Modelling flexibility from heat pumps: a bottom-up approach for Swiss buildings

Curtis Meister (HSLU)
Sarah Schneeberger (HSLU)
Philippe Buchecker (ETHZ)
Philipp Schütz (HSLU)

sweet swiss energy research for the energy transition

PATHFNDR

ETH zürich · Empa · Paul Scherrer Institut PSI · zhaw · HSLU Hochschule Luzern · Université de Genève · EPFL · TU Delft

Lunch talk series V: **Flexibility provision from buildings and electromobility**

1. Impacts of electric vehicles and heat pumps flexibility: European and Swiss perspectives
2. End-user flexibilities for electrical distribution grid planning
3. Modelling flexibility from electric vehicles: where, when, why, and how
4. Modelling flexibility from heat pumps: a bottom-up approach for Swiss buildings
5. Electrification, flexibility or both?
6. Emerging trends in recent Swiss and European policy
7. Operation and market mechanisms: from dynamic electricity tariffs to day-ahead and intraday auctions

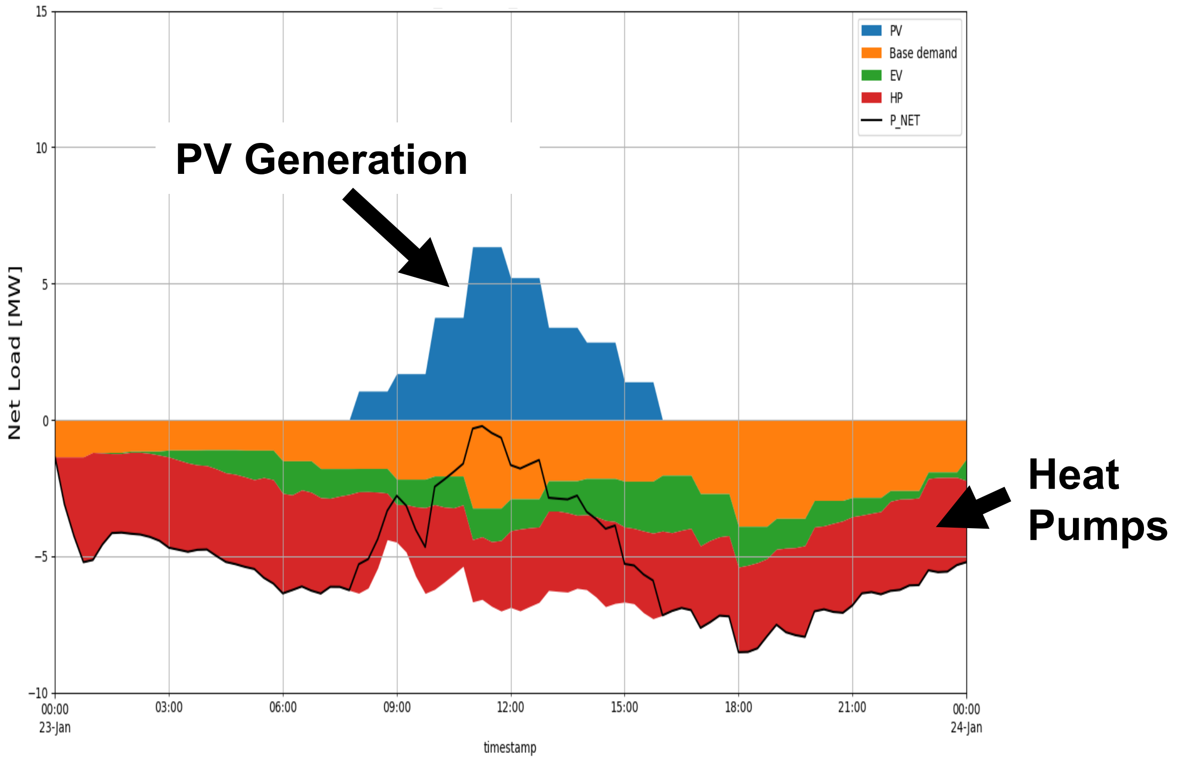
Motivation

Number of heat pumps ↑

\+

Renewable electricity ↑

= Alignment of electricity supply & demand ↓



Alignment of PV generation potential and heat pump loads over one day in Losone, TI

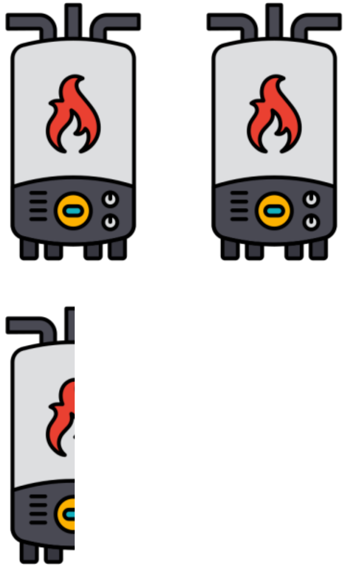
What is thermal inertia?

- Many building materials have significant **thermal mass** (concrete, plaster, brick)
- Greater mass + better insulation = higher ***thermal inertia***
- Buildings with high thermal inertia can last **several hours without heating,** allowing them to function as a **thermal battery**
- This permits the **shifting of heat pump loads** to help the electrical grid!

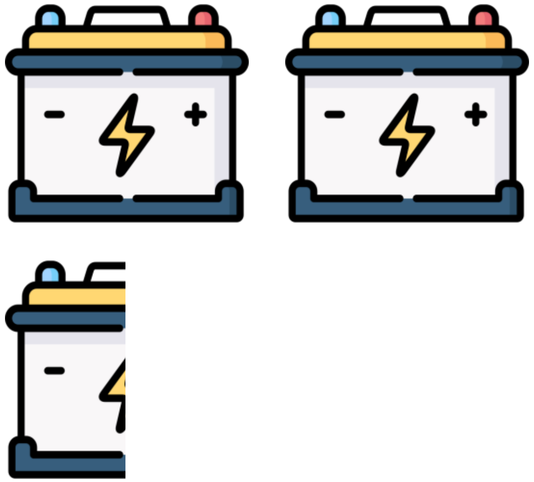
Quelle: Adobe Stock, ISO 52016-1:2017

How much energy can be stored?

≈



≈



Typical single family home,
200 m^2, medium construction:
33 kWh

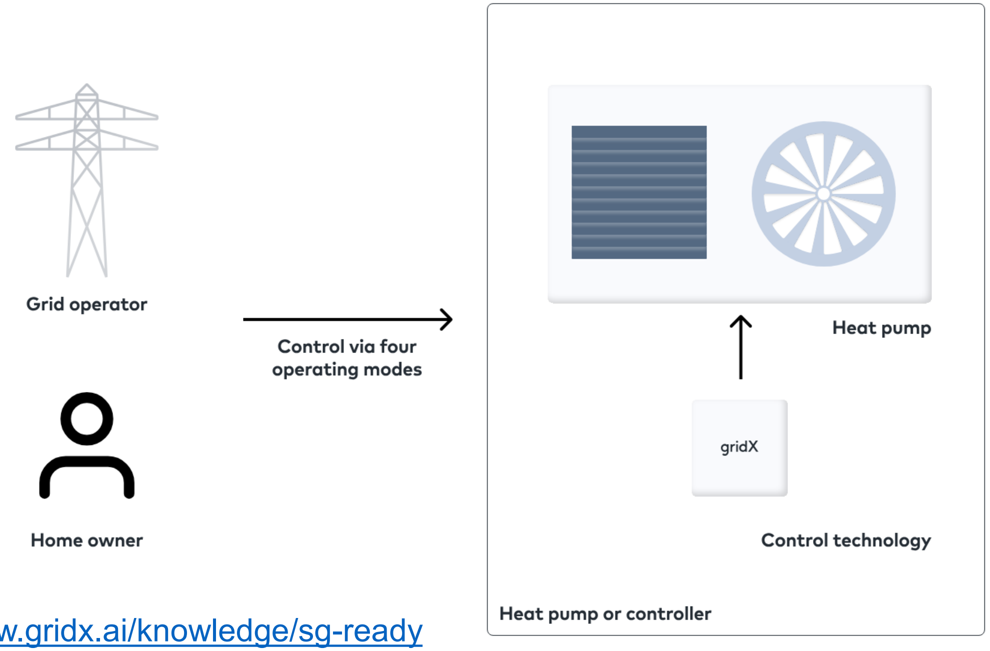
2-3 domestic hot
water tanks

2.5 residential
battery modules

Icon sources:
https://www.flaticon.com/free-icons/home" title="home icons">Home icons created by Freepik - Flaticon
https://www.flaticon.com/free-icons/boiler" title="boiler icons">Boiler icons created by cah nggunung - Flaticon
https://www.flaticon.com/free-icons/battery" title="battery icons">Battery icons created by Freepik - Flaticon

State of the art – heat pump flexibility

- Growing adoption of standards for flexible heat pumps, e.g. *Smart Grid Ready, SG Ready*
- Swiss DSOs offer reduced tariffs for heat pump interruptions, limited to maximum interruptions of 2 hrs
- Commercial availability of “smart” heating controllers



