



2026 ASHRAE WINTER CONFERENCE

Seminar 27, Recent refrigerant leakage research published in ASHRAE's research journal, Science and Technology for the Built Environment

On-Site Performance Assessment of an Exhaust Air Heat Pump: Impact of Refrigerant Leakage and Key Performance Indicators

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Learning Objectives

- Objective 1

Describe the operating principles and control strategies of an exhaust air heat pump system in residential applications.

- Objective 2

Understand the effects refrigerant leakage can have on an exhaust air heat pump.

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Outline

- Introduction
- Description of the system
 - The exhaust air heat pump technology
 - Building characteristics
 - HVAC system characteristics
- System instrumentation
- Results
 - Behavior of the system for typical days
 - Thermal comfort
 - Heat pump performance
 - Yearly performance extrapolation
- Conclusion

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Introduction

- In new residential buildings, in Belgium, the ventilation accounts for 30 to 60 % of the total building heating demand.
- Consequently, highly efficient heat recovery systems on the ventilation system must be developed.
- These buildings are also characterized by a low peak heating demand (< 4 kW) and a non-negligeable energy demand related to domestic hot water.
- In that context, the simple exhaust ventilation system combined with an exhaust air heat pump is an interesting solution.

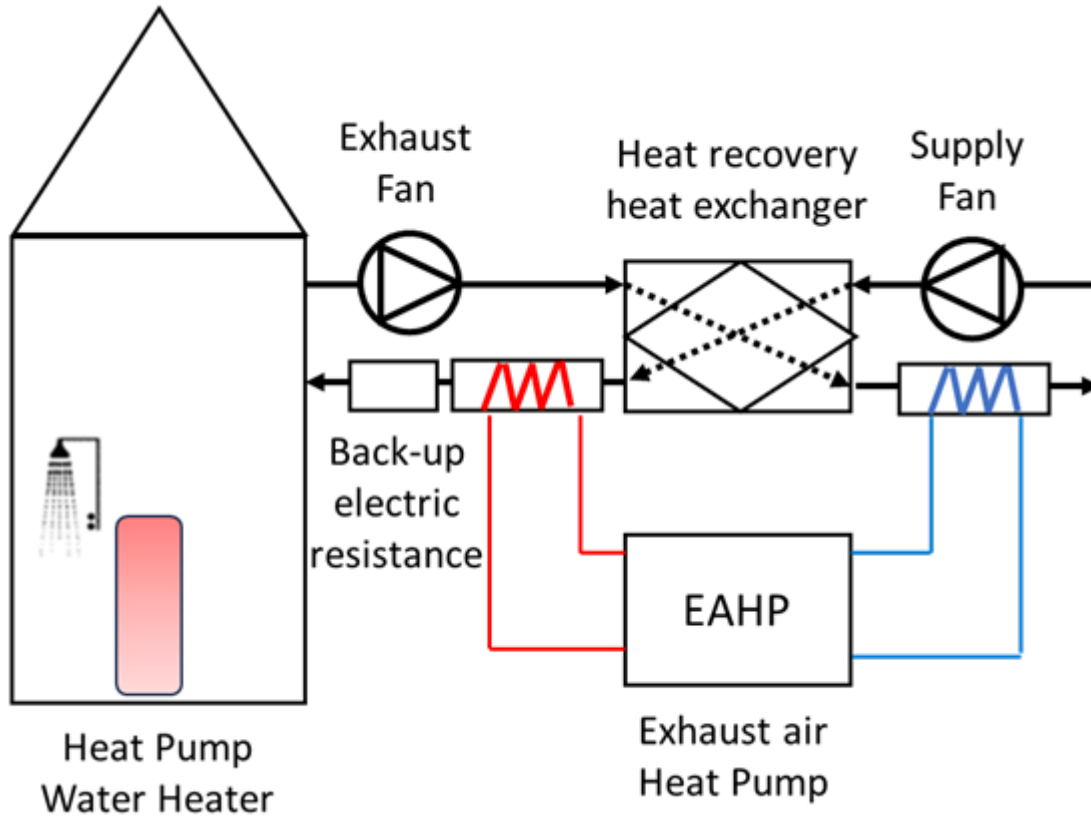
Introduction

- Refrigerant leakage in heat pump systems can have a significant impact on the heating capacity and the COP.
- Low refrigerant charge causes flash gas at the TXV inlet, leading to valve choking, reduced mass flow rate, and degraded COP and heating capacity (Mauro, Pelella, and Viscito, 2023).
- Llopis-Mengual and Navarro-Peris (2024) showed that the loss of refrigerant was responsible for lower evaporating and condensing pressures, lower subcooling and higher superheating values, lower mass flow rate and heating capacity. A decrease in the COP of between 8 and 15% for a refrigerant leakage of 20% is reported.
- Pelella, Viscito, and Mauro (2022) reported a 26% reduction in capacity given a 40% refrigerant leakage.

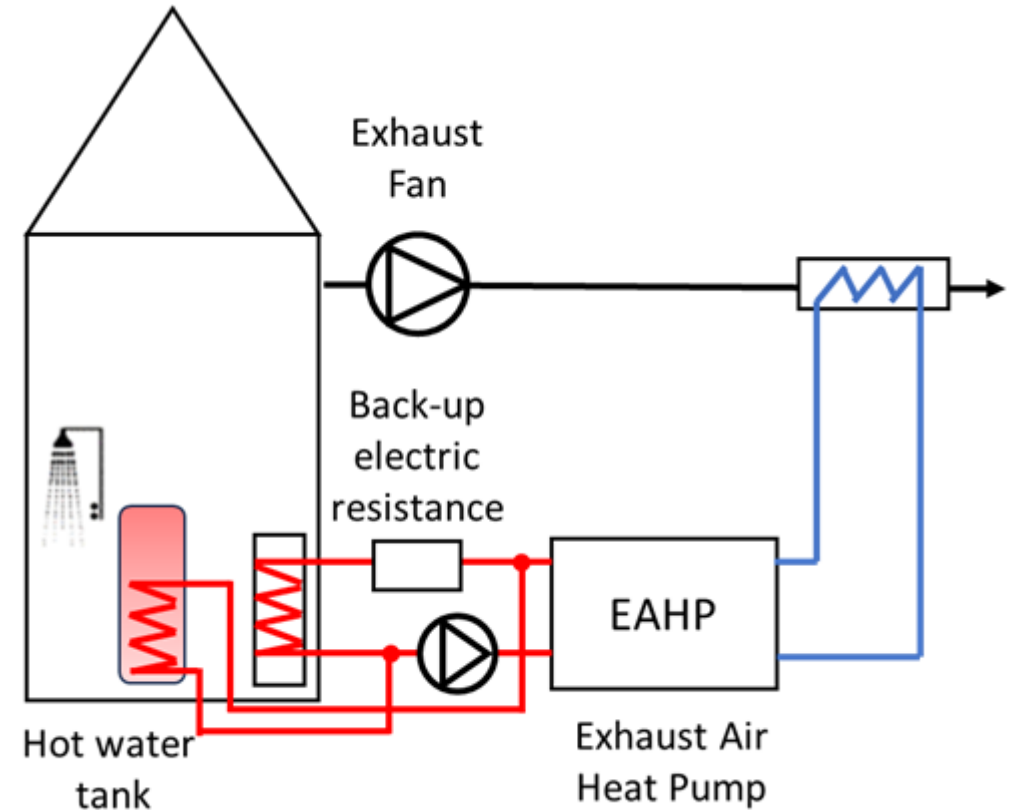
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The exhaust air heat pump technology



System 1: air-to-air EAHP combined with a balanced ventilation system and a heat pump water heater.

