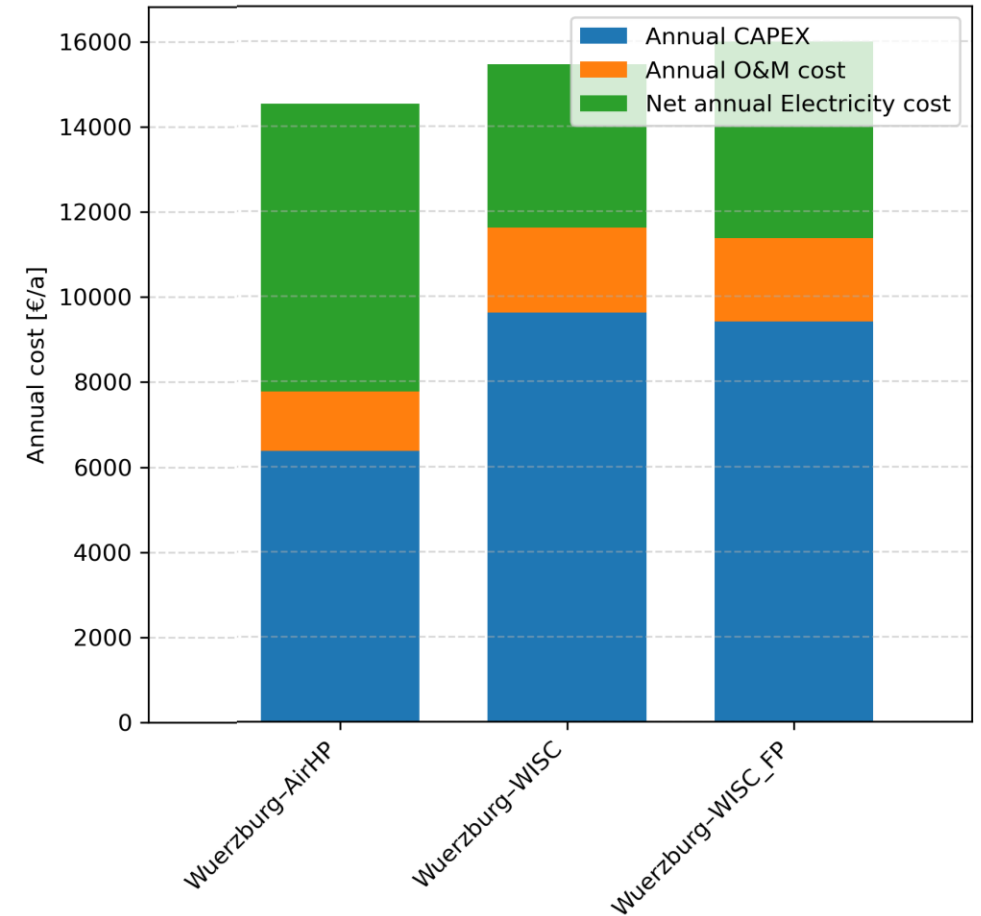
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System performance and solar thermal