Source: https://www.gridx.ai/knowledge/sg-ready

DSO	Tariff name	Load spec.	Max. int./day	Max. int. cons.
IWB	Wahltarif Elektromobilität	EV, others	6h	2h
IWB	Wahltarif Wärmepumpe	HP	6h	2h
SIG	Tarif pompe à chaleur*	HP	3h	2h
CKW	Doppeltarif sperrbar DS	HP & others	6h	-
Groupe-e	Doppelt unterbrechbarer Tarif	HP, EH, others	2h (yearly avg)	-
Groupe-e	Bonus	HP, EH, (EV)	2h	-
Repower	Vergütung Flexibilitätsnutzung	EB, HP, others	4h	2h
ewz	Netzdienliche Leistungsbegrenzung	others	6h	2h
EKZ	Netz 400F	others	-	-
EKZ	Netz 400WP	HP, EH	4h	2h
BKW	NS UR*	others	4h	2h

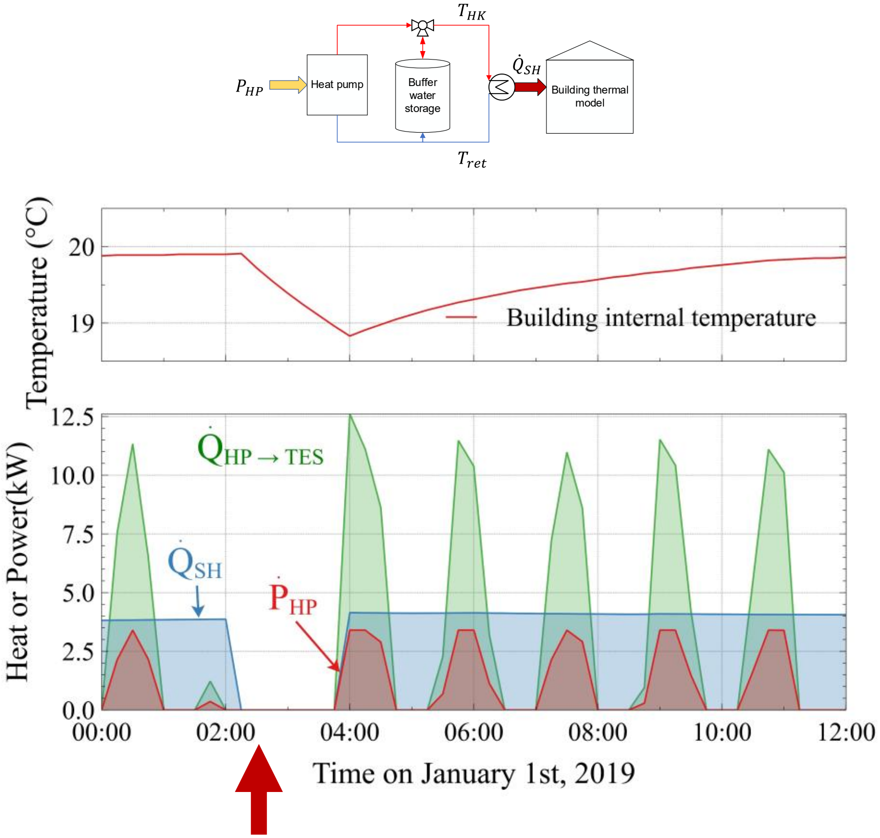
Source: Mellot, A., et al. 2025, May. Exploratory Analysis of Direct Load Control Policies for Heat Pumps in the Future Swiss Electricity System. In 2025 21st International Conference on the European Energy Market (EEM) (pp. 1-11). IEEE.

Knowledge Gaps:

- How much flexibility does building thermal inertia permit for heat pump loads?
- How do local HP control schemes affect grids?
- Is 2 hours a suitable limit?

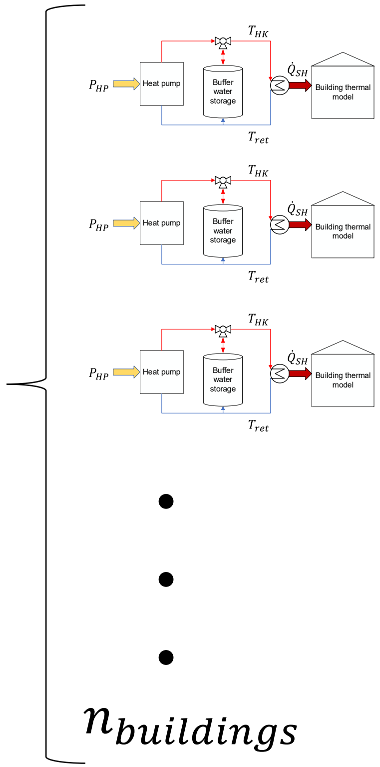
Simulation framework

Individual building + HP models

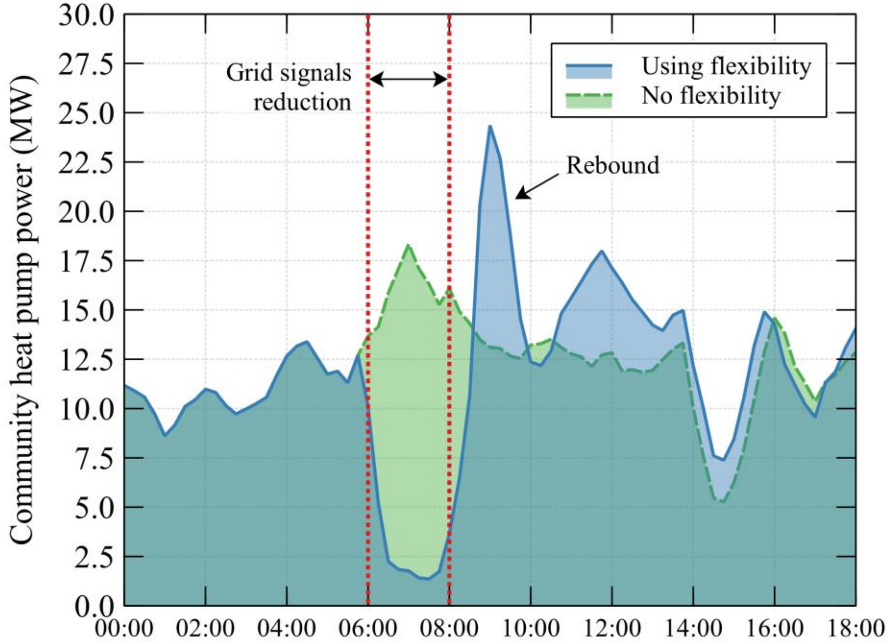


Grid signal:
Heat pumps OFF

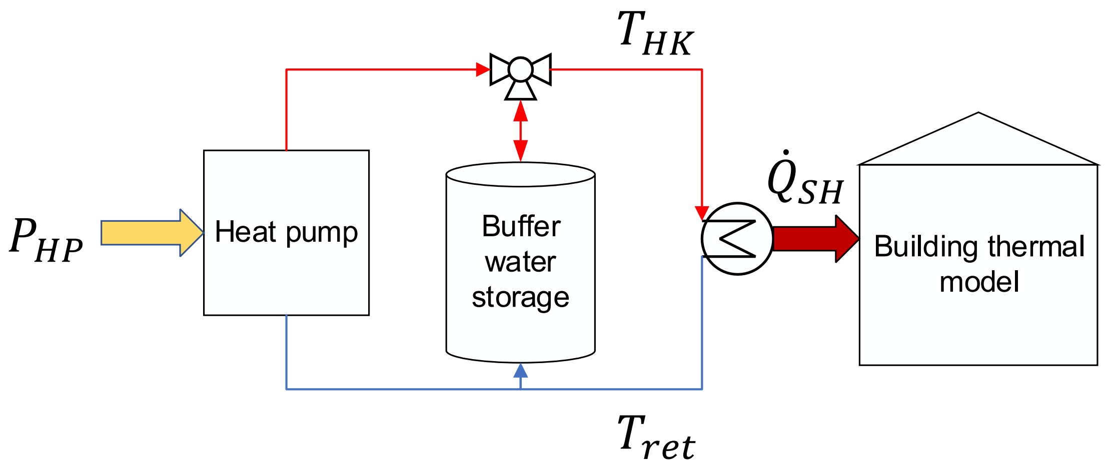
Simultaneous simulation of full communities



Aggregated flexibility assessment

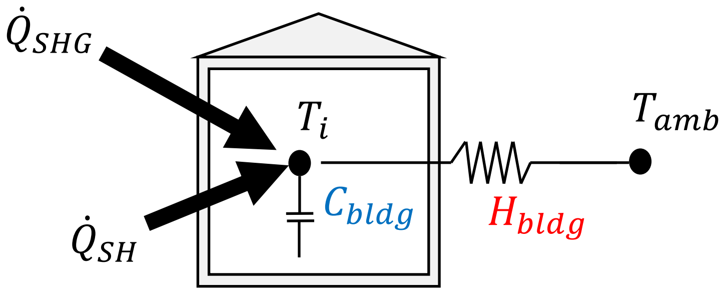


Basic heating system & building thermodynamics model



Heating system model

Parameter	Value
Heating curve temperature	Based on building age
Buffer storage size	25-45 L/kWp
Buffer storage delta-T	10°C
Bivalent temperature	-7°C
Quality factor	0.4
Simulation timestep	15 min
Auxiliary heat	Electric backup
Basic operation	Heat pump charges buffer storage OR supplies building directly

