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RENOWAVE
DECARBONIZATION OF THE BUILDINGSTOCK

Design and technical improvement of heat-pump systems for existing multifamily buildings

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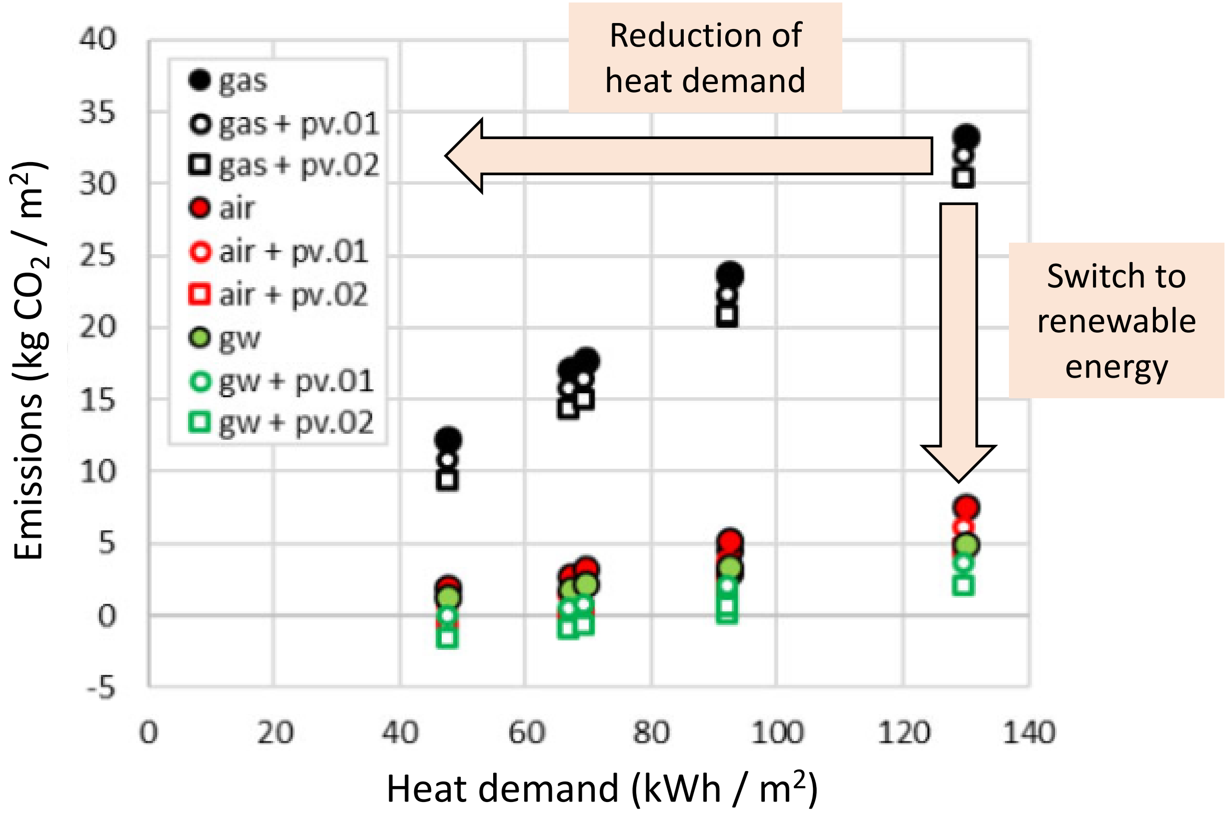
University of Geneva

Overall challenge

Pathways for CO_2 reduction of the Building stock



Romano et al, 2020: https://archive-ouverte.unige.ch/unige:136512

Overall challenge:

- Reduction of heat demand ➔ retrofit of building envelope
- Switch to renewable energy ➔ change of heat production system

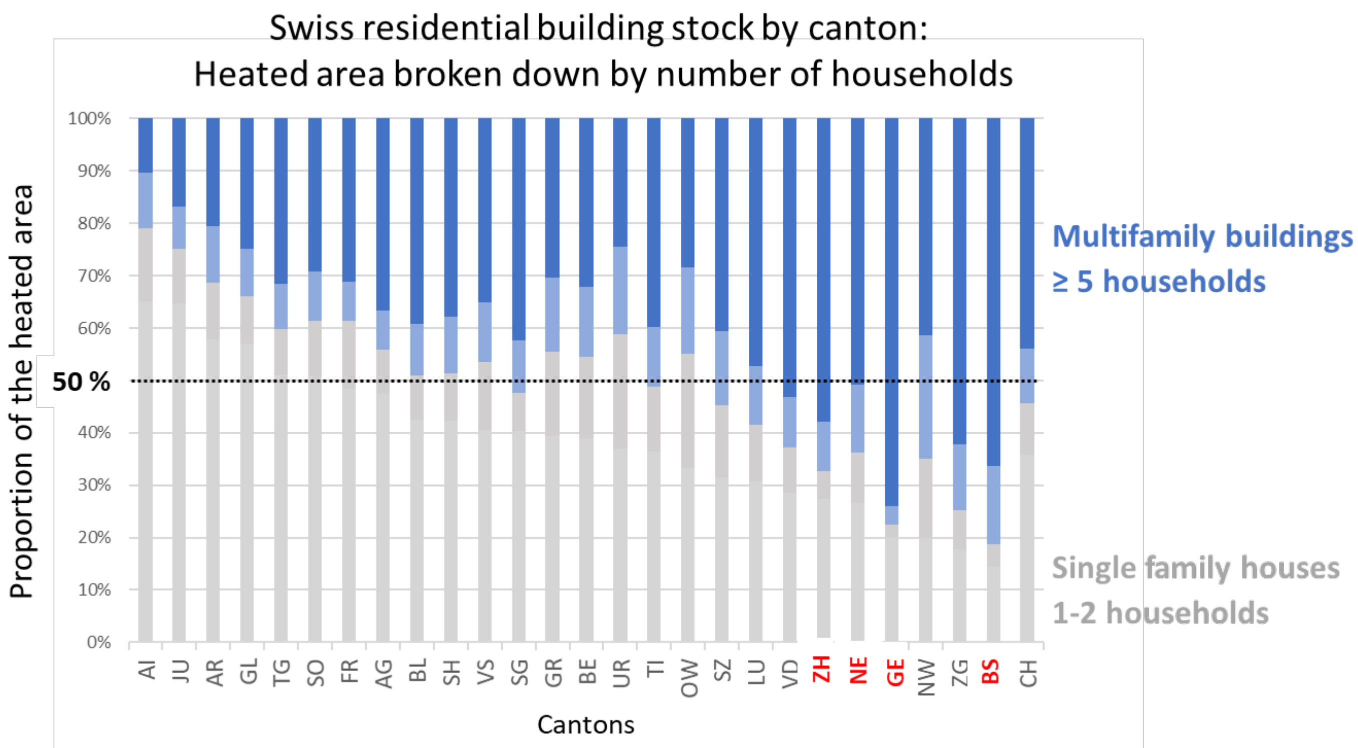
Challenge of Multifamily buildings (MFB)

MFB, share of heated area :

- CH: 45%
- Urban cantons: 60 – 75%

Specific challenges:

- Dense urban areas ➔ air as only HP source
- HP systems > 50kW not standardized
- Owner-Tenant dilemma ➔ contracting as a possible solution



Data source: Schneider et al., 2018: https://archive-ouverte.unige.ch/unige:103112

Challenges of Building retrofit

Retrofit rate of multi-family buildings

Construction Period	Retrofit rate		fraction by energy class improvement: r_{Ei}/r_E (%)						Efficient retrofit rate		Mean savings MJ m^{-2} y^{-1}
	r_E	r_A	>2	2	1	0	-1	≤-2	r_{E2+}	r_{E1+}	
Before 1919	1.7%	1.8%	0.6%	5.3%	26.2%	58.2%	8.8%	0.9%	0.1%	0.5%	45.9
1919-1945	2.0%	2.0%	0.0%	4.6%	23.2%	62.4%	9.3%	0.5%	0.1%	0.6%	39.4
1946-1960	1.7%	2.0%	5.4%	3.5%	27.3%	56.5%	7.3%	0.0%	0.2%	0.6%	48.9
1961-1970	2.4%	2.6%	8.1%	8.1%	29.1%	50.1%	4.2%	0.2%	0.4%	1.1%	91.1
1971-1980	1.3%	1.5%	3.3%	3.3%	31.3%	48.9%	12.6%	0.5%	0.1%	0.5%	51.4
1981-1990	0.4%	0.6%	0.0%	2.5%	37.5%	37.5%	22.5%	0.0%	0.0%	0.2%	34.5
Total	1.7%	1.9%	3.9%	5.3%	27.8%	54.4%	8.2%	0.4%	0.2%	0.6%	67.9

