Multi-PCM Thermal Energy Storage system for hot water and space heating:

Design, Simulation and Measurements

Haute école d'ingénierie et d'architecture Fribourg
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EnInnov 2026, February 11-13th 2026, TU Graz, Austria

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