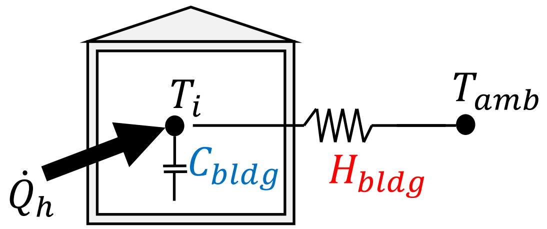


Building thermodynamic model

Parameter	Value
Heat loss coefficient, H	From heat demand modelling procedure
Heat capacity, C	SIA380: Light: 0.1 MJ/m2K Medium: 0.3 MJ/m2K Heavy: 0.5 MJ/m2K
Solar heat gains	SHGC = 0.7 at normal incidence Framing factor 0.3, Shading factor 0.6 Window areas based on building age

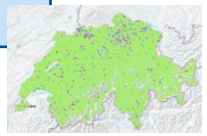
Which data do we use?

$$Time\ const, \tau = C_{bldg}/H_{bldg}$$



- Heat loss parameters → H_{bldg}
- Building properties (age, area, etc.)

Heat demand modelling



Source: GWR

Building construction data

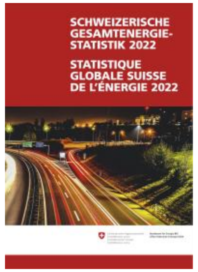
GEAK
Gebäudeenergieausweis der Kantone

Building monitoring data

Thermal capacitances: C_{bldg}

Dynamic simulations → **Flexibility assessment**

Control & heating system sizing assumptions



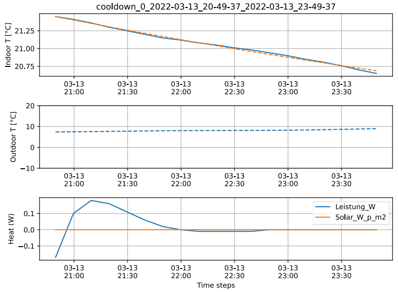
Source: BFE

P_{HP}

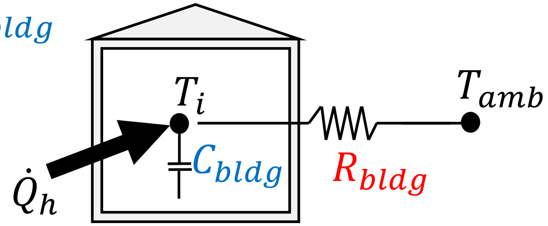
T_{HK}

How reasonable are building heat capacity assumptions?

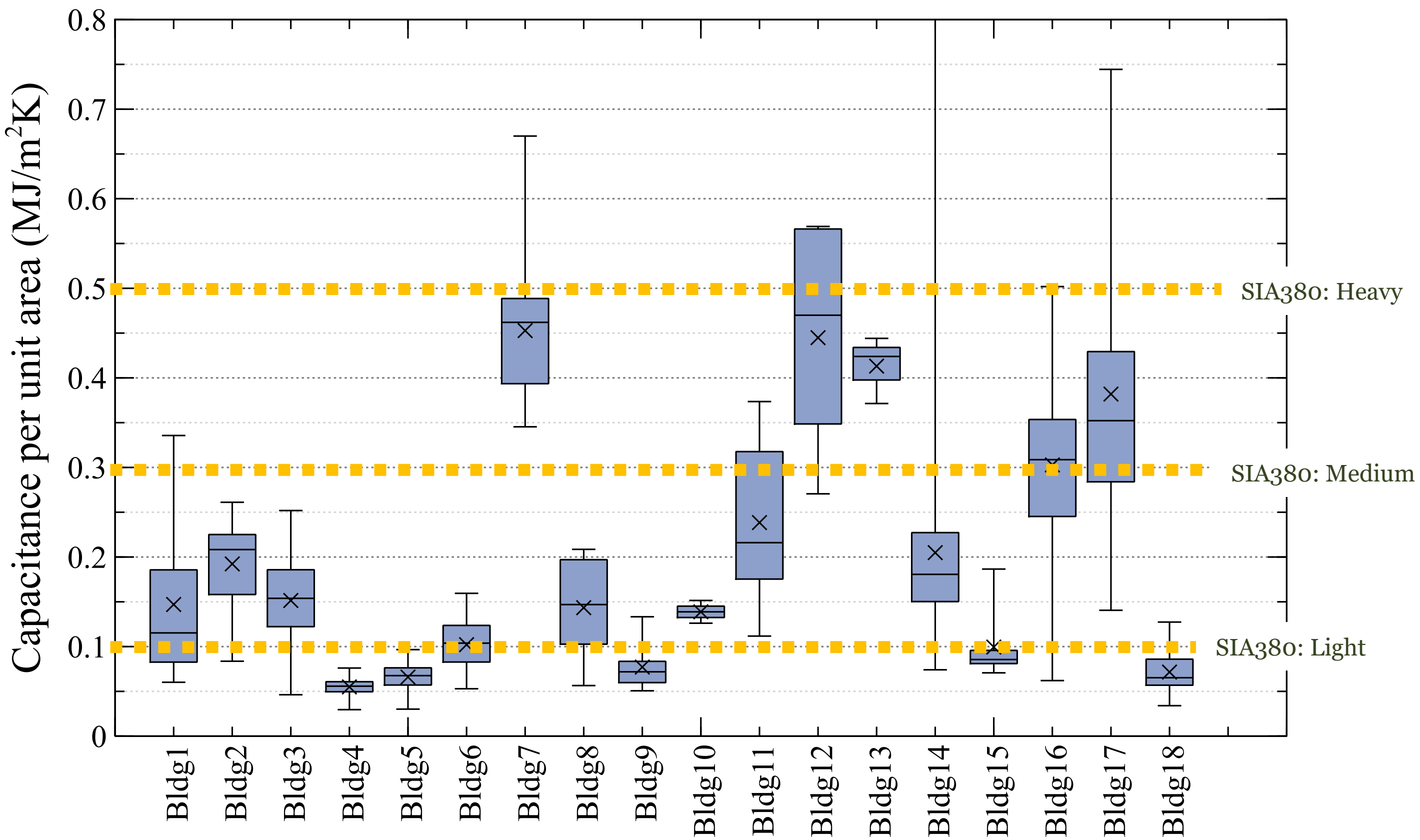
Monitoring data (temperature, heating) from 18 buildings



Effective heat capacitance C_{bldg}

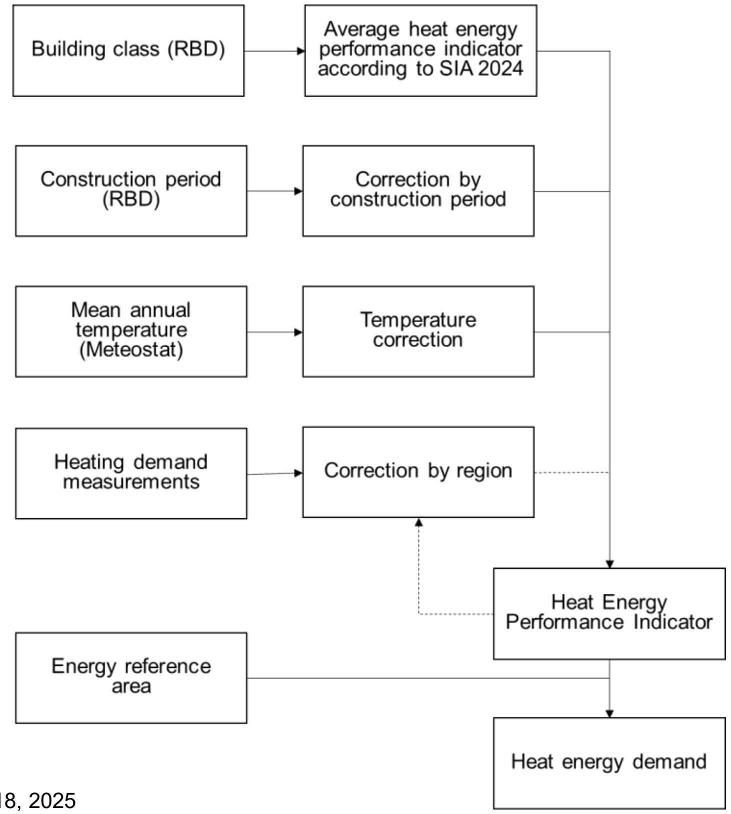


Effective heat capacitance C_{bldg} /A for 18 monitored buildings



How can we estimate the heating demand of a building?