Grandjean et al., 2021: *https://archive-ouverte.unige.ch/unige:156968*

Challenges:

- Cost / Benefit
- Owner-Tenant dilemma
- Administrative complexity
- Heritage protection
- Lifecycle – Timing
- Availability of skills
- Constructive, architectural and user issues Performance gap
- …

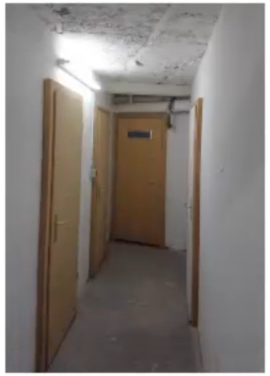
Challenges of Fuel switch

Challenges (for MF-buildings) :

- Reduced space for heat storage
- HP weight / roof structure
- Noise (air-source HP)
- Integration in existing system
- Evolution of demand (future retrofit)
- Lack of case studies, factsheets & training programs

Weight limitation

Limited space

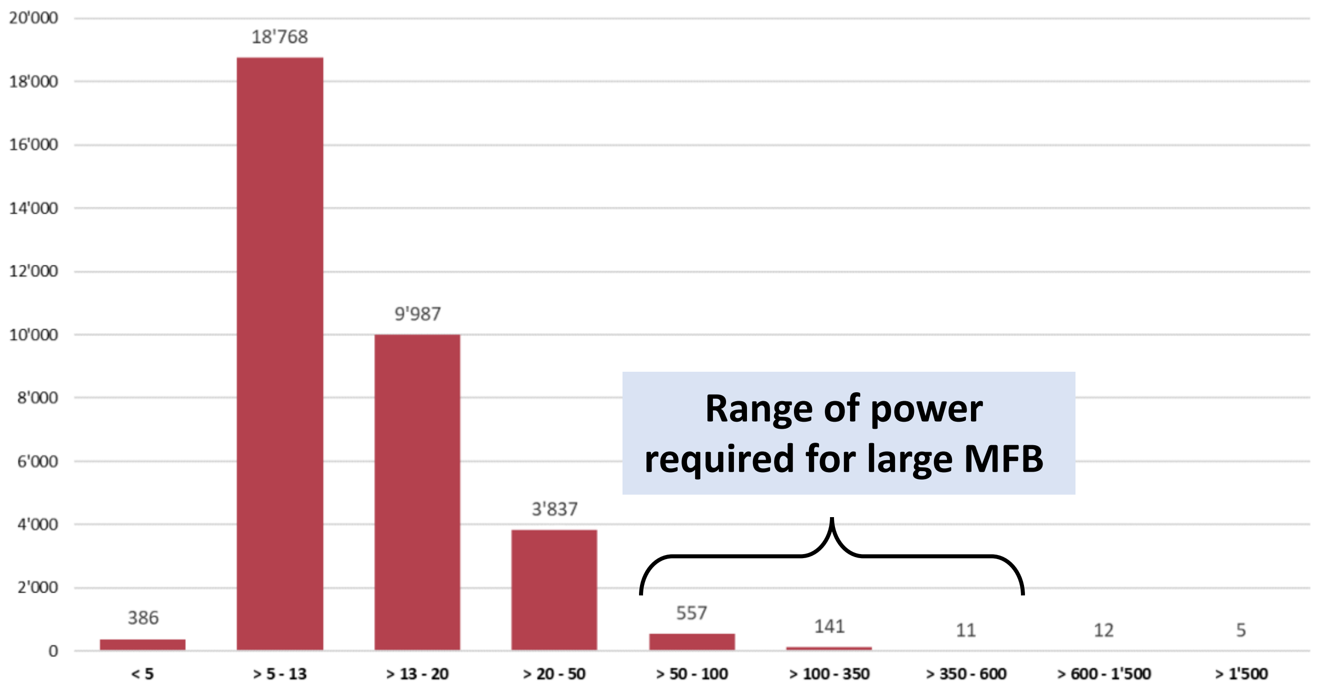


Integration in existing system

Future retrofit / demand reduction

Challenges of Fuel switch

HP sales in Switzerland (2021) according to power capacity (kW)



Source: Groupement professionnel Suisse pour les pompes à chaleur (GSP). Statistiques 2021

- Lack of standardized schemes → oversized, ill-integrated systems
- Lack of robust control strategies (in particular for bivalent systems) → underperformance

P+D projects

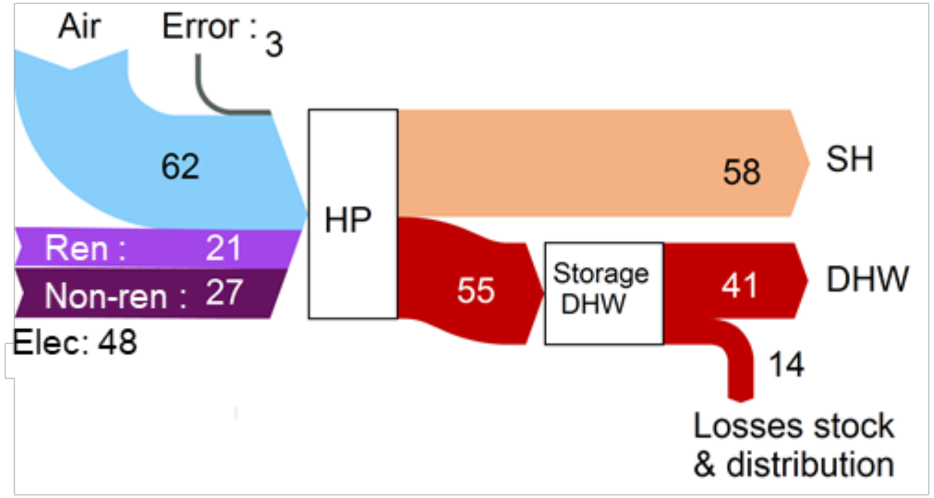
Monovalent system – Large industrial HP units

Bivalent system – Small standardized HP units

	Monovalent	Hybrid
Type of building	Residential	Mixed (residential + commercial)
Construction year	1972	1992
Heated floor area	4'047 m^2	7'563 m^2
Old heating system	Oil boiler (319 kW_{th})	Gas boilers (2 x 200 kW_{th})
New heating system[1]	2 industrial ASHPs (2 x 156 kW_{th})	6 ASHPs (6 x 34 kW_{th}) + existing gas boiler (200 kW_{th})
SH demand (measured)	58 $kWh_{th}/m^2/yr$	64 $kWh_{th}/m^2/yr$
SH demand (normalized)[2]	77 $kWh_{th}/m^2/yr$	72 $kWh_{th}/m^2/yr$
DHW demand[3]	55 $kWh_{th}/m^2/yr$	30 $kWh_{th}/m^2/yr$
Monitoring period	July 2018 – June 2020	July 2017 – June 2019