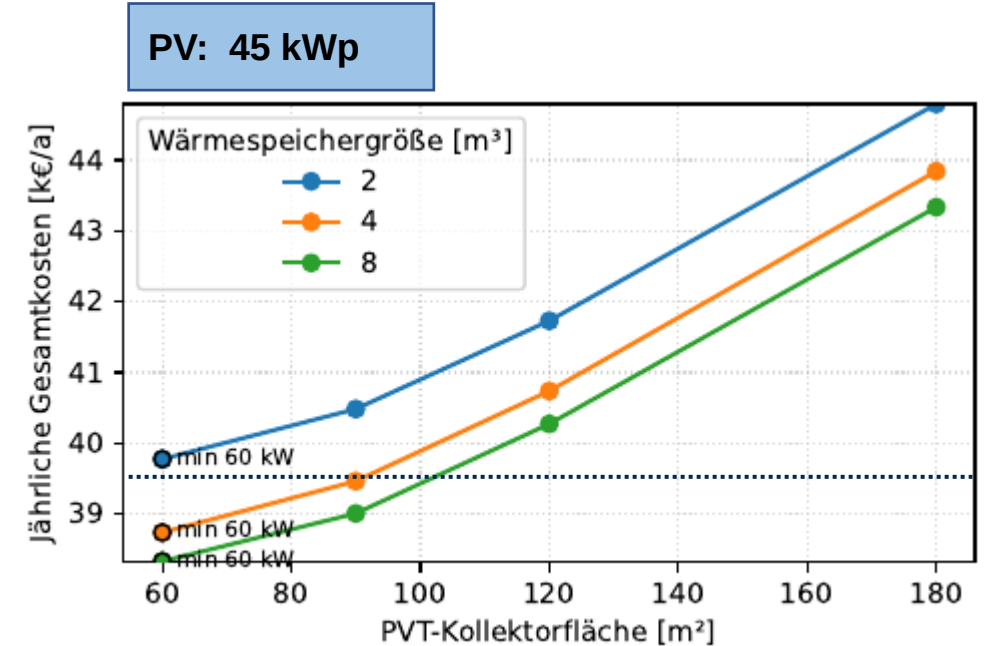
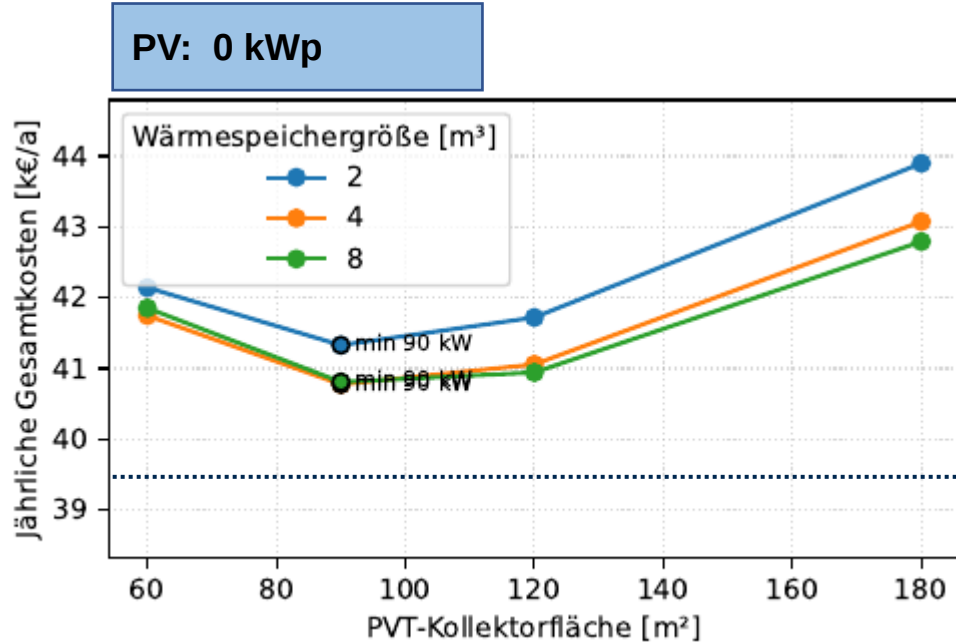
Using a **solar thermal area** increases the thermal system performance but **does not reduce the system costs**.

- Simplified economic calculations: no subsidies, Costs from „Technikkatalog KW“, interest rate 4%, inflation rate 2%
- Main advantage of PVT systems: not the thermal performance, but the self-sufficiency from PV electricity!
- Solar thermal areas reduce the amount of PV electricity available, but do not increase winter performance
→ Substituting PVT area with solar thermal collectors is not beneficial!
- **How about substituting PVT with PV area instead?**