Standard factor method: Based on RDB data and SIA 2024 for heating demand, statistical building period correction factor and mean temperature correction



Heat loss coefficient method: Building properties estimated based on RDB data

$$Demand = H \cdot \underbrace{\sum_{t=1}^{8760} \big(T - T_{amb}(t)\big) X_t}_{=:Heating\ degree\ hours}$$

$Heat\ loss\ coefficient,\ H$: Estimated using RBD data and reference heat transfer coefficients

T: Target room temperature (here 20°C)

T_{amb}: Average ambient during heating season

X_t: Indicator function of heating function:

$$X_t = \begin{cases} 1, & if\ t\ is\ a\ heating\ hour \\ 0, & else \end{cases}$$

Schneeberger, S., Meister, C. and Schuetz, P., 2025. Estimating the heating energy demand of residential buildings in Switzerland using only public data. *Energy and Buildings*, p.116371 https://doi.org/10.1016/j.enbuild.2025.116371

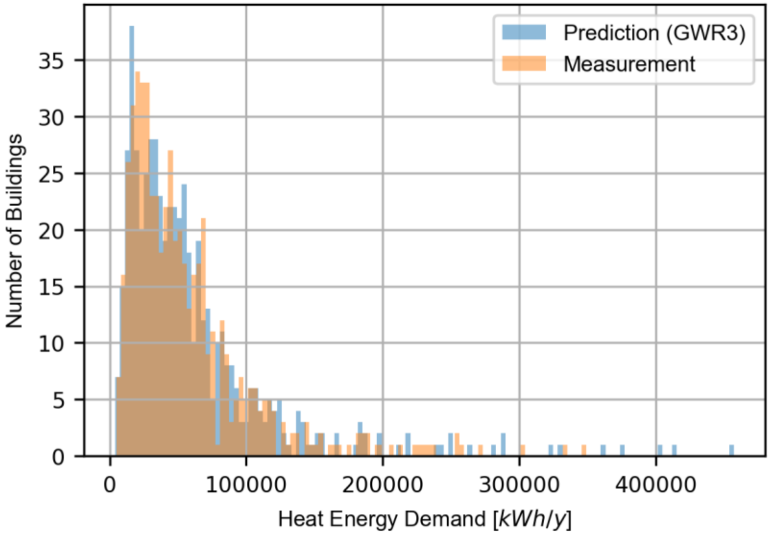
Validation of heat demand estimations

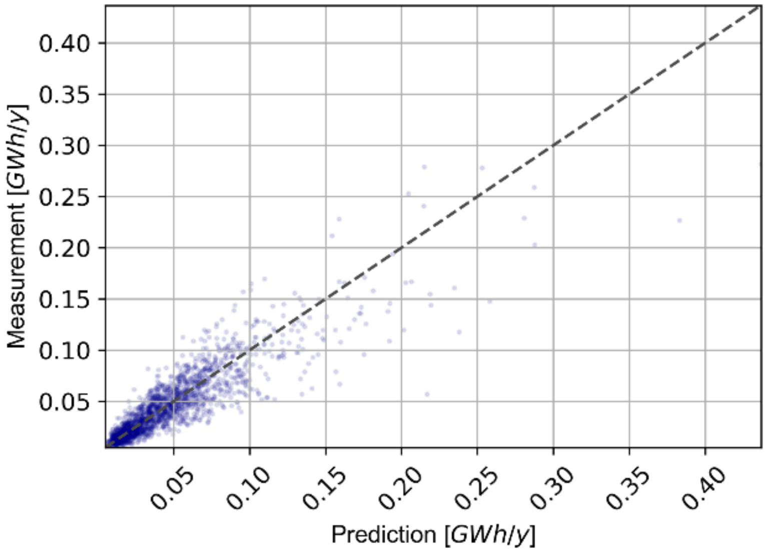
Approach:

Validate model with gas consumption, district heating consumption of larger city in eastern Switzerland.

Observation:

- Good reproduction of distribution of heating demands.
- Good reproduction of building-level heating demand achieved via calibration.





Schneeberger, S., Meister, C. and Schuetz, P., 2025. Estimating the heating energy demand of residential buildings in Switzerland using only public data. *Energy and Buildings*, p.116371 https://doi.org/10.1016/j.enbuild.2025.116371

Validation of heat pump dynamics

Approach:

- Compare cyclic behaviour of simulated heat pumps against real heat pump data:
  - Operational hours (h)
  - Number of heat pump cycles per day
  - Average heat pump cycle length (h)

- Order of magnitude and general trend match well -> reasonable approximation of real HP behaviour

Dataset used for validation:

Brudermueller, T., Kreft, M., Fleisch, E., & Staake, T. (2023). Large-scale monitoring of residential heat pump cycling using smart meter data. *Applied Energy*, 350, 121734. https://doi.org/10.1016/j.apenergy.2023.121734

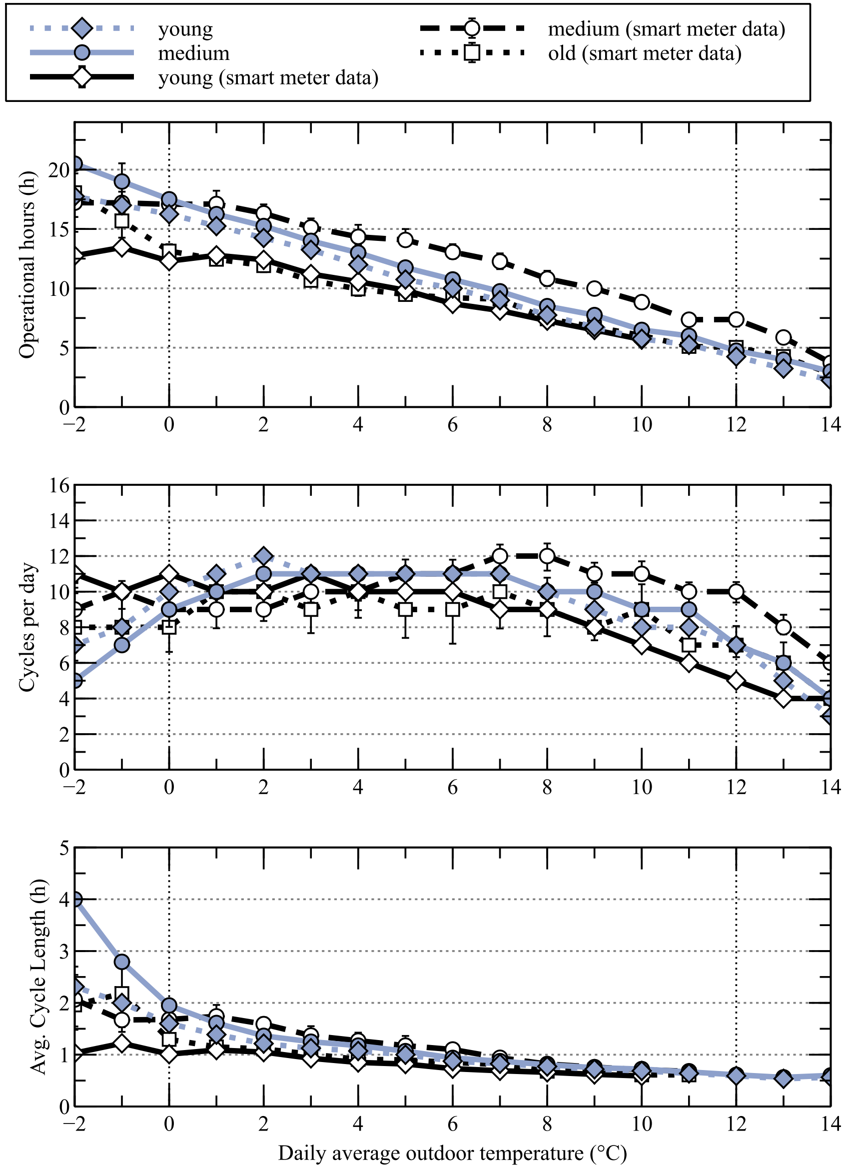
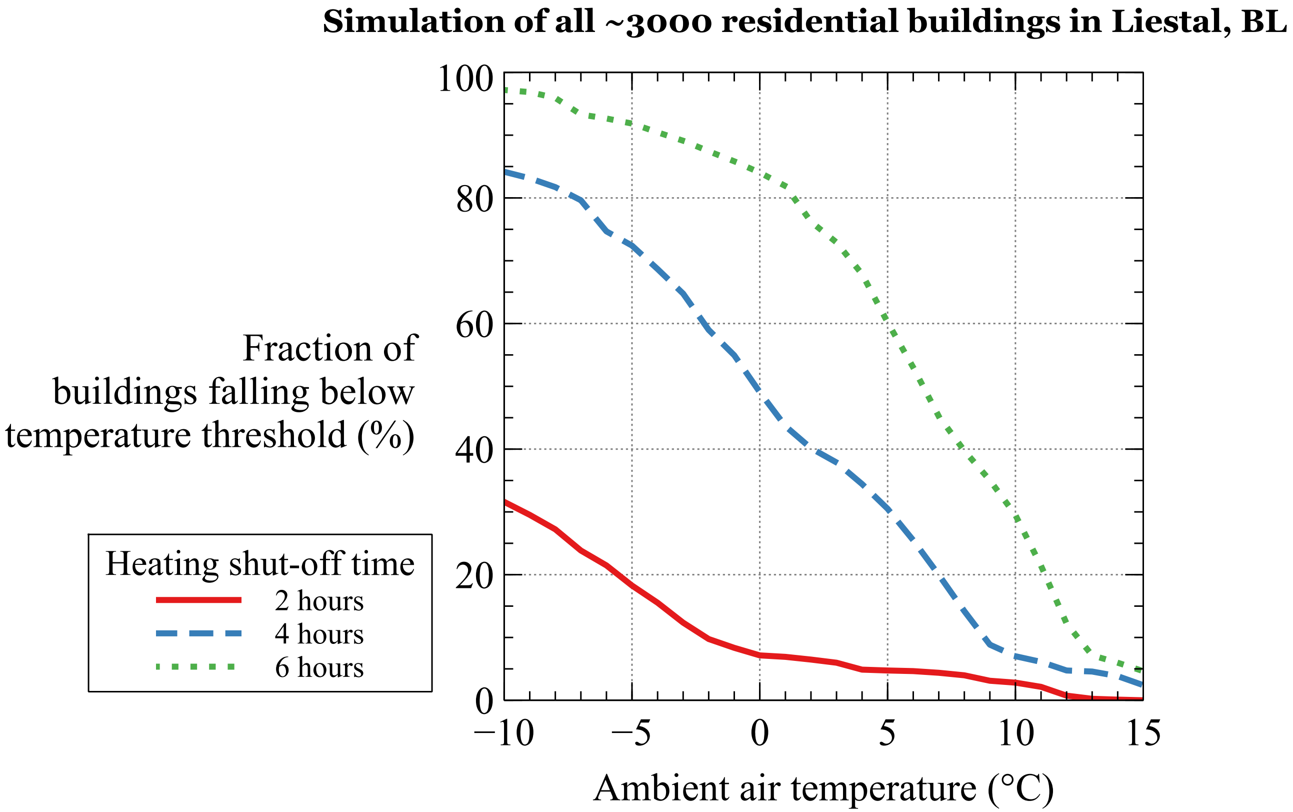