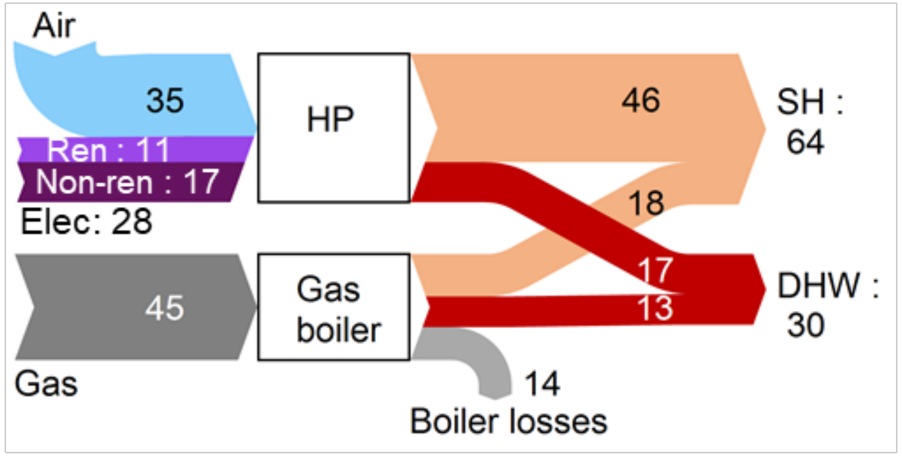
P+D projects

Monovalent HP system



SPF$_{sys}$: 2.29
HP share : 100%
Ren. fraction : 75%

Bivalent HP system



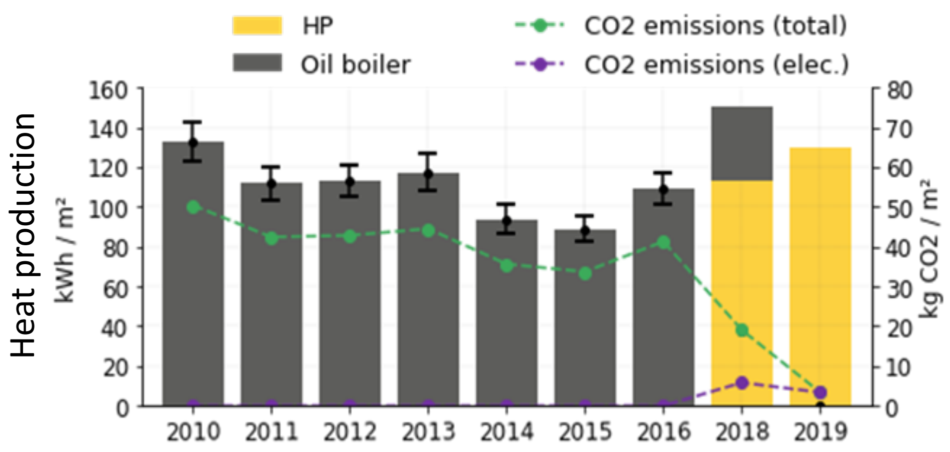
SPF$_{sys}$: 2.28
HP share : 67%
Ren. Fraction : 43%

Montero et al. (2022)
https://archive-ouverte.unige.ch/unige:162052

Renewable electricity fraction based on hourly Swiss electricity mix (Romano, 2018, https://archive-ouverte.unige.ch/unige:131622)

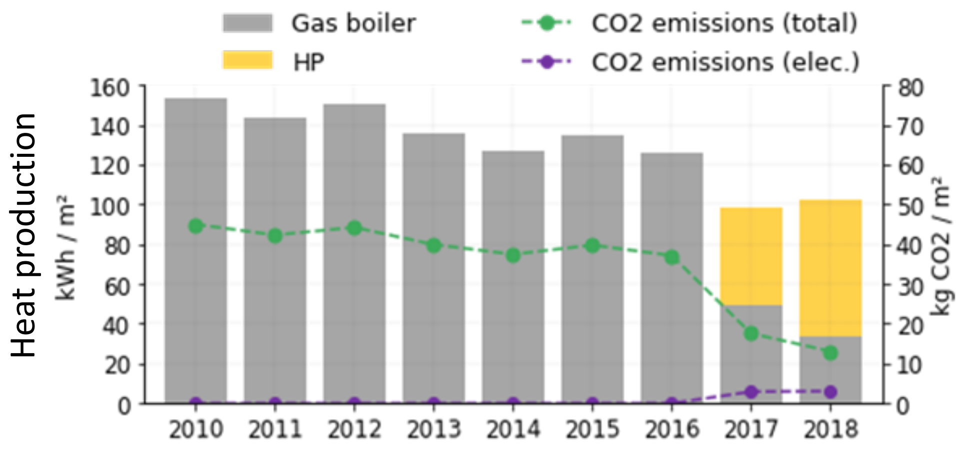
P+D projects

Monovalent HP system



Emission savings: 92%

Bivalent HP system



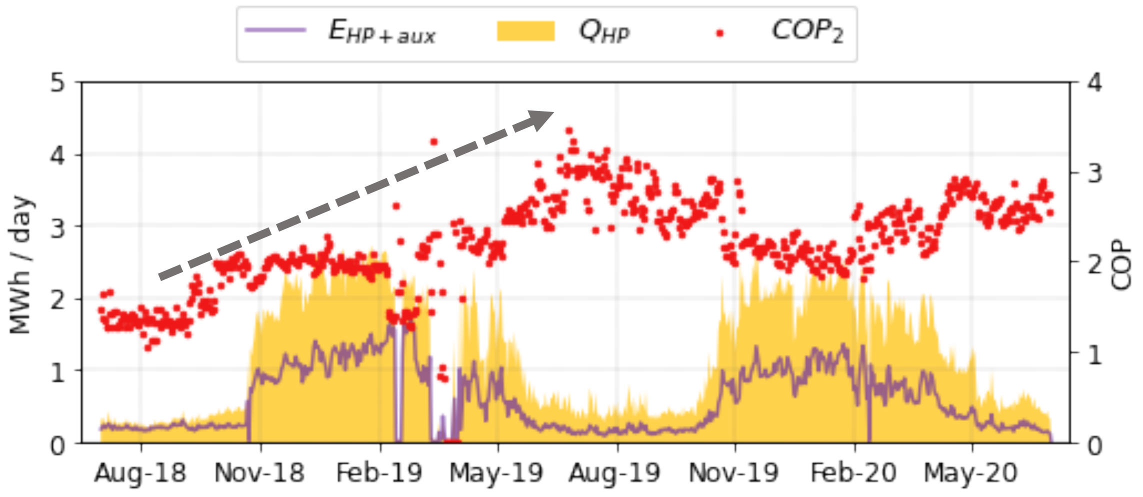
Emission savings: 68%

Montero et al. (2022)
https://archive-ouverte.unige.ch/unige:162052

CO_2 content of electricity based on hourly Swiss electricity mix (Romano, 2018, https://archive-ouverte.unige.ch/unige:131622)

P+D projects

Monovalent system



Increase of the COP from 1.5 to 3.4

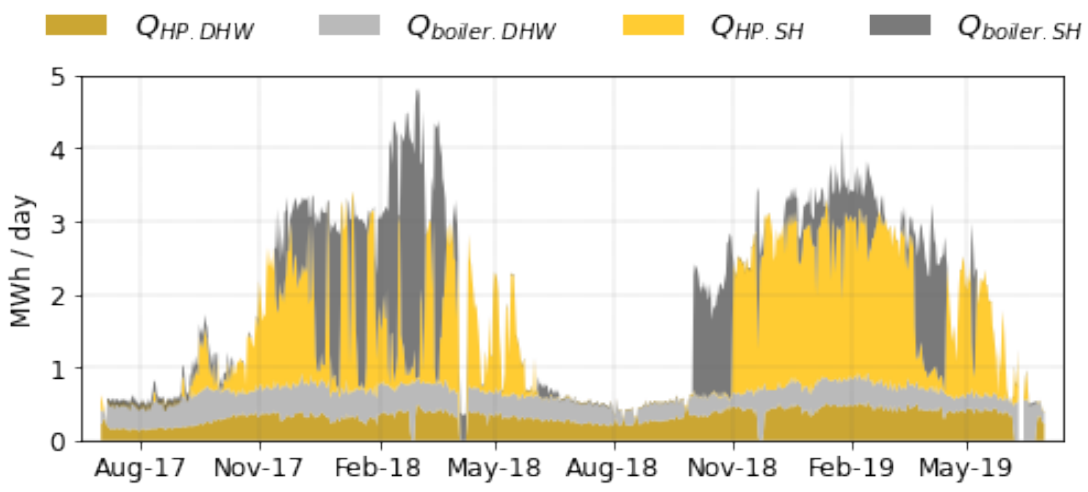
Identified issues:

(i) Circulation pumps ON (24h/24)

(ii) Heating curve not taken into account

(iii) HP oversized (+146 %)