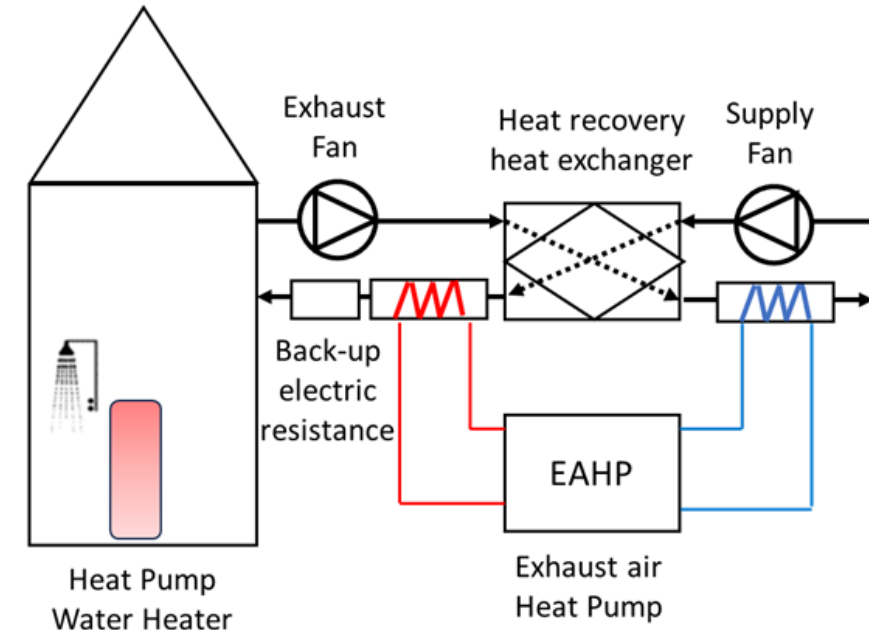


System 2: air-to-water EAHP combined with a simple exhaust ventilation system and a hot water tank.

The exhaust air heat pump technology

Field studies in low-energy residential buildings

- Long-term monitoring shows a systematic need for backup heating
(*Fracastoro & Serraino, 2010 – 729 simulated cases*)
- Coverage factor identified as the key parameter of seasonal efficiency
- In-situ measurements reveal significant auxiliary energy use
(*Dermentzis et al., 2018 – **SPF** $\approx$ 2.8*):
 - Electric post-heater: $\approx$ 36%
 - Fans: $\approx$ 24%
 - Compressor: $\approx$ 28%
 - De-frost system $\approx$ 12 %
- Control strategies strongly influence performance



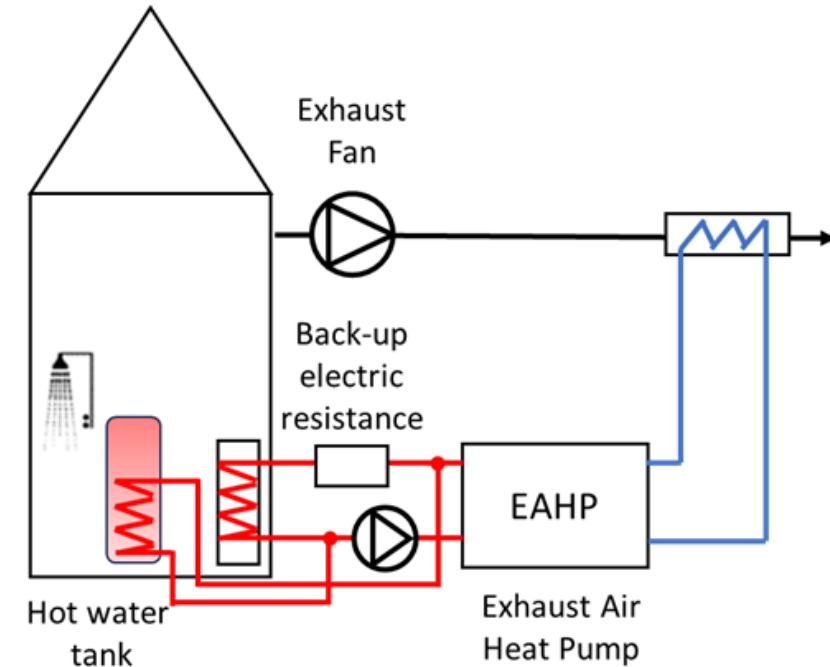
The exhaust air heat pump technology

Limits of air-to-air EAHPs

- Unable to produce domestic hot water (DHW)
- DHW can represent a significant share of total building energy demand

Air-to-water EAHPs as an alternative

- Allow space heating and DHW production
- Very limited on-site performance data available in the literature
- Field study available highlights the necessity of backup system (*Pollet et al., 2015*):
 - => Backup gas boiler covered $\approx 33\%$ of total energy demand

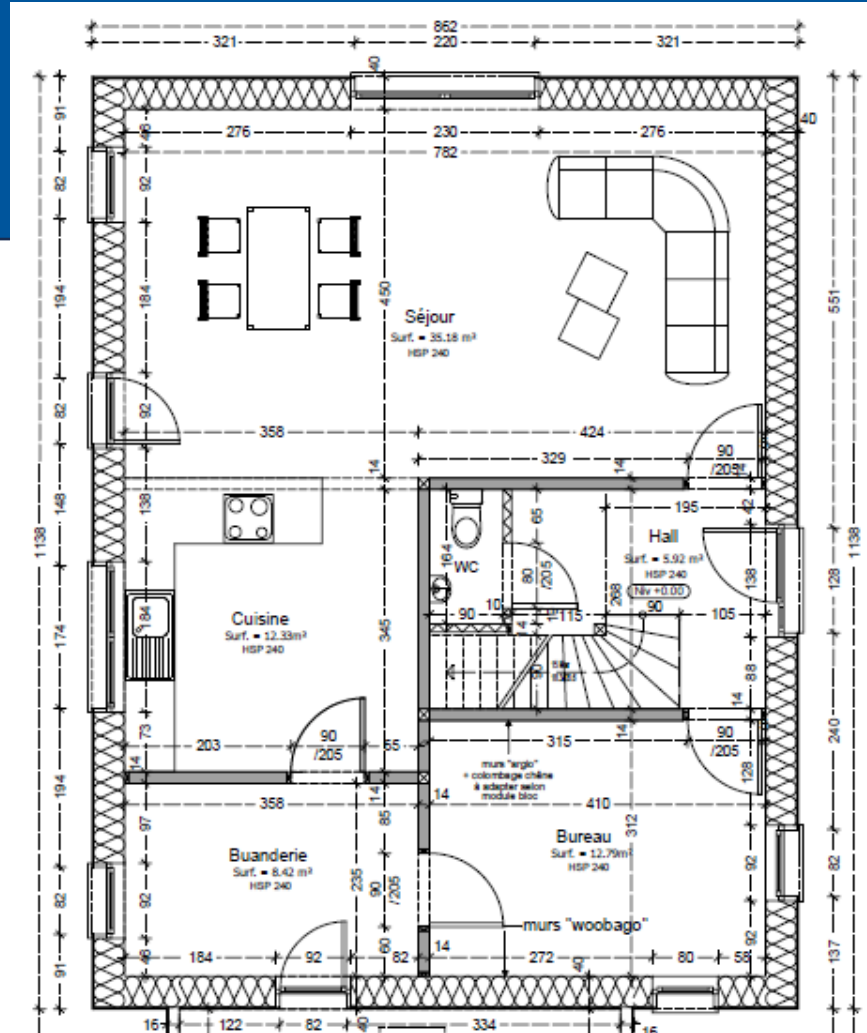


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Building characteristics

- Residential building built in 2016
- Wooden two-story freestanding house
- Floor area: 155 m²
- Total exposed area: 389 m²
- U-values:



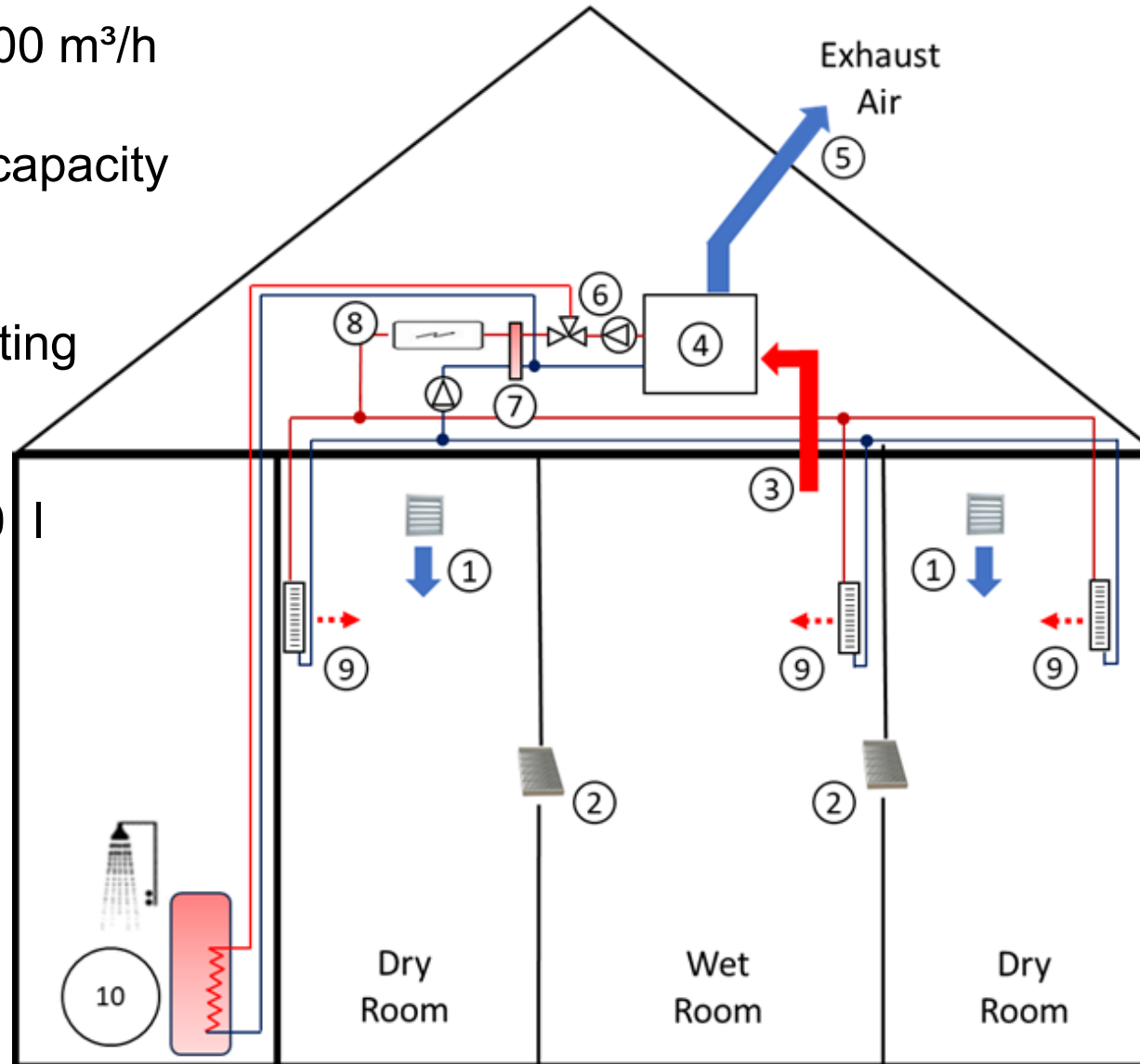
Wall type	Composition	Area [m ²]	U-value [W/m ² -K]
Outer wall	Wood structure + 40 cm cellulose	139	0.11
Roof	Wood structure + 40 cm cellulose	127.2	0.15
Floor	Concrete slab floor + 65 cm cellular glass	82.7	0.07
Window	Triple-glazed + aluminum frame	18.5	0.84

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System characteristics

- Ventilation airflow: 200 m³/h
- Heat Pump heating capacity A20W35: 1500 W
- Back-up electric heating resistor: 3000 W
- Storage volume: 200 l



Legend:

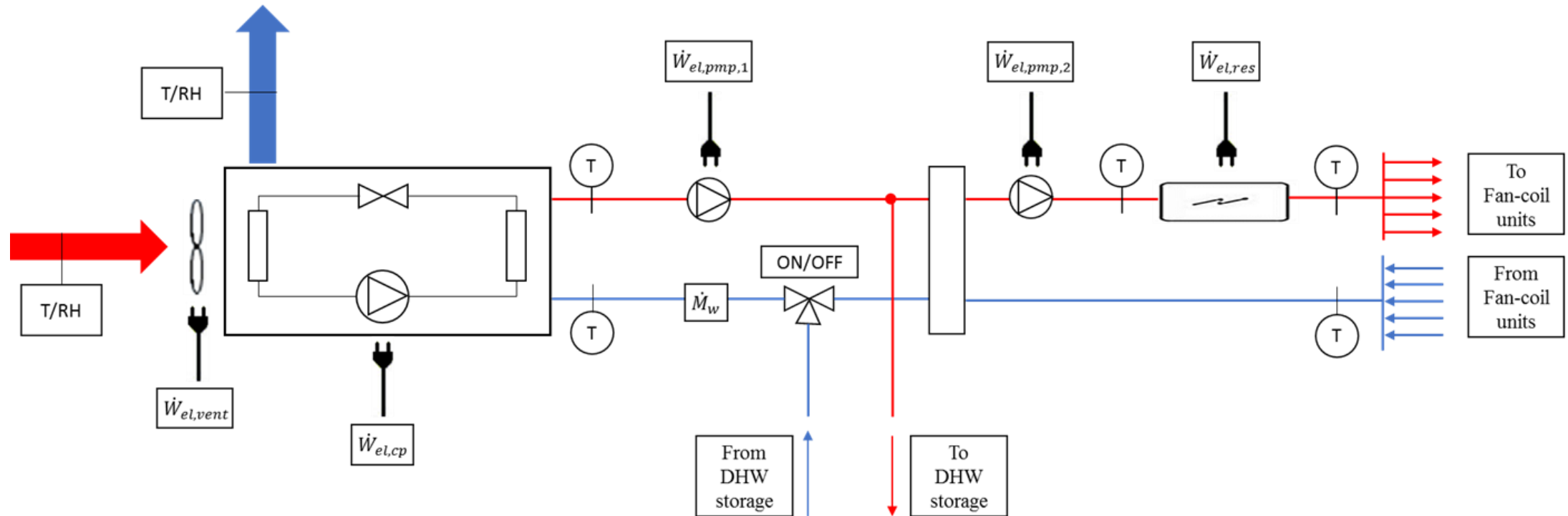
- ① : Fresh air inlet
- ② : Transfer orifice
- ③ : Exhaust air extraction
- ④ : Exhaust air heat pump
- ⑤ : Exhaust air evacuation
- ⑥ : Three-way valve
- ⑦ : Hydraulic separator
- ⑧ : Back-up electrical resistance
- ⑨ : Fan-coil unit