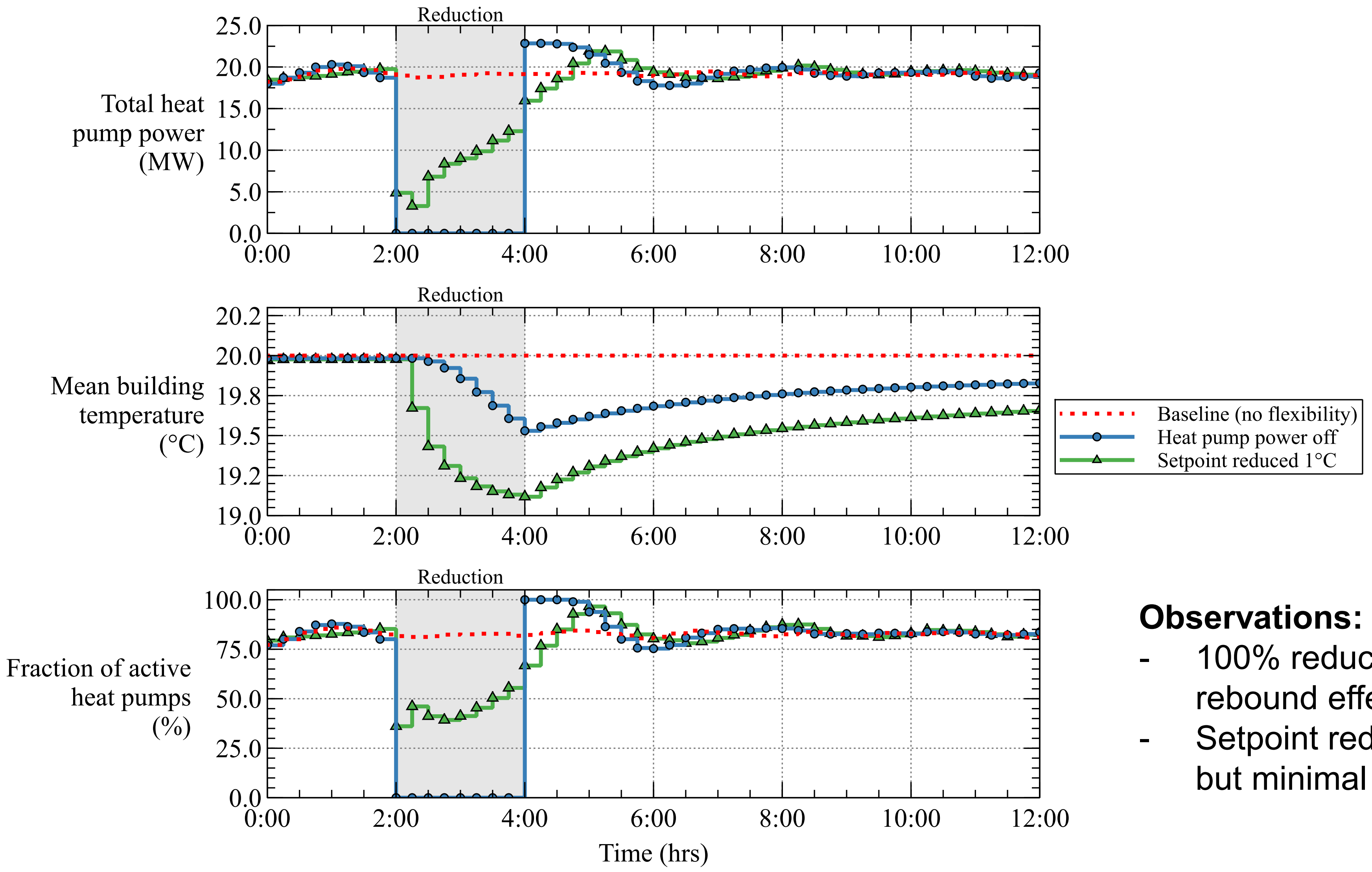
Fig: Comparison of HP cycling statistics (simulation vs. monitoring data)

How long can buildings withstand with no heat?



- **Two-hour limit**: quite safe in most weather
- **Four-hour limit**: safe above ~9°C
- Longer curtailments in cold weather will require **selective blocking** (e.g. by building age)

How do local control schemes affect cumulative flexibility?



Case Study in Liestal (BL):

- ~3000 heat pumps (HP)
- Cold weather (0°C)

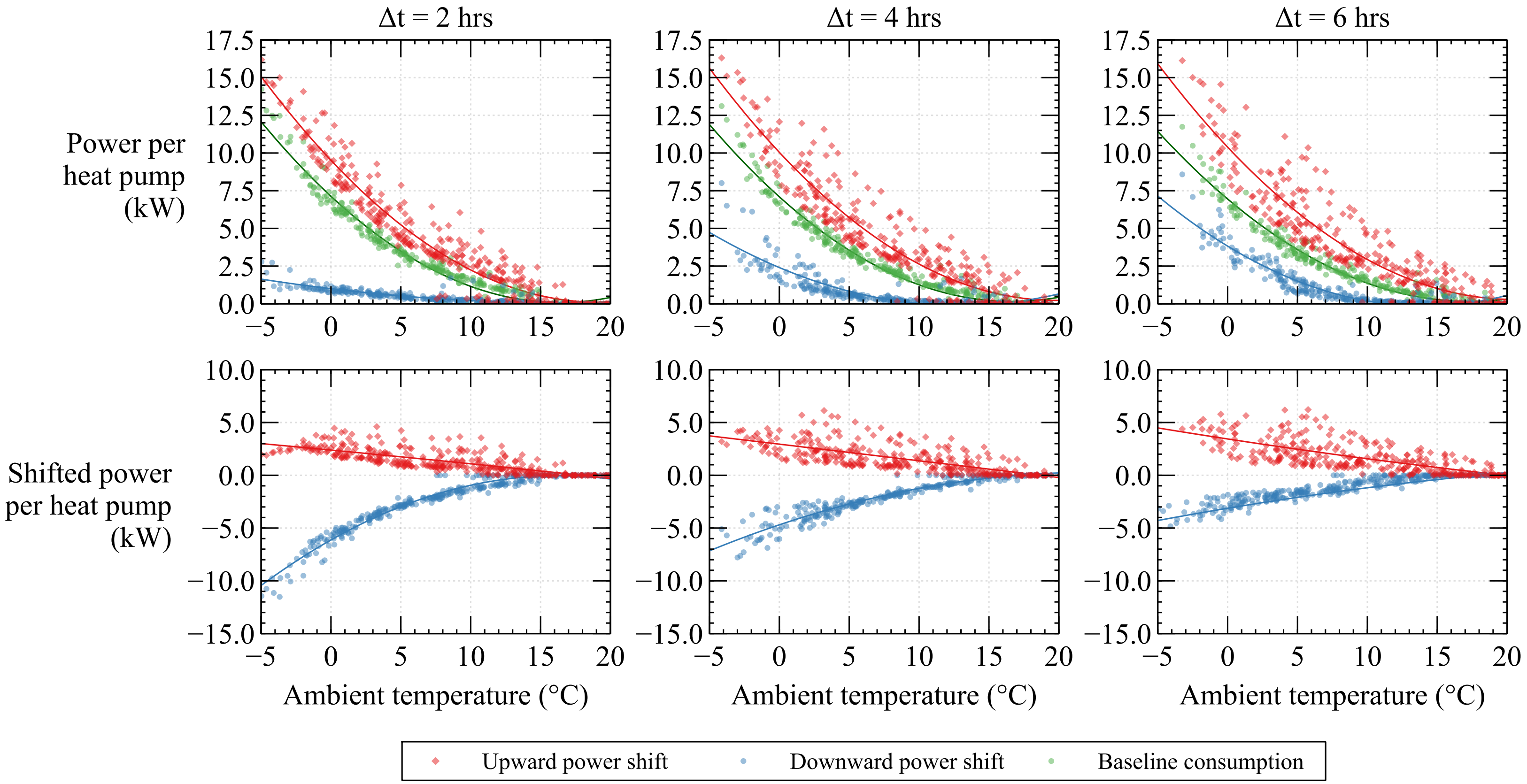
Control modes:

- *HP off*: all HP off during 2h
- *Set point reduced by 1°C*

Observations:

- 100% reduction for 2 h is possible, creates a strong rebound effect (HP off mode)
- Setpoint reduction strategy: more modest savings, but minimal rebound

How much power can we shift per HP?



Case Study in Liestal (BL):

- ~3000 heat pumps in 2050
- Test 1°C setpoint change strategy (upward and downward)

Two-hour DR events:

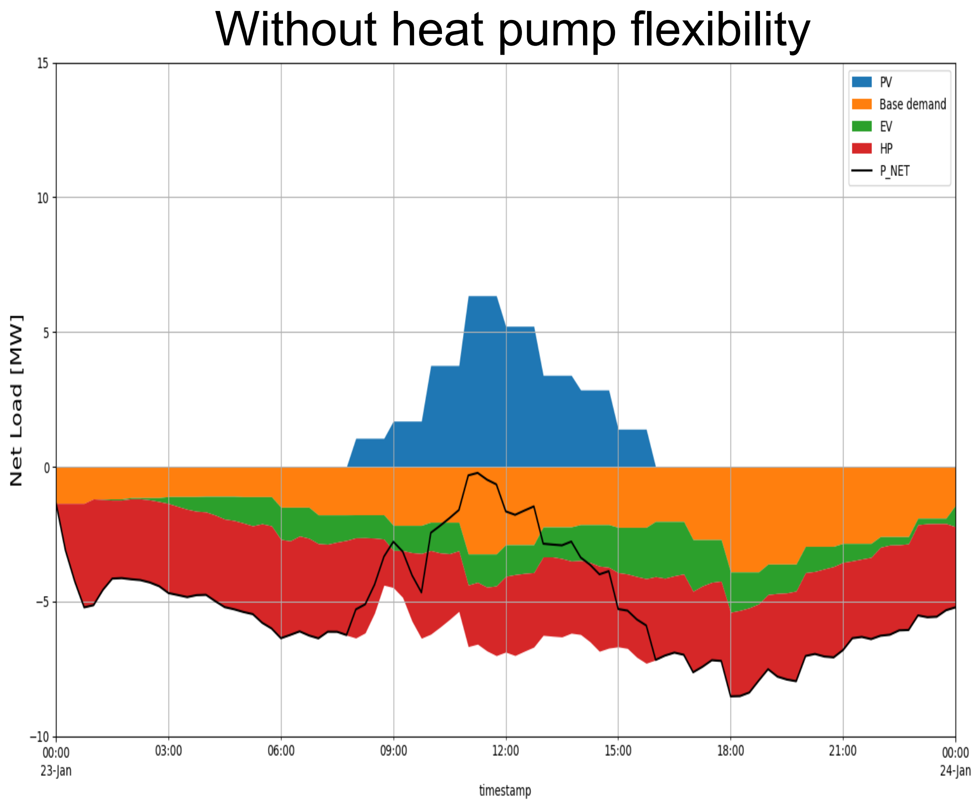
- Average HP consumes 7.5 kW at 0°C
- Utilising flexibility, we can:
  - Shift up to 10 kW (+2.5 kW, +33%)
  - Shift down to 1 kW (-6.5 kW, - 87%)

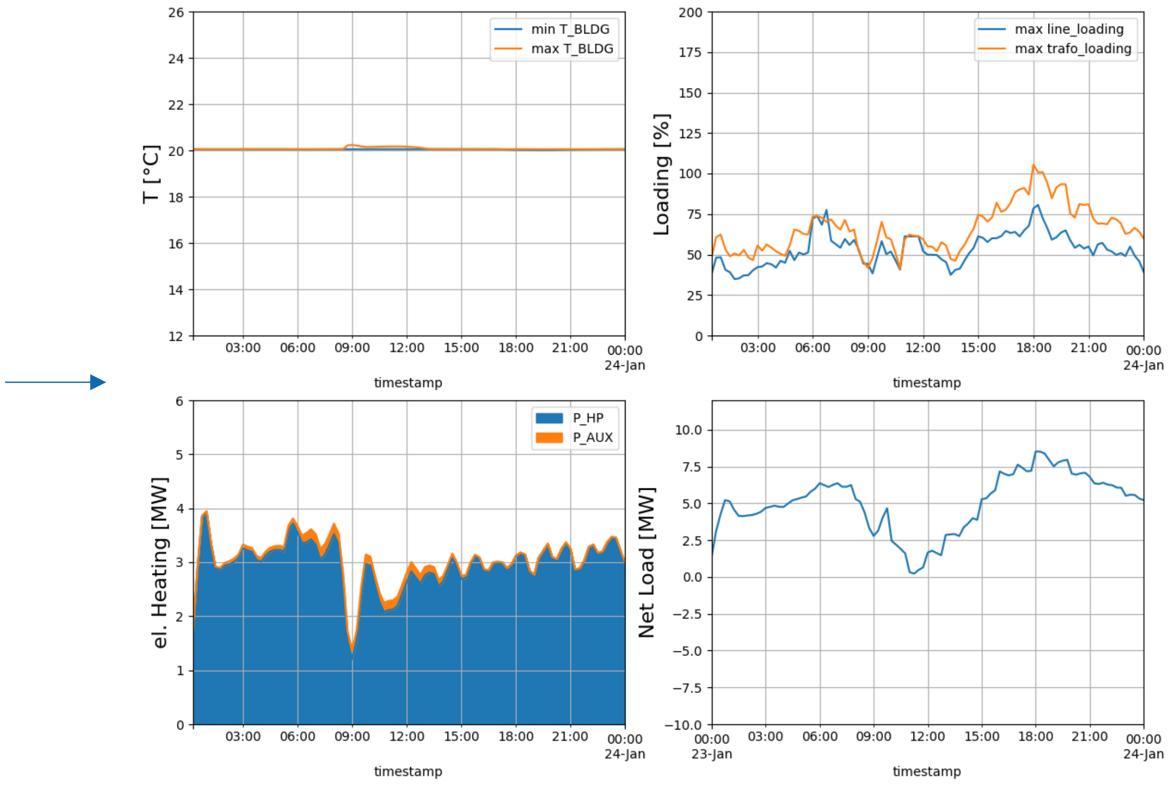
Longer windows = smaller power reductions, but similar power increase

(Why? Reductions limited by minimum building temp. Increases limited by maximum HP capacity)

Case Study - Municipality of Losone Energy System

Aggregated Energy Demand (Winter Day)



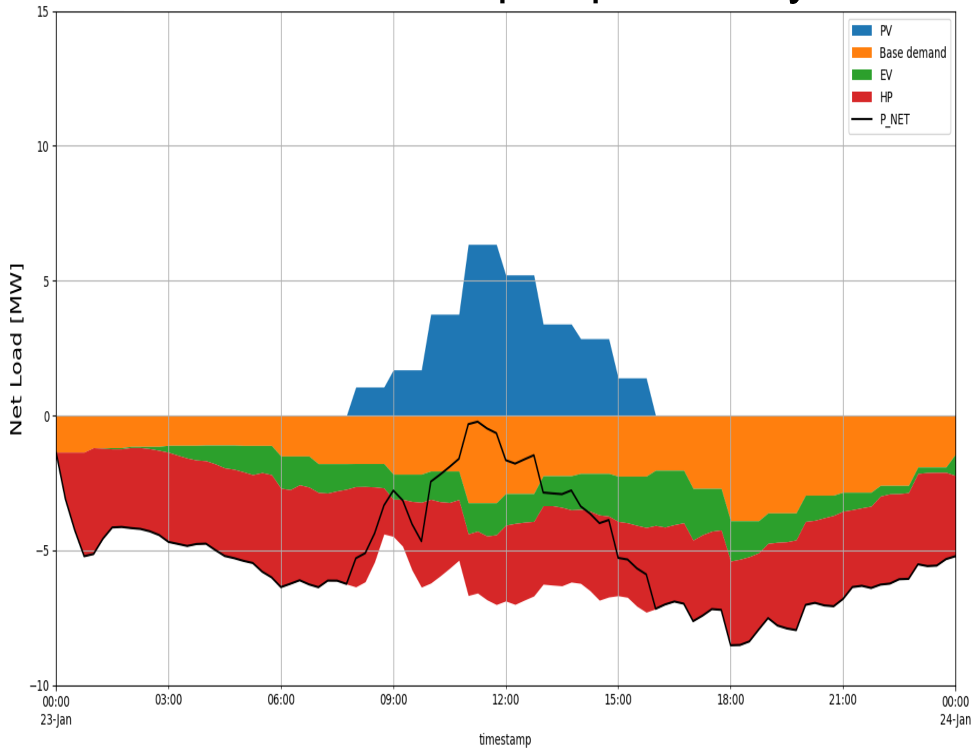


In collaboration with Research Center for Energy Networks, ETHZ:

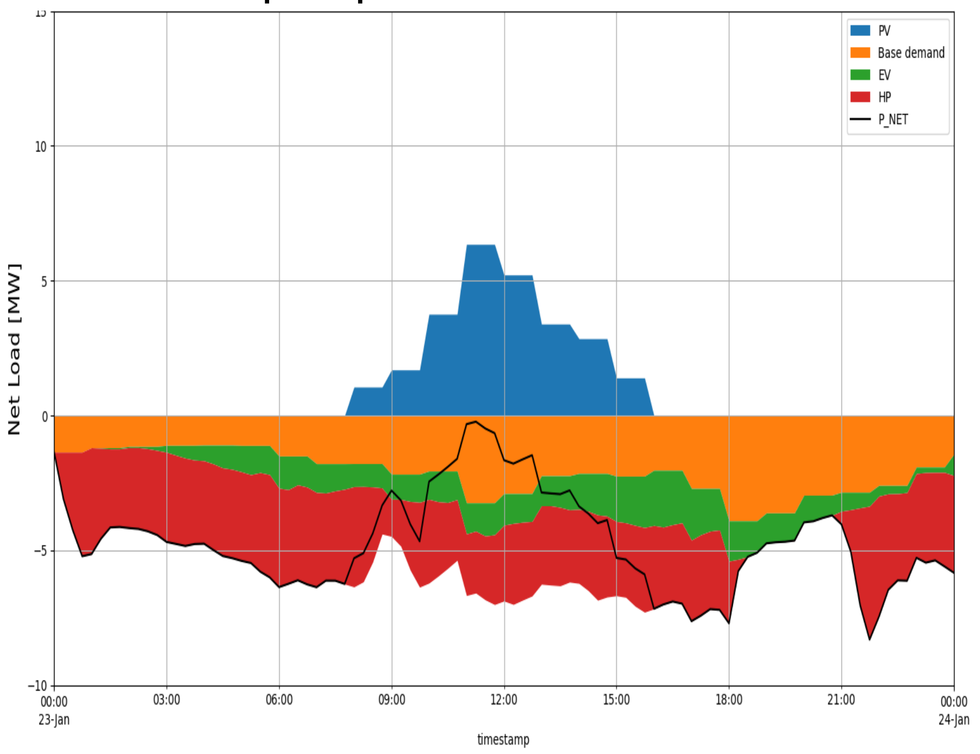
Synthetic Grid: A. Oneto, B. Gjorgiev, F. Tettamanti, and G.Sansavini "Large-scale generation of geo-referenced power distribution grids from open data with load clustering", 2025 in Sustainable Energy, Grids and Networks.

Case Study - Municipality of Losone Energy System
Aggregated Energy Demand (Winter Day)

Without heat pump flexibility



All heat pumps forced off 17:45-20:45

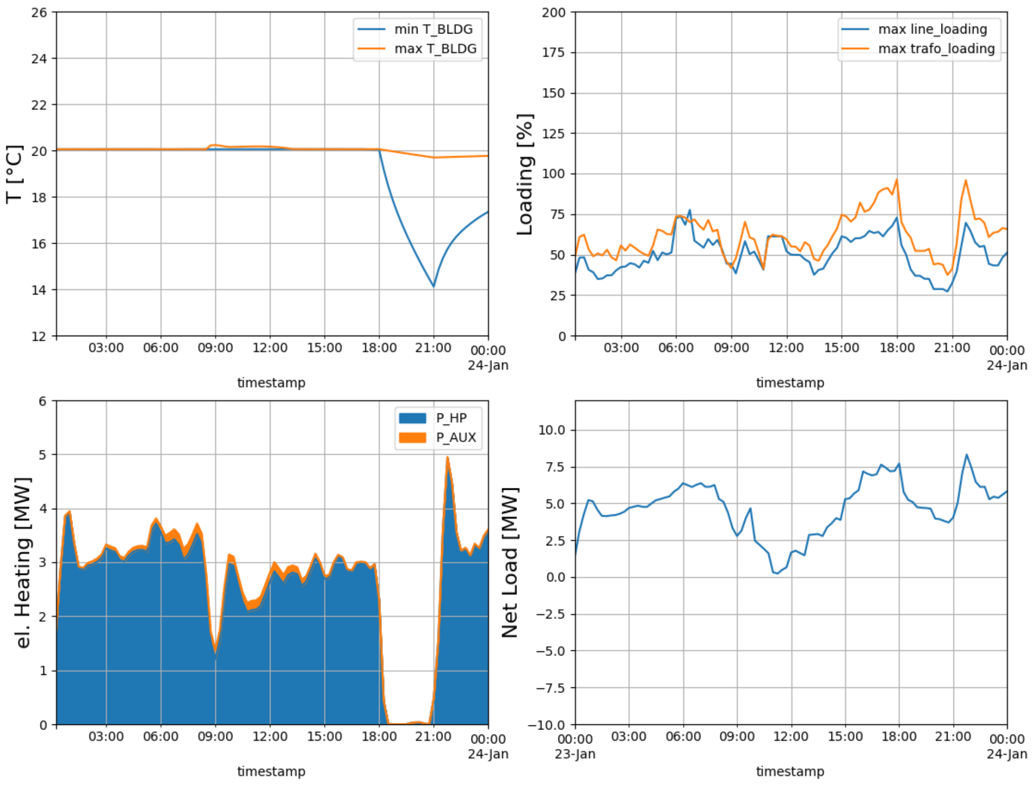


In collaboration with Research Center for Energy Networks, ETHZ:

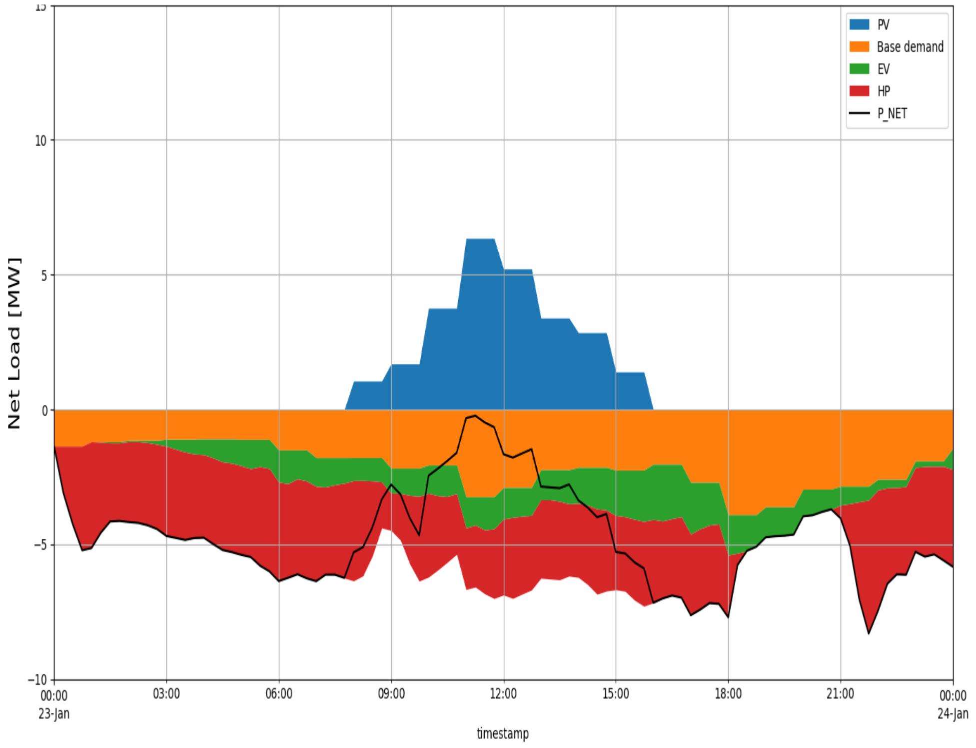
Synthetic Grid: A. Oneto, B. Gjorgiev, F. Tettamanti, and G.Sansavini “Large-scale generation of geo-referenced power distribution grids from open data with load clustering”, 2025 in Sustainable Energy, Grids and Networks.