Hybrid system



Increase of the annual HP fraction from 50% to 67%

Identified issues:

(i) HP shutdowns → high return temperatures from boiler

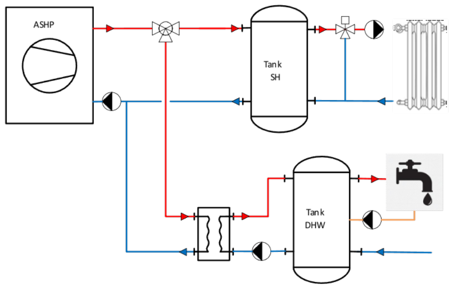
(ii) Limited master/slave control

(iii) Significant heat losses in the pipes

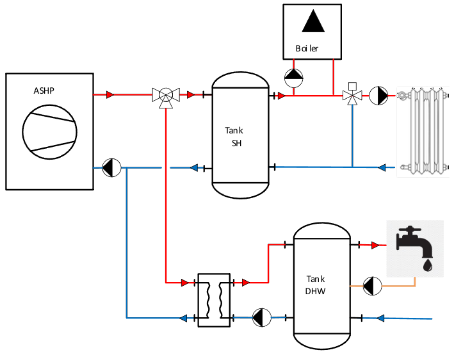
Montero et al. (2022). https://archive-ouverte.unige.ch/unige:162052

Hydraulic schemes

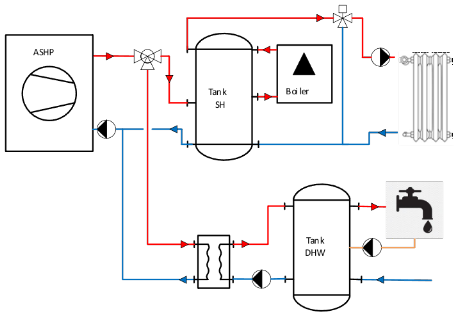
- **HP concepts based on :**
  - Discussions with experts in the field
  - Long-term in-situ monitoring of pilot projects
- **Model validation with in-situ monitoring (TRNSYS)**
- **Normalization to reference conditions**
  - Climate, space heating and DHW demand
- **Sensitivity analysis**
  - Levels of heat demand and heat pump capacity
- **Conclusions and recommendations**



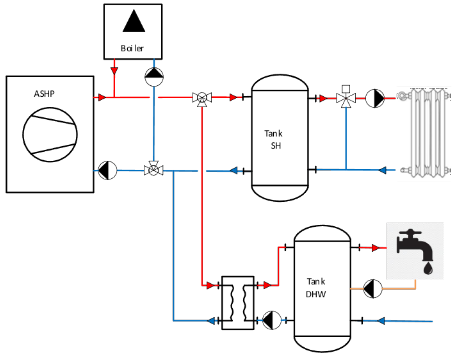
A) Monovalent



B) Hybrid parallel operation with modulating boiler



C) Hybrid parallel operation with a non-modulating boiler

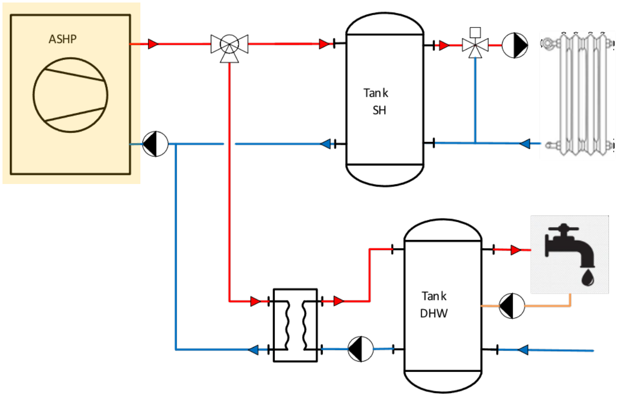


D) Hybrid alternative operation with a non-modulating boiler

Montero et al., 2023: https://archive-ouverte.unige.ch/unige:169365

Hydraulic schemes

Monovalent system

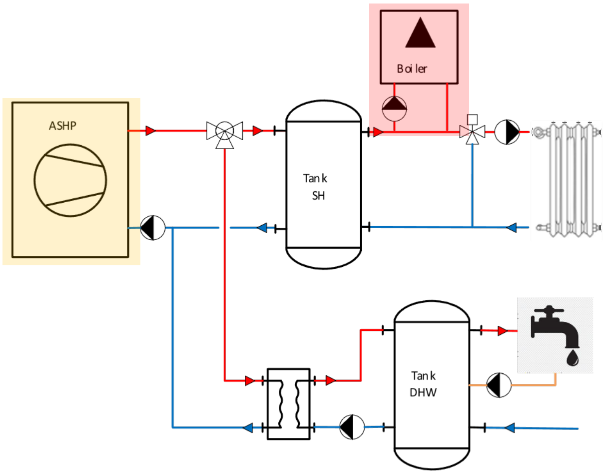


- HP to cover 100% of the demand (SH and DHW)
- **Easier to control**, but requires measures of noise reduction, rooftop static and extra height construction limits
- Cost → More HP capacity than hybrid systems
- **Risk of HP oversizing**

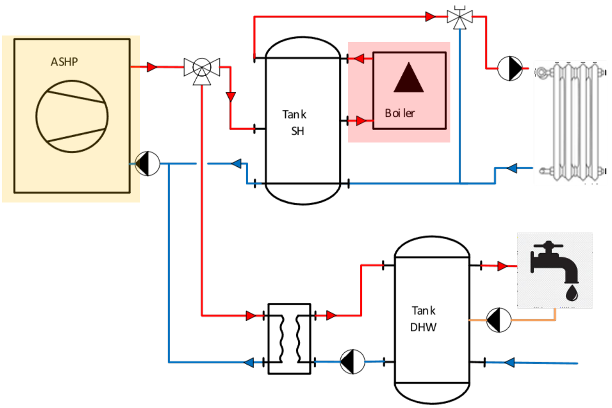
Hydraulic schemes

Hybrid parallel system

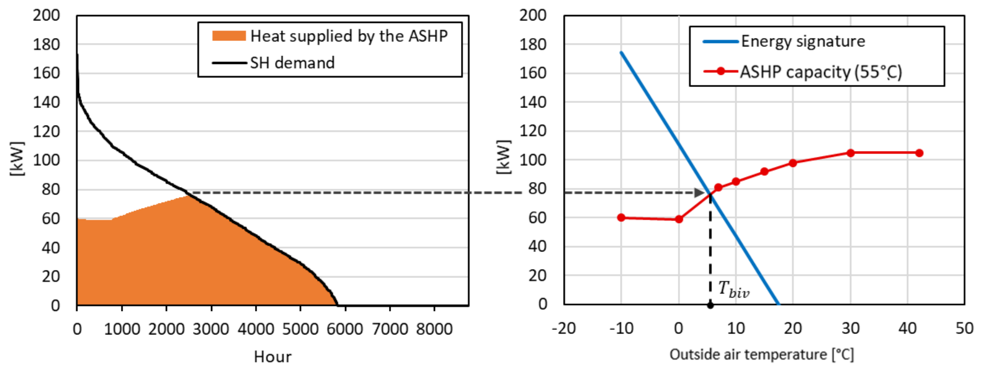
Modulating boiler



Non-modulating boiler



Operation mode

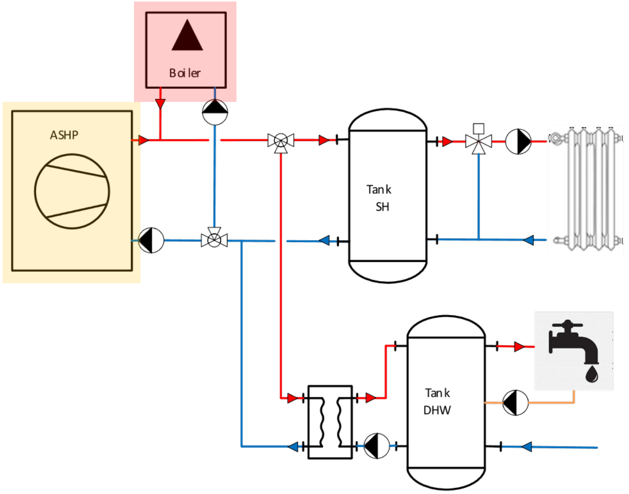


- **Economic choice** (HP to over 80% of the demand ➔ 50% of the load)
- **Transitional solution**, while awaiting an envelope renovation
- **More complex** (hydraulic and control) than monovalent system
- HP supplies 100% of the DHW production