Substitution with PV area

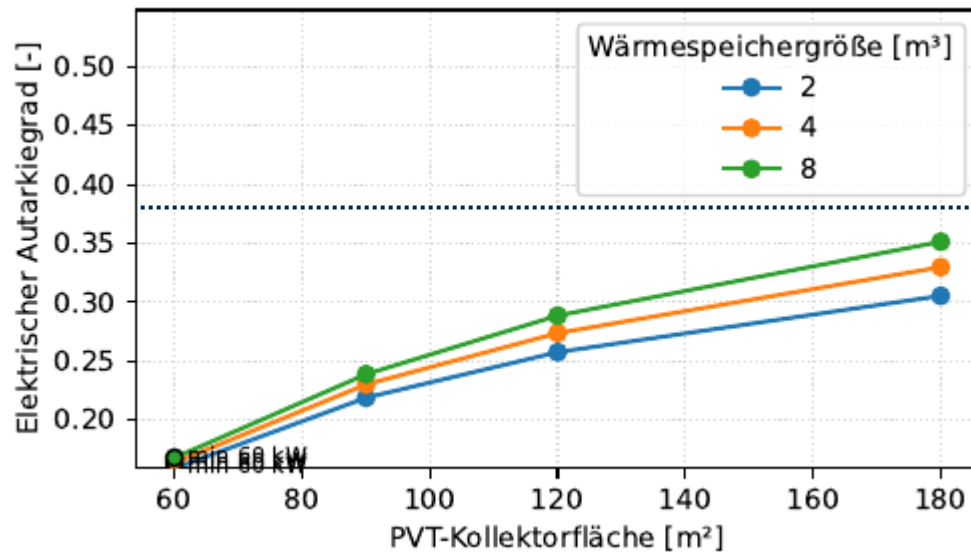
- Similar models, but bigger thermal demands
 - Including electricity demand
 - Model calibrated collector
 - Thermal power HP: 60 kW
- Reducing PVT area reduces annual total costs (PVT is CAPEX intensive)
 - Substituting PVT area with PV is beneficial for reducing annual costs



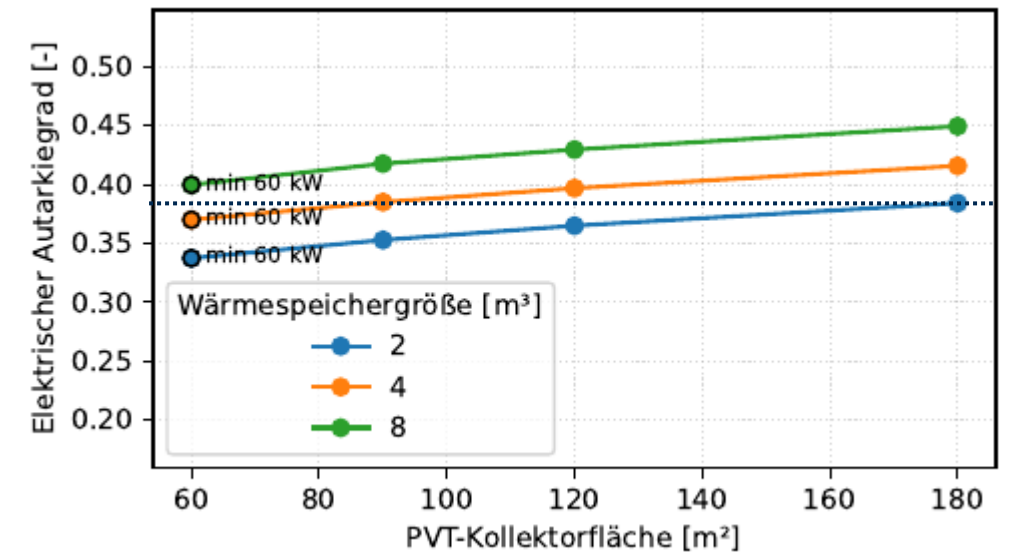
Substitution with PV area

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 - Thermal power HP: 60 kW
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 - Substituting PVT area with PV is beneficial for reducing annual costs

PV: 0 kWp



PV: 45 kWp





Conclusions

- Simplified collector model can be calibrated to represent real performance data reasonably, at the level of energy balances (not suitable for deriving control strategies!)
- Main advantage of PVT systems: not their thermal performance, but their option of operating as single source
- Substituting PVT area with solar thermal collectors increases thermal performance but also system total costs (due to lower self-sufficiency higher operation costs)
- Substituting PVT area with PV is beneficial for reducing annual costs