Case Study - Municipality of Losone Energy System

Aggregated Energy Demand (Winter Day)



All heat pumps forced off 17:45-20:45



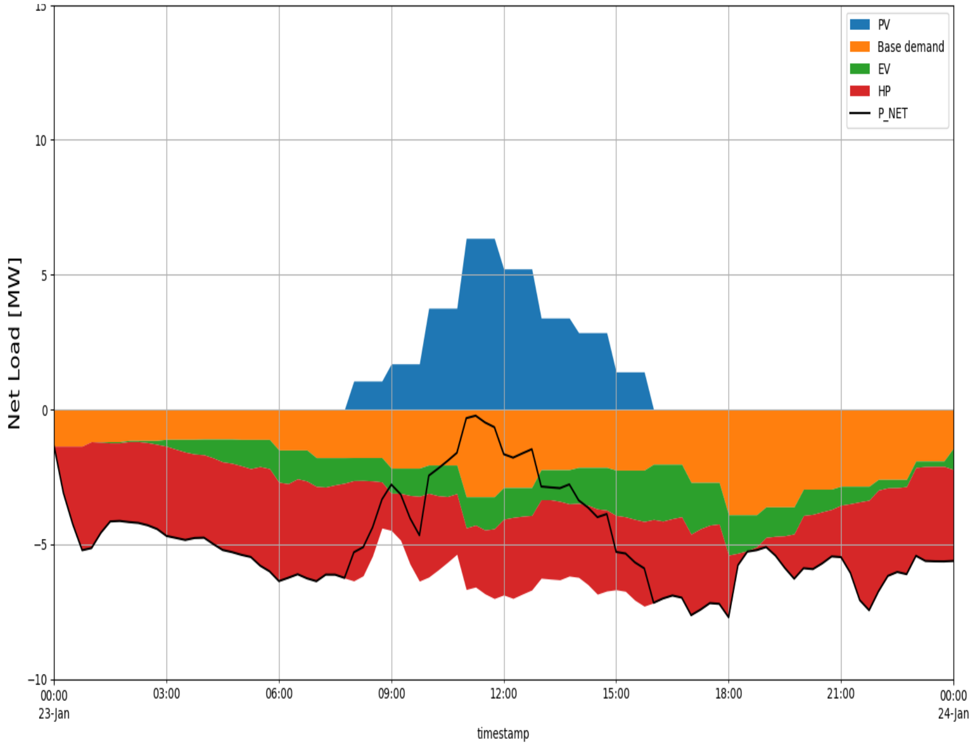
In collaboration with Research Center for Energy Networks, ETHZ:

Synthetic Grid: A. Oneto, B. Gjorgiev, F. Tettamanti, and G.Sansavini “Large-scale generation of geo-referenced power distribution grids from open data with load clustering”, 2025 in Sustainable Energy, Grids and Networks.

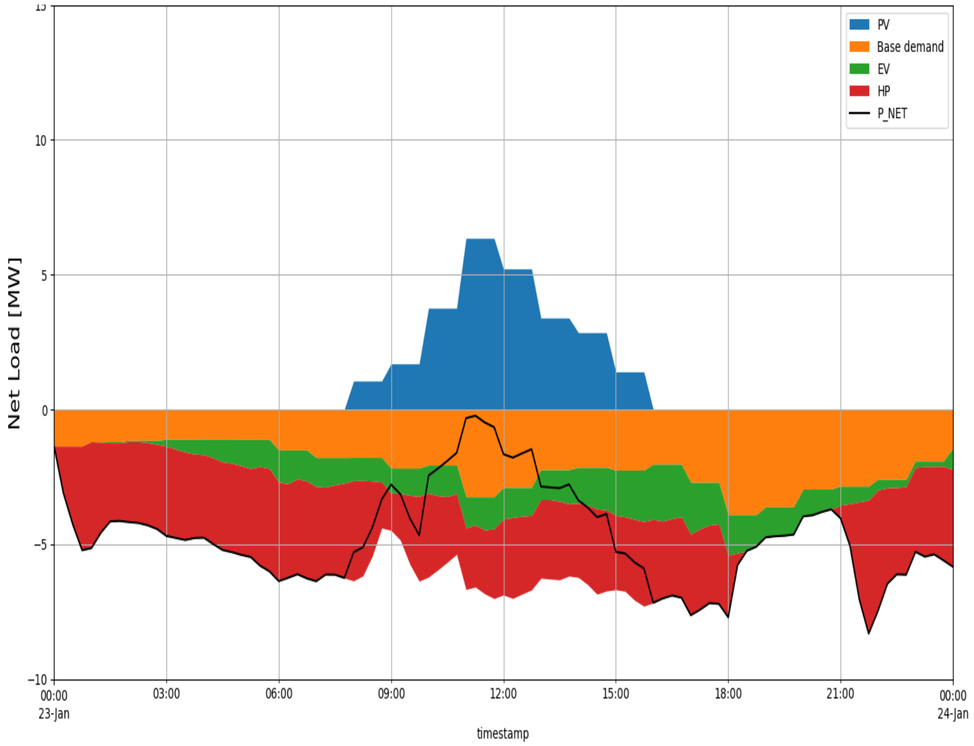
Case Study - Municipality of Losone Energy System

Aggregated Energy Demand (Winter Day)

1°C setpoint reduction 17:45-20:45



All heat pumps forced off 17:45-20:45



Reducing temperature setpoint instead of switching space heating off completely reduces rebound.

Key Messages

Heat pump loads are inherently flexible due to building thermal inertia. Buildings may be utilised as a thermal battery, storing energy with the **same order of magnitude as hot water and battery energy storages**.

Typical two-hour heat pump interruptions **safely maintain comfort for 90% of buildings at 0°C**. For longer interruptions or in very cold weather, DSOs should examine smart control strategies, like selective blocking based on age or construction type.

Generally, **more downward flexibility is available from heat pumps than upward**, as upward flexibility is limited by maximum heat pump capacity. A typical heat pump might increase its power consumption by only +33% over 2 hours at 0°C, but can shed up to 86% of its load in the same conditions.

How heat pump flexibility is controlled locally **strongly affects communal response**. Setpoint adjustments offer lower power savings compared to full shut-offs, but significantly reduce rebound effects.

Greater **standardisation of HP communication and control interfaces** is a key step towards permitting better local control mechanisms like selective blocking or building setpoint adjustments.

For more…see the PATHFNDR Synthesis Report!

ENERGY SCIENCES • RESEARCH

How electric cars and heat pumps can help Switzerland implement its Energy Strategy

In future, flexibly operated heat pumps and electric cars could reduce both electricity imports and electricity prices. That is according to a new study by a Swiss research consortium led by ETH Zurich.

11.11.2025 by Christoph Elhardt, Corporate Communications   Read • • Share

Flexible use of EVs + HPs can:

- increase renewable utilisation by 4%
- decrease electricity imports by 20%
- delay & reduce grid reinforcements

Link to report:

Powell S, Marinakis A, Ruefenacht L et.al., Flexibility provision from electromobility and buildings. Synthesis report, PATHFNDR Consortium, 11.11.2025, doi: 20.500.11850/787060

PATHFNDR: www.sweet-pathfndr.ch

Call for participation

We *offer*:

- Heat demand profiles
- Heat pump profiles
- Procedures to estimate flexibility and mitigate peak loads

We *search* for:

- **Building/Site owners/Planners:** Using profiles for planning process
- **Utilities**: Interested in flexibility aware planning or operation
- **Cantonal offices**: Identifying suitable districts for flexibility aware operation

Please contact us:

THERMAL ENERGY STORAGE

sweet swiss energy research for the energy transition

PATHFNDR

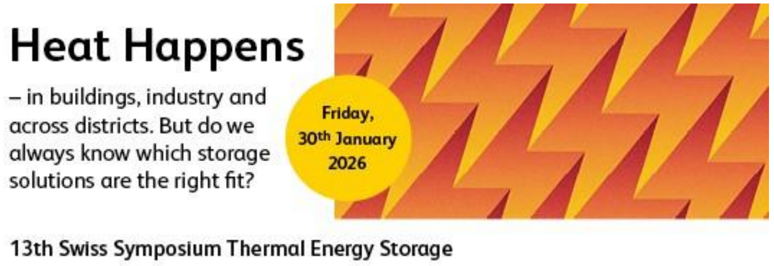
Curtis Meister
curtis.meister@hslu.ch

Sarah Schneeberger
sarah.schneeberger@hslu.ch

Philipp Schütz
philipp.schuetz@hslu.ch

Lucerne University of Applied Science and Arts
Competence Centre for Thermal Energy Storage
www.hslu.ch/TES

Thank you for your attention!



ETH zürich | Empa | PAUL SCHERRER INSTITUT PSI | zh aw | HSLU Hochschule Luzern | UNIVERSITÉ DE GENÈVE | EPFL | TU Delft