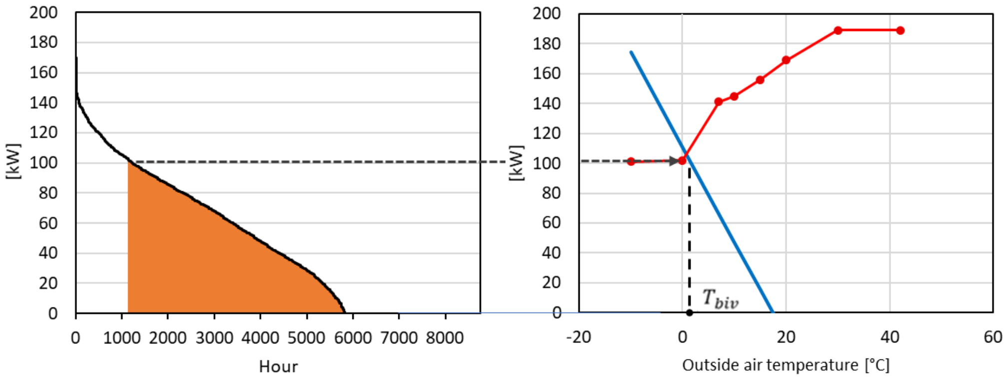
Hydraulic schemes

Hybrid alternative system

with non-modulating boiler



Operation mode

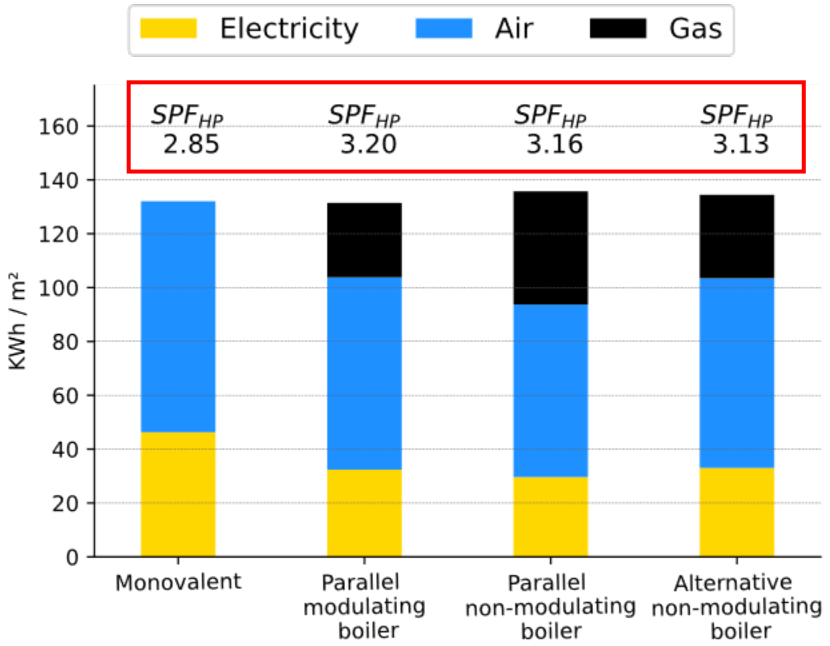


- **Existing boiler will be disconnected** (eg. old boiler with low modulation)
- **Boiler removal with minor hydronic modifications**
- HP supply 100% of the DHW production

Sensitivity analysis

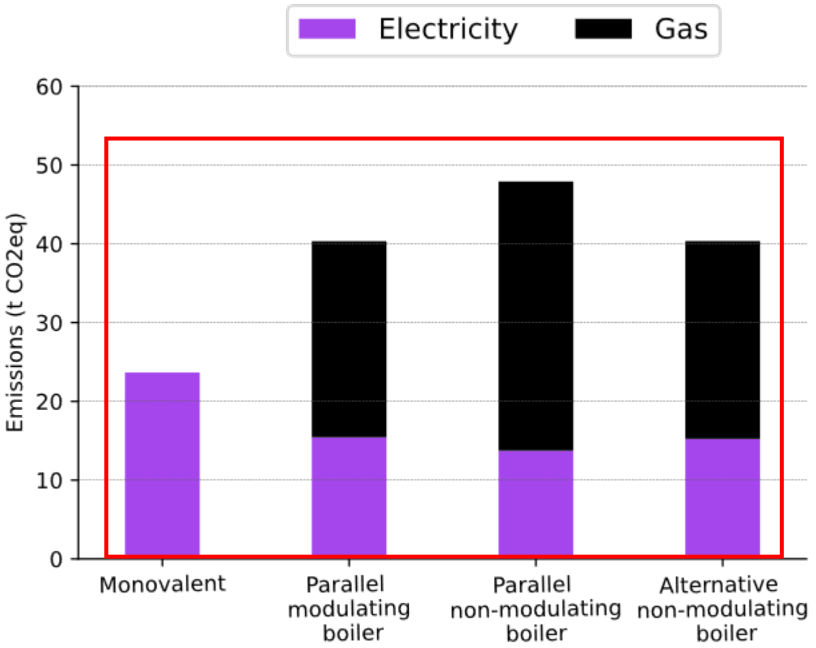
Sensitivity to hydraulic scheme (reference heat demand + sizing)

Energy mix and performance



	Mono	Parallel	Parallel	Alternat.
		modulating	non-mod.	non-mod.
HP (kW)	274	88	88	137
Boiler (kW)		95	95	189

CO_{2eq} emissions



Heat demand and climate:

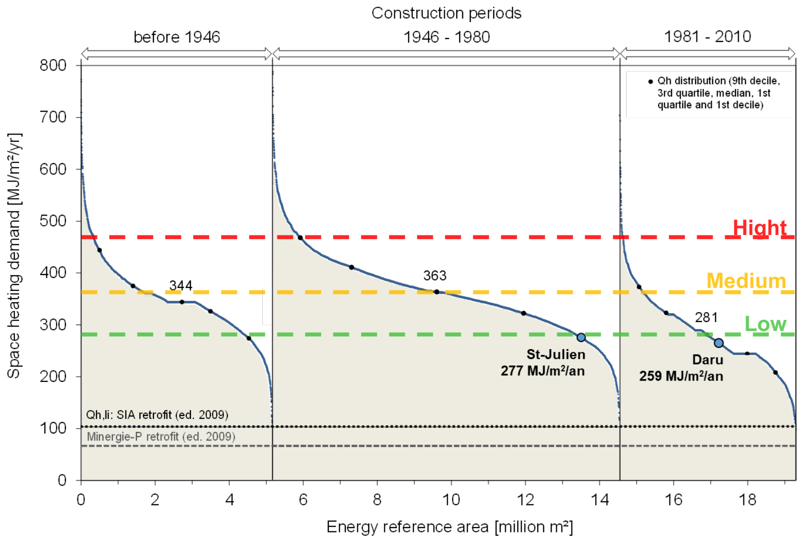
- SH: 101 kWh/m2
- DHW: 35 L/day.pers
- Climate: SIA 2028 average

- Heated area: 4047 m2

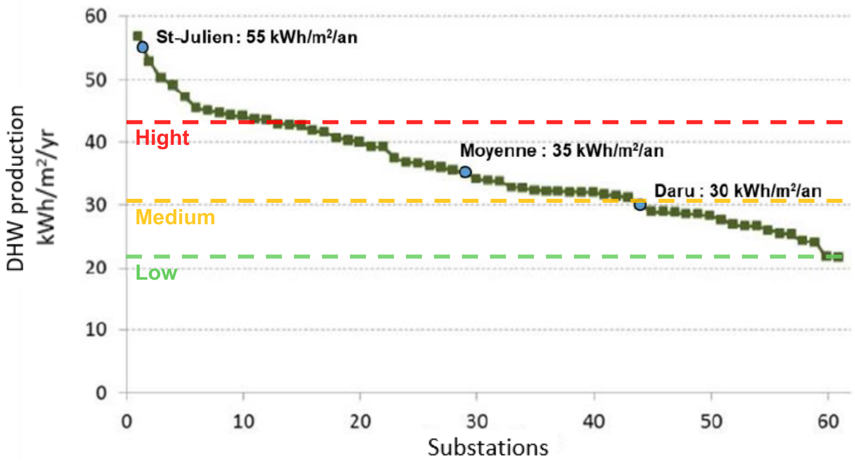
Montero et al., 2023: https://archive-ouverte.unige.ch/unige:169365

Sensitivity analysis

Variation of SH and DHW demand (low/medium/high)



SH demand of Geneva's multifamily building stock sorted in three construction periods Khoury, Jad. 2014. https://doi.org/10.13097/archive-ouverte/unige:48085.