⑩ : Domestic hot water storage tank

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System instrumentation



- 5 temperature sensors
- 1 water flow meter
- 3 electric meters
- 2 humidity sensors

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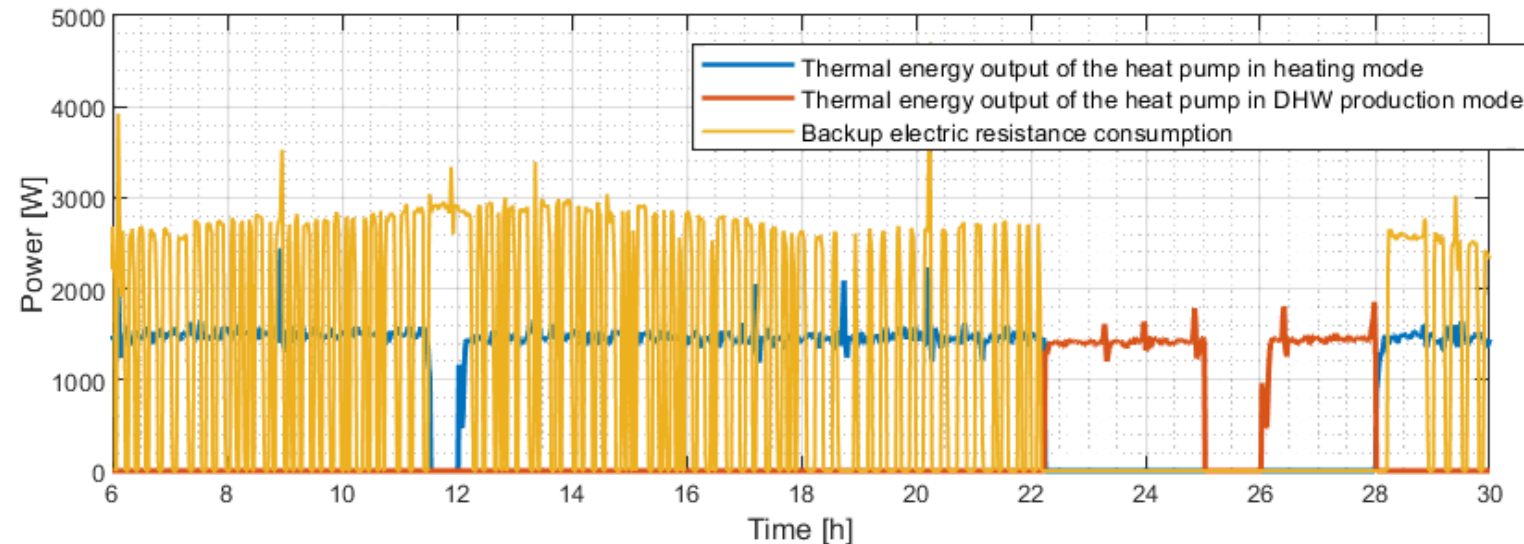
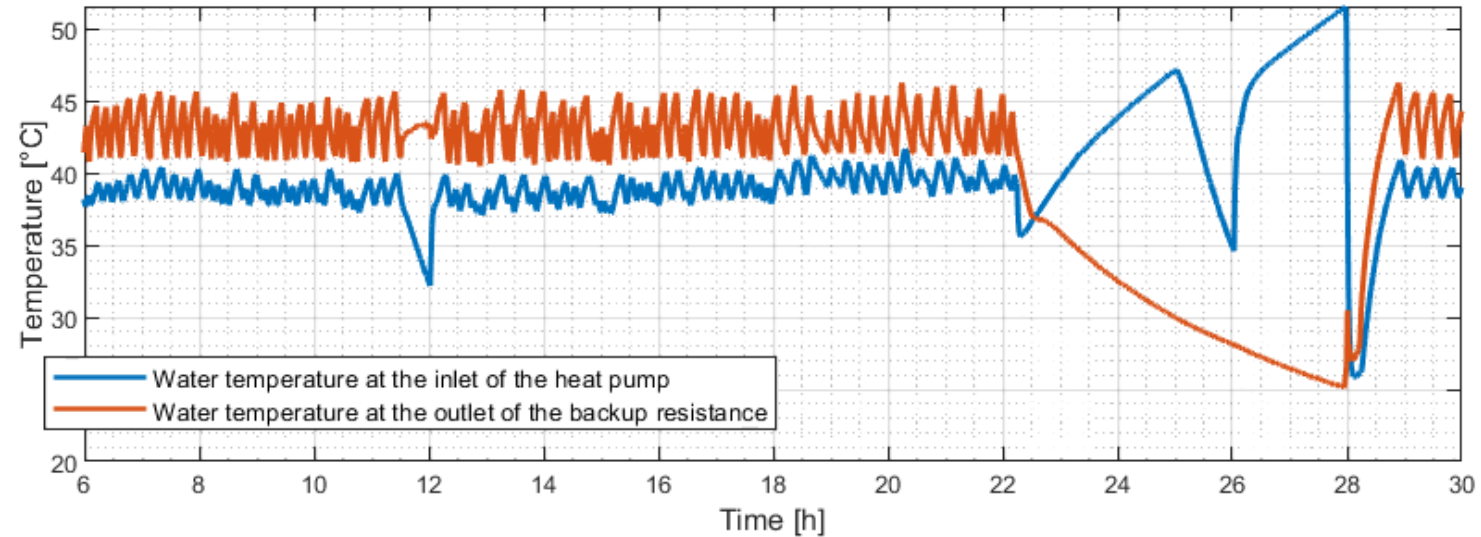
Behavior of the system for typical days

Cold outdoor temperature day (-3°C average)

- The heat pump operates at constant heating capacity (1500 W)
- DHW production at night (22:00–04:30), space heating during the day
- On a cold day (-3 °C average outdoor), heat pump capacity is not sufficient

=> Electric backup resistance cycles ON/OFF (0–3000 W)

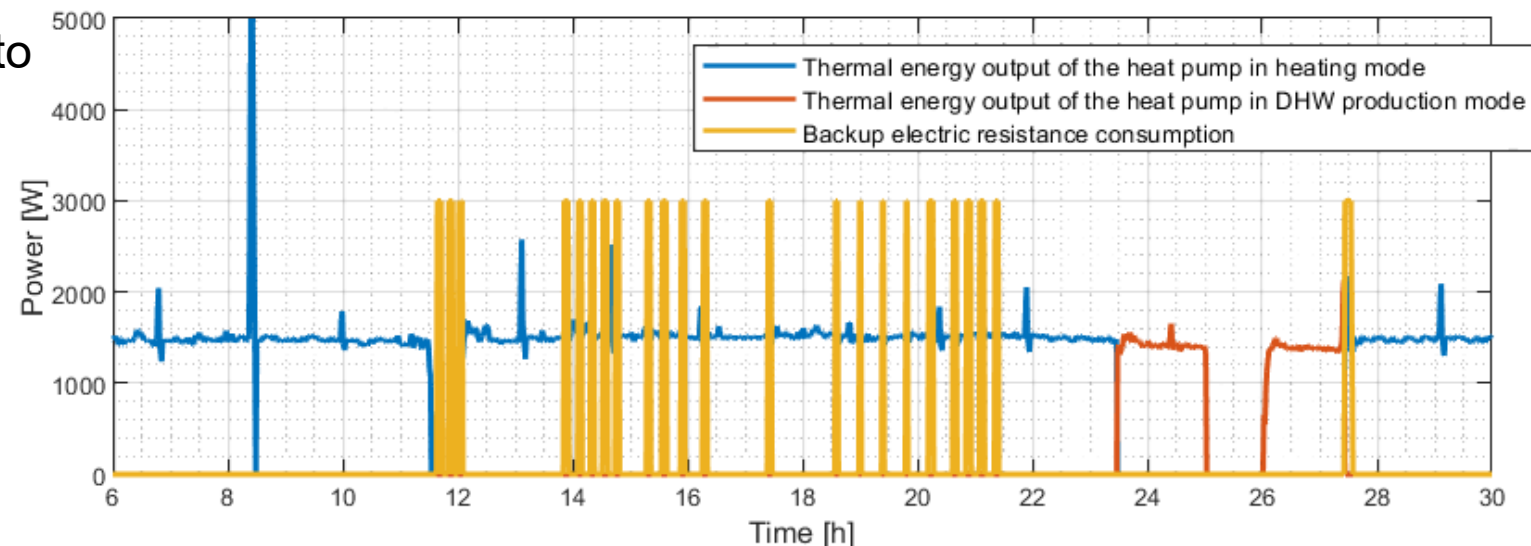
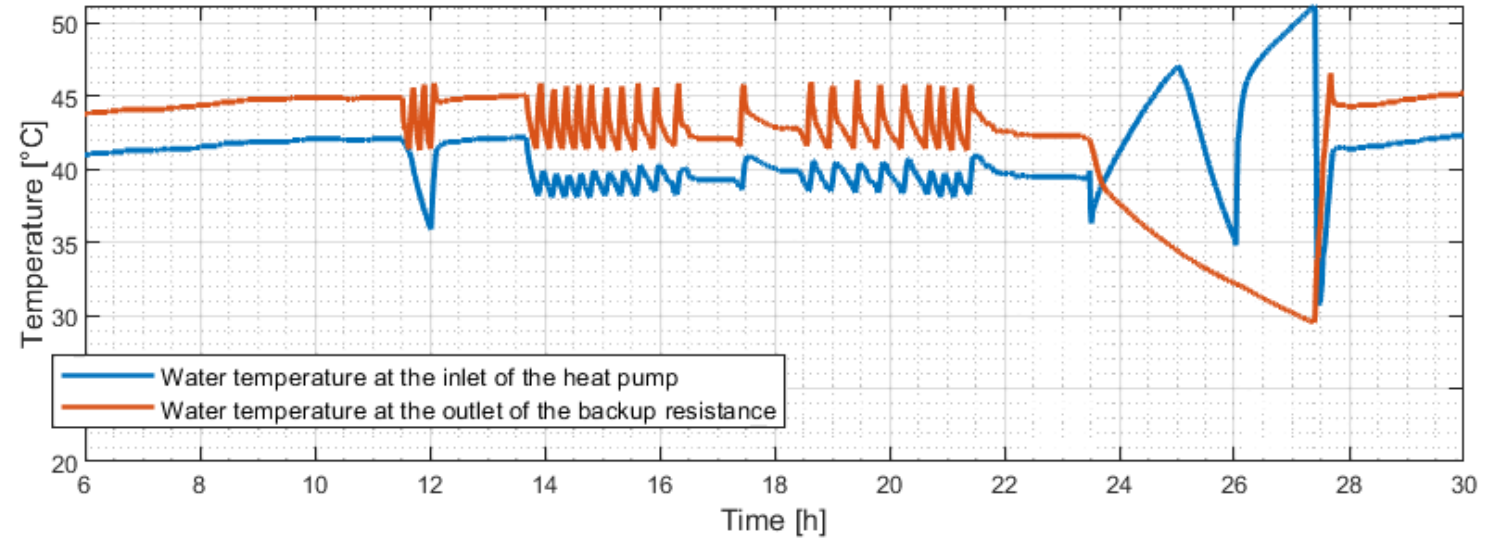
- Backup heater maintains outlet water temperature between 41–45 °C
- During DHW production mode, the outlet temperature rises from 36 to 52 °C



Behavior of the system for typical days

Mild outdoor temperature day (8°C average)

- The heat pump still operates at constant capacity (1500 W)
- No backup resistance operation in the morning (05:00–11:00)
=> Smooth inlet and outlet water temperatures
- Lower building heating demand compared to cold day
- Backup resistance activates intermittently after 14:00
=> Temperature fluctuations observed
- Significantly fewer ON/OFF cycles than on cold day



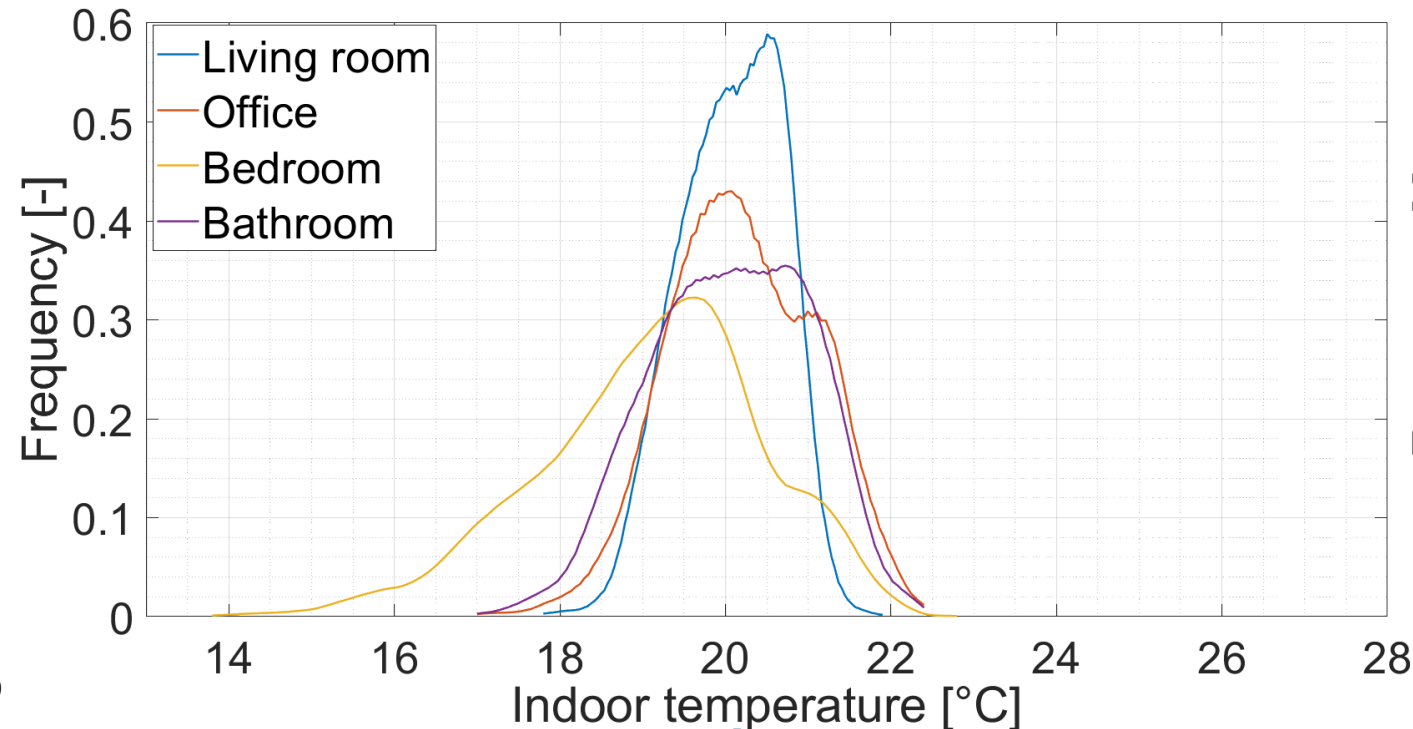
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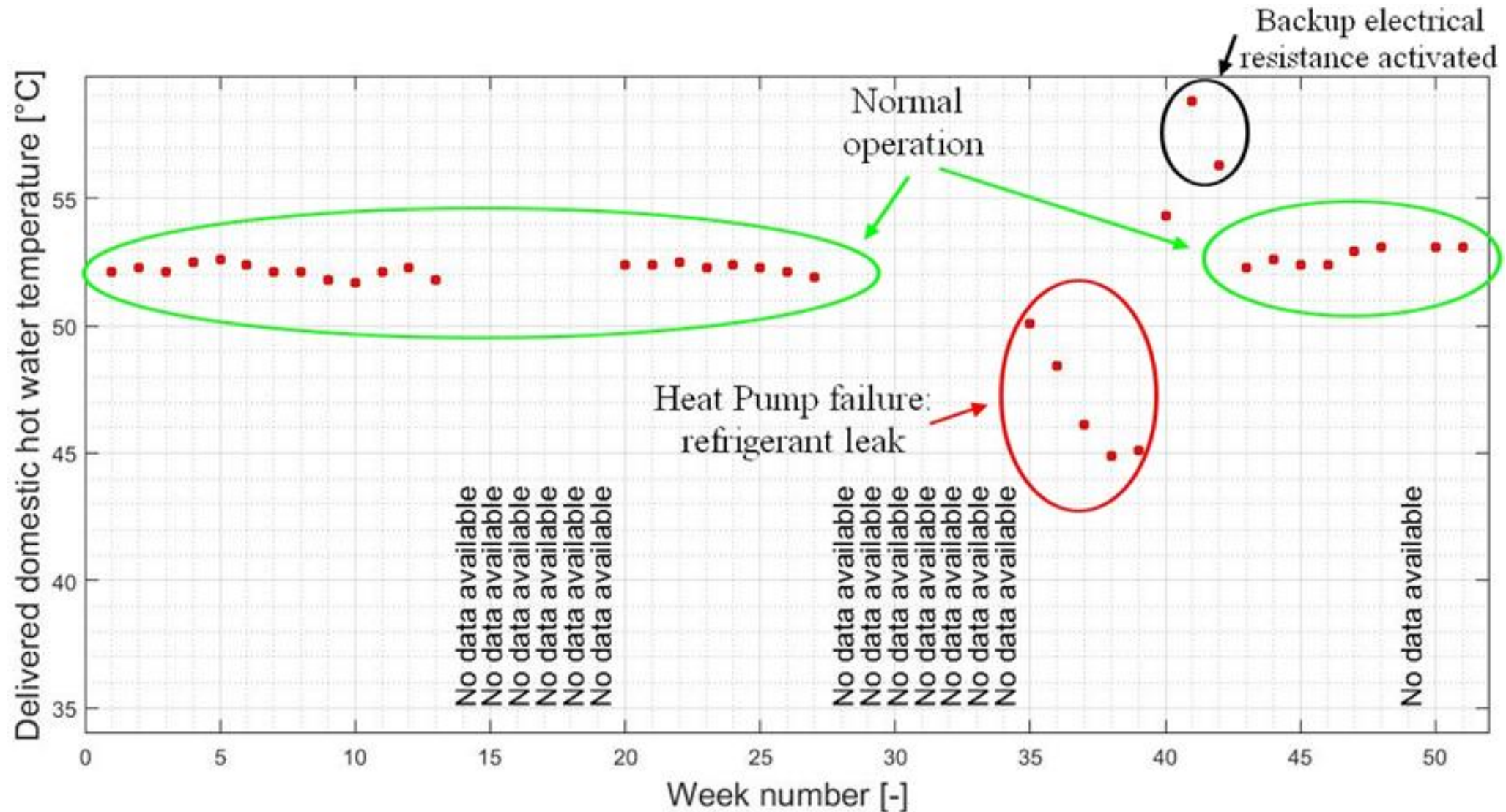
Thermal comfort – Indoor temperature

- Living room temperature well controlled around the 20 °C set-point
Average: 20.0 °C, low variability ($\sigma = 0.6$ K)
- Heating system maintains indoor temperature close to set-point throughout winter
- Living room, office, and bathroom have similar average temperatures (≈ 20 °C)
- Bedroom temperatures significantly lower
Average: 19.1 °C, higher variability ($\sigma = 1.4$ K)
- Cold temperatures (12–14 °C) observed due to no heating in winter
- Results confirm proper sizing of the heating system and fan-coil units

Frequency distribution of indoor temperature in winter



Thermal comfort – Hot water temperature



Outline

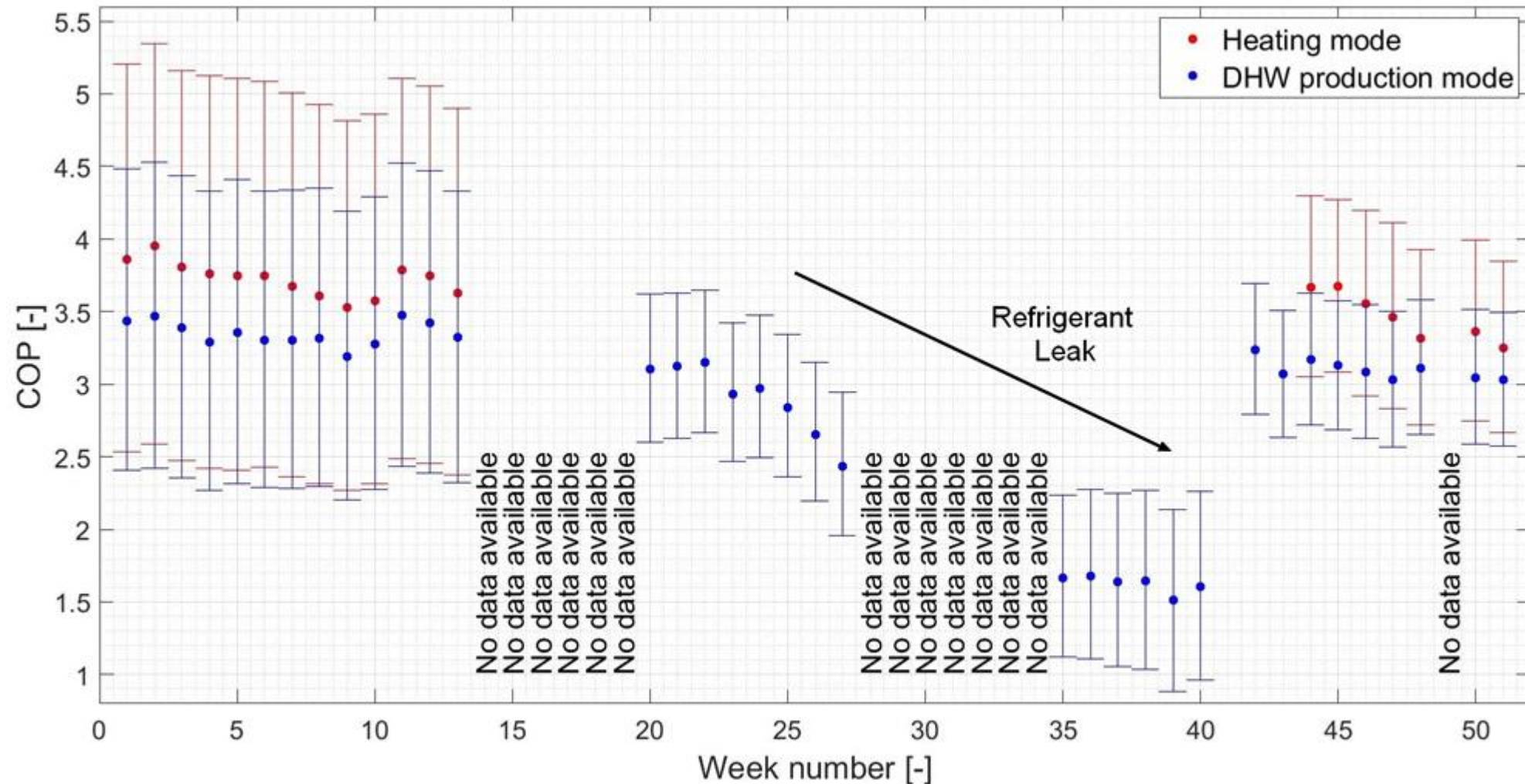
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Heat Pump performance - COP

$$\dot{Q}_{cd} = \dot{M}_w c_{p_w} (T_{w,ex,cd} - T_{w,su,cd})$$

$$Q_{cd} = \int_{t_{start}}^{t_{end}} \dot{Q}_{cd} dt$$

$$E_{el,cp} = \int_{t_{start}}^{t_{end}} \dot{W}_{cp} dt$$

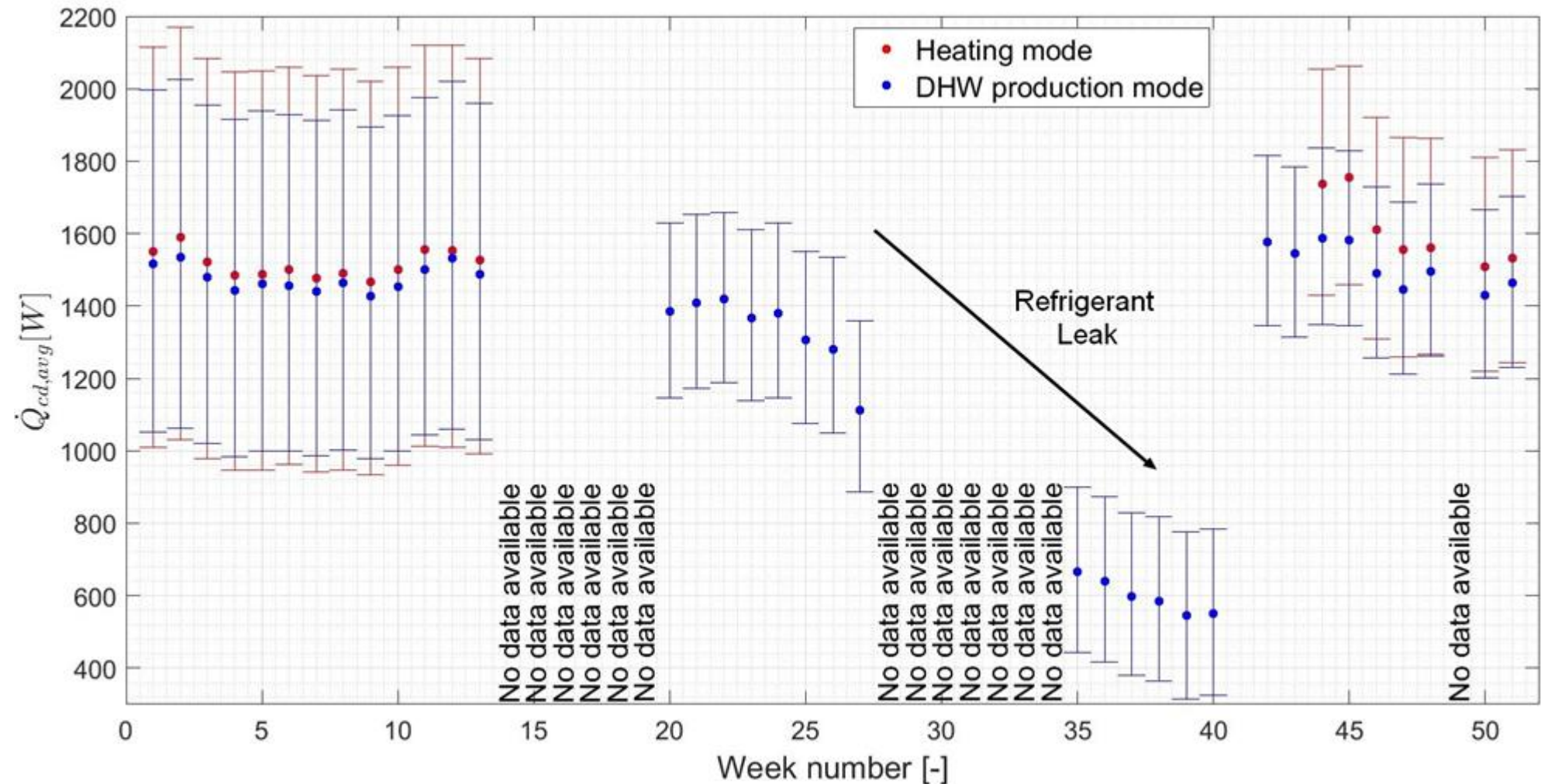


Heat Pump performance - Heating capacity

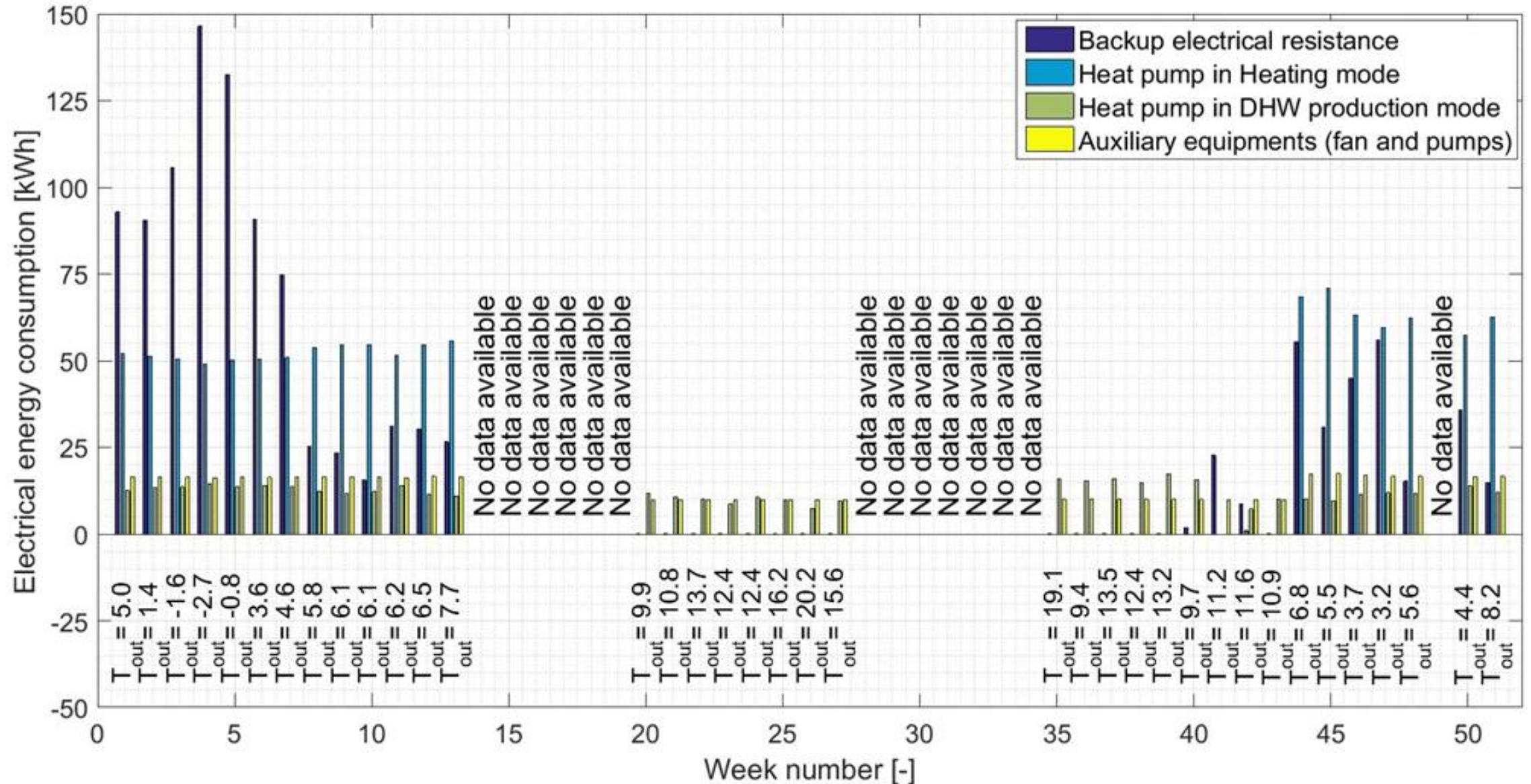
$$\dot{Q}_{cd} = \dot{M}_w c_{p_w} (T_{w,ex,cd} - T_{w,su,cd})$$

$$Q_{cd} = \int_{t_{start}}^{t_{end}} \dot{Q}_{cd} dt$$

$$E_{el,cp} = \int_{t_{start}}^{t_{end}} \dot{W}_{cp} dt$$



Heat Pump performance – whole system



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Yearly performance extrapolation

	$T_{out, avg}$ [°C]	$Q_{Heating}$ [kWh]	Q_{DHW} [kWh]	$Q_{HP, total}$ [kWh]	$Q_{HP, DHW}$ [kWh]	$Q_{HP, Heating}$ [kWh]	$W_{el, Res}$ [kWh]	$W_{el, HP, DHW}$ [kWh]	$W_{el, HP, Heating}$ [kWh]	$W_{el, aux}$ [kWh]
Jan	3.2	1545	180	1079	180	899	646	55	250	75
Feb	3.9	1278	162	974	162	812	466	49	226	68
Mar	5.9	1084	180	1079	180	899	185	55	250	75
Apr	9.2	548	174	722	174	548	0	53	152	61
May	13.3	74	180	254	180	74	0	55	21	46
Jun	16.2	0	174	174	174	0	0	53	0	42
Jul	17.6	0	180	180	180	0	0	55	0	43
Aug	17.6	0	180	180	180	0	0	55	0	43
Sep	15.2	10	174	184	174	10	0	53	3	42
Oct	11.2	376	180	556	180	376	0	55	104	57
Nov	6.3	1061	174	1044	174	870	191	53	242	73
Dec	3.5	1511	180	1079	180	899	612	55	250	75
Tot		7487	2118	7504	2118	5387	2100	642	1496	700
Avg	10.2									

- Total building energy demand: 9605 kWh
- Energy provided by the heat pump: 7505 kWh
- Coverage factor: 78 %
- Seasonal Performance Factor: 1,94
- Electrical consumption: 43 % for the heat pump, 43 % for the electric heater, 14 % for the fan and the pumps

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Conclusion - Summary

- The heat pump initially performed normally: 1450 W heating capacity, COP 3.6.
- Due to refrigerant leak, the heating capacity dropped by 60%, and the COP by 50% in 30 weeks
- The seasonal system COP (including auxiliaries) is extrapolated to be 1.9
- The electrical consumption repartition is as follows
 - Heat pump: 43%
 - Electric resistance: 43%
 - Auxiliaries: 14%

Conclusion - Perspectives

System optimization:

- Increase the compressor size could increase the refrigerant mass flow and heating capacity
=> An optimum could be found to maximize the seasonal COP
- A higher mass flow would lower the evaporating temperature
=> The COP may decrease, the frost formation risk would increase
=> defrost strategy needed.

DHW management:

- Utilization of sensors to monitor the tank energy content for better control.
- Objective: optimize the heat pump design and operation for each building type to maximize the seasonal performance factor (SPF).

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Questions

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