Distribution of the DHW demand of residential buildings (one million m2 of heated area). Quiquerez, Loic. 2017. https://archive-ouverte.unige.ch/unige:91218.

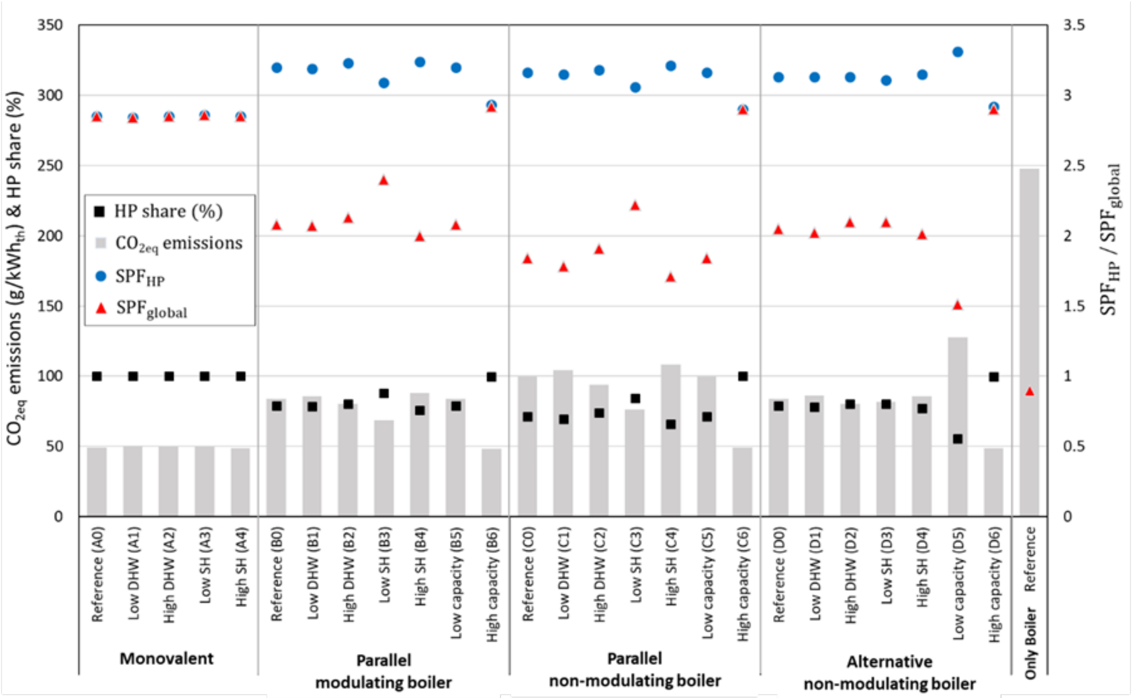
Variation of HP capacity (hybrid systems)

HP capacity: 30%, 40-60% and 80% of the maximum hourly SH demand

Sensitivity analysis

Results (26 cases = 4 reference cases + 22 variants)

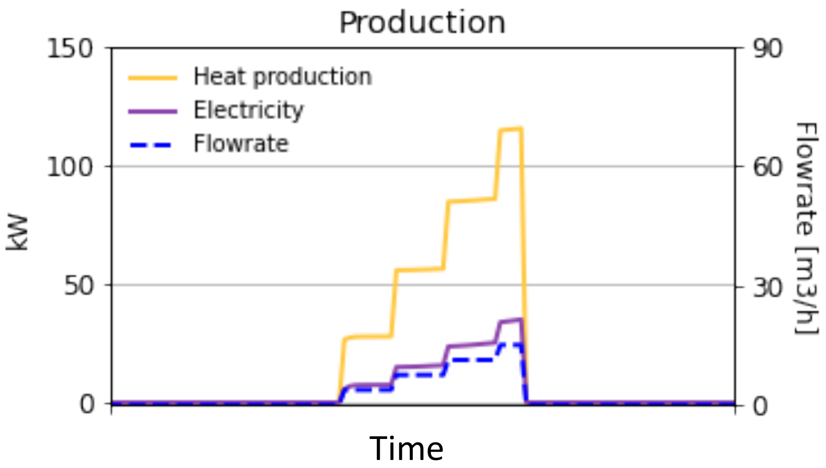
	Mono. scenarios	Hybrid scenarios	Boiler only
SPF_{HP}	2.85	3.06 - 3.31	-
SPF_{global}	2.85	1.52 - 2.40	0.9
HP fraction	100 %	56% - 88%.	-
Emissions gCO_{2eq}/kWh_{th}	49	68 -127	247

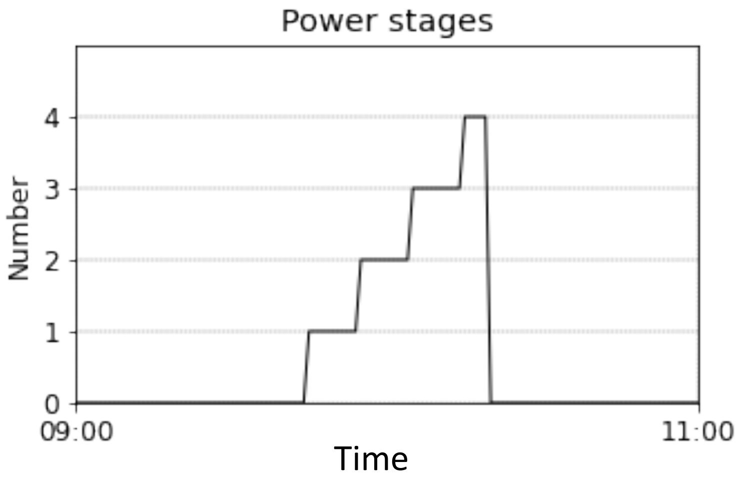


Montero et al., 2023: https://archive-ouverte.unige.ch/unige:169365

HP control

Cascade: Successive activation of HPs or compressors



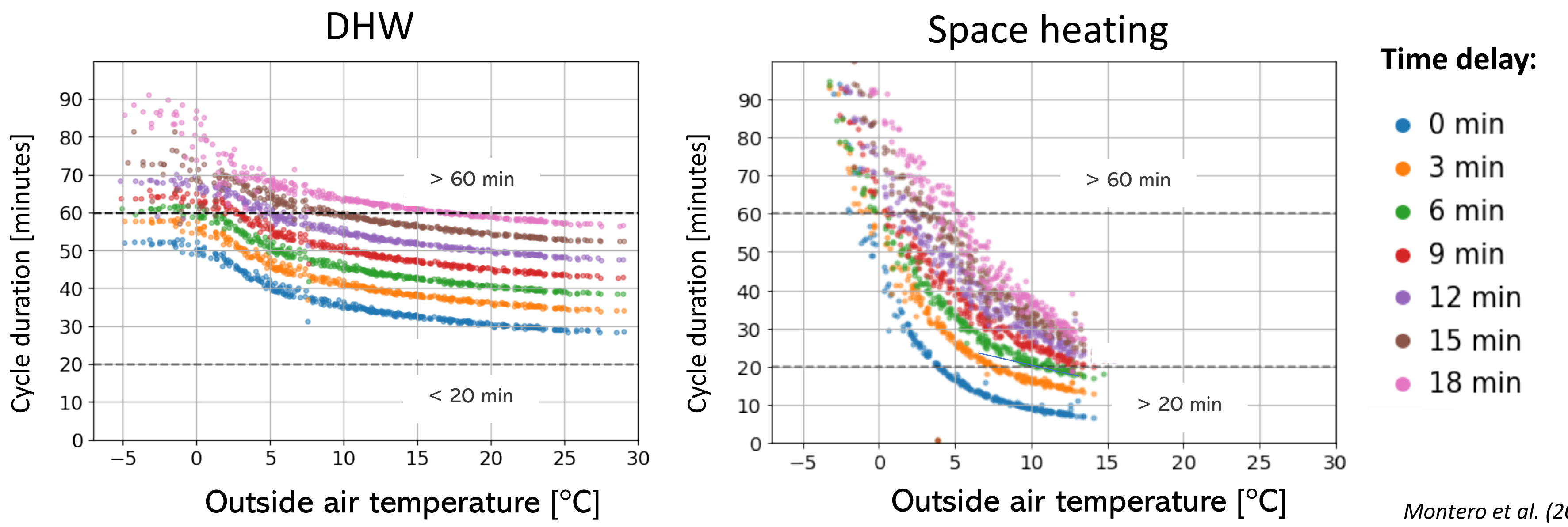


Issue:
- Limitations of cascade control of HPs available on the market (> 50 kWth)
- Good cascade control guarantees machine lifetime, performance and user comfort

Examples (P+D projects)

HP control

Sensitivity analysis on time delay



Montero et al. (2023): https://archive-ouverte.unige.ch/unige:169458

Time delay of the cascade should be adjusted to:

- Heating season (especially for space heating)
- Production mode (space heating or DHW)
- Characteristics of the installation (tank volume, HP capacity, etc.)

Conclusions

P&D projects:

- Even in non-retrofitted buildings, air-source HP systems can supply the required temperature levels + cover the entire heat demand.
- Major CO_2 savings (92% and 68%) and increased renewable energy share (75% and 43%).
- Specificities of HP systems as compared to fossil fuel boilers ➔ implementation requires adequate professional training and careful execution.

Sensitivity analysis:

- Energy mix and CO2 emissions ➔ consider the overall system performance (HP and boiler).
- Monovalent systems lead to lower emissions than hybrid systems.
- However, emissions of hybrid systems remain 2.3 to 3.5 times lower than for a fossil boiler ➔ transitional solution to before retrofitting of building.
- Monovalent HP capacity 2 to 3 times higher than hybrid HP ➔ cost issue (in particular for transitional solution).

Thank you

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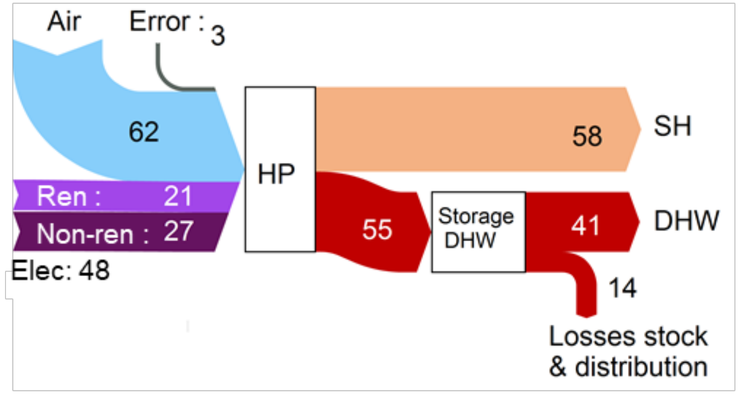
Backup slides

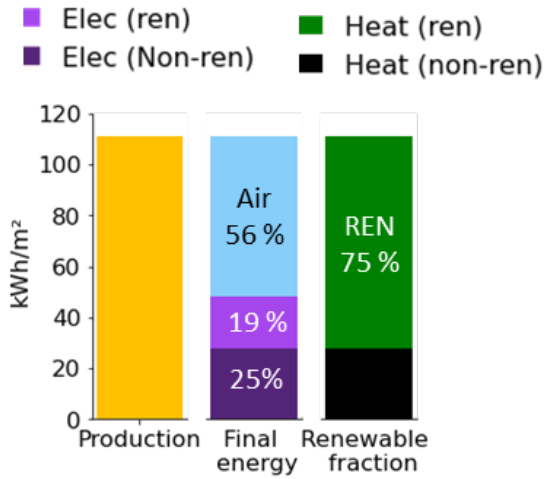
Abstract

Switching from fossil boilers to heat pumps (HP) can drastically reduce CO2-emissions of the Swiss building stock. Such can be achieved with or without combined envelope retrofit, which will stretch over several decades. While the potential market is huge, many challenges and obstacles need to be solved, in particular for existing multi-family buildings and related large capacity air-source HPs (> 50 kW). Analysis of case studies in actual condition of use, complemented by numerical simulation, allow to highlight these challenges and indicate potential optimization in terms of sizing, system integration, control strategies, as well as industrial developments.

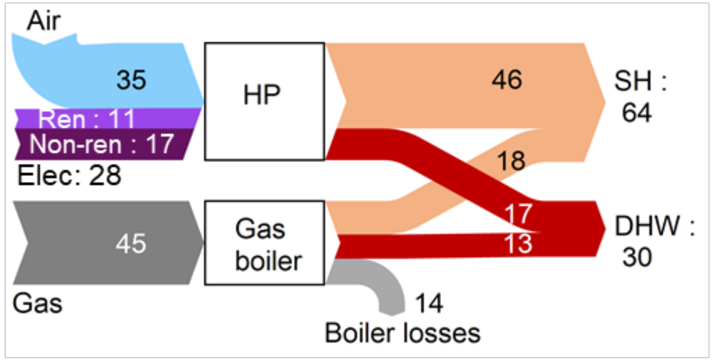
P+D projects

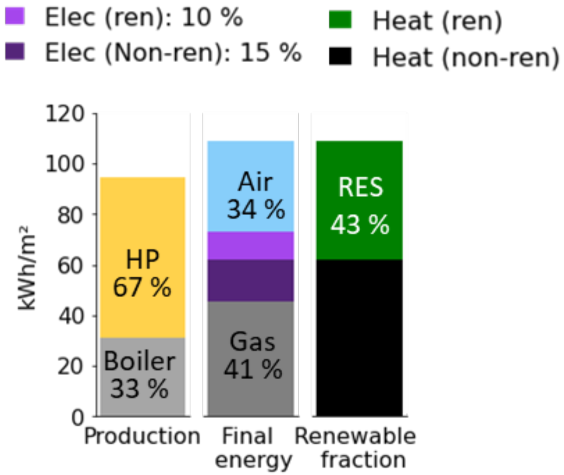
Monovalent system





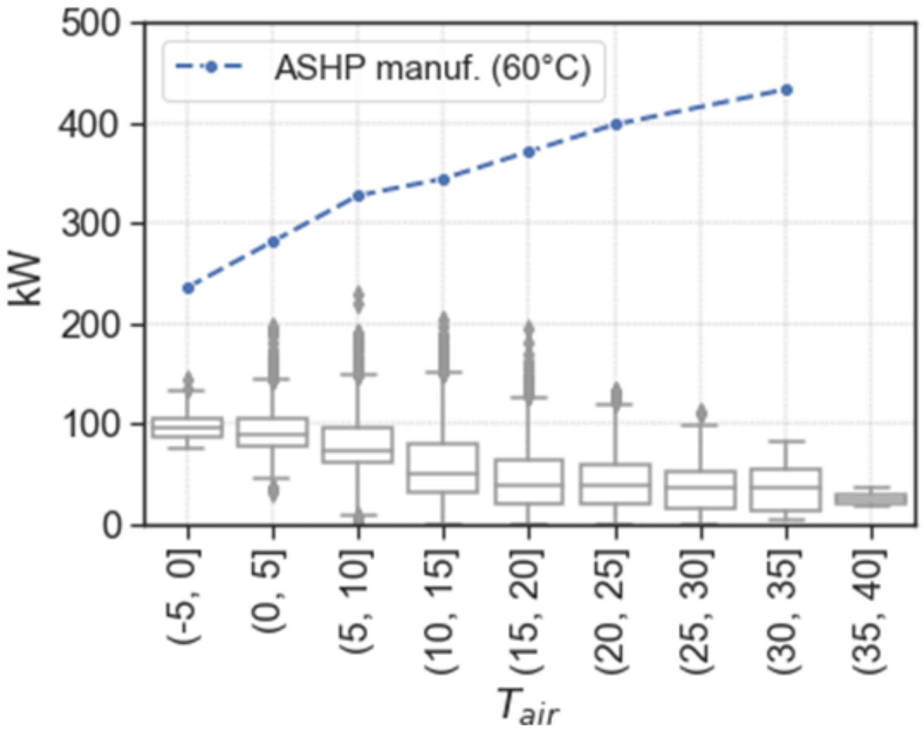
Bivalent system



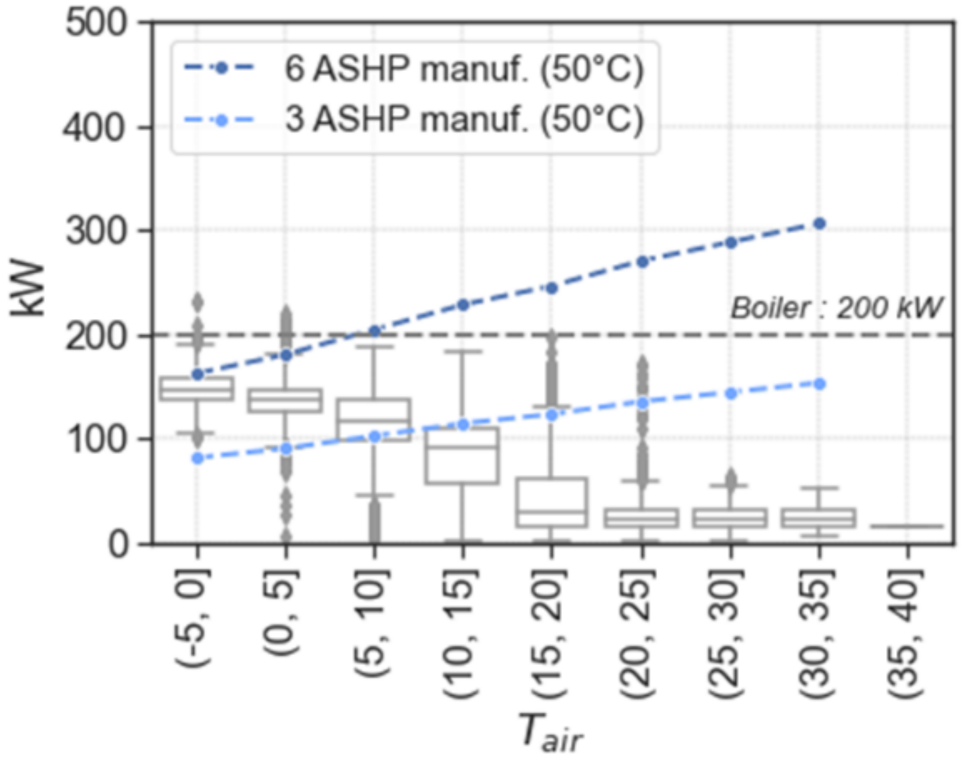


P+D projects

Monovalent system



Hybrid system



Sensitivity analysis

Reference cases / Design parameters

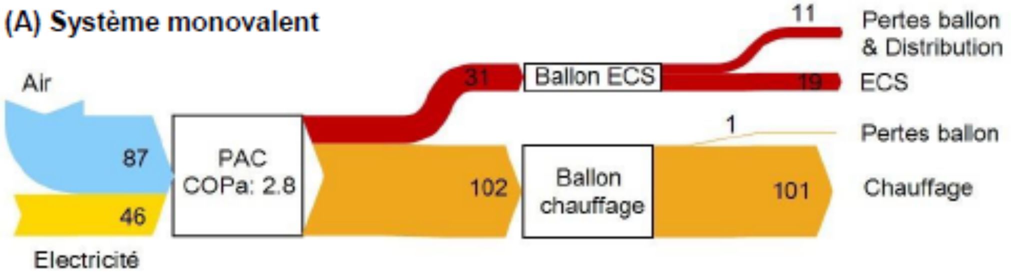
	Monovalent	Parallel modulating boiler	Parallel non-modulating boiler	Alternative non-modulating boiler
HP capacity required for SH*	250	78	78	137
HP capacity required for DHW*	84	84	84	84
Mode with the highest capacity requirements	SH	DHW	DHW	SH
HP capacity retained [kW_{th}]*	274	88	88	137
Boiler capacity [kW_{th}]	-	95	95	189
Bivalence temperature [°C]	-	4.5	4.5	0.5
Volume of SH tank [m^3]	2.2	2.9	2.9	2.2
Volume of DHW tank [m^3]	1.9	1.9	1.9	1.9

* HP capacities for 7 °C at the evaporator inlet and 45 °C at the condenser outlet

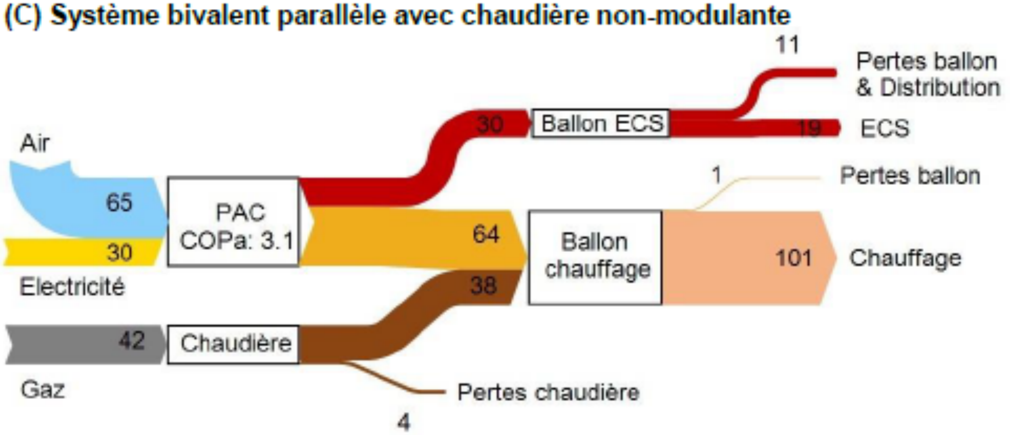
Sensitivity analysis

Reference cases

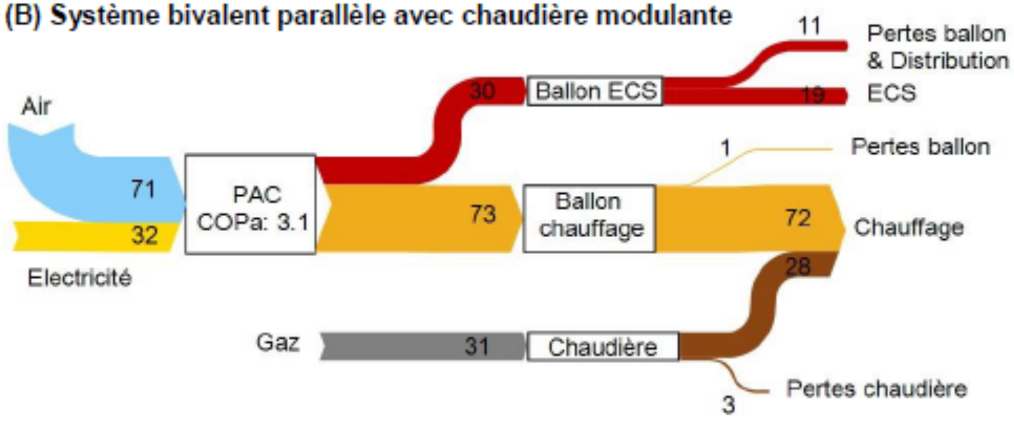
(A) Système monovalent



(C) Système bivalent parallèle avec chaudière non-modulante



(B) Système bivalent parallèle avec chaudière modulante



(D) Système bivalent alternatif avec chaudière non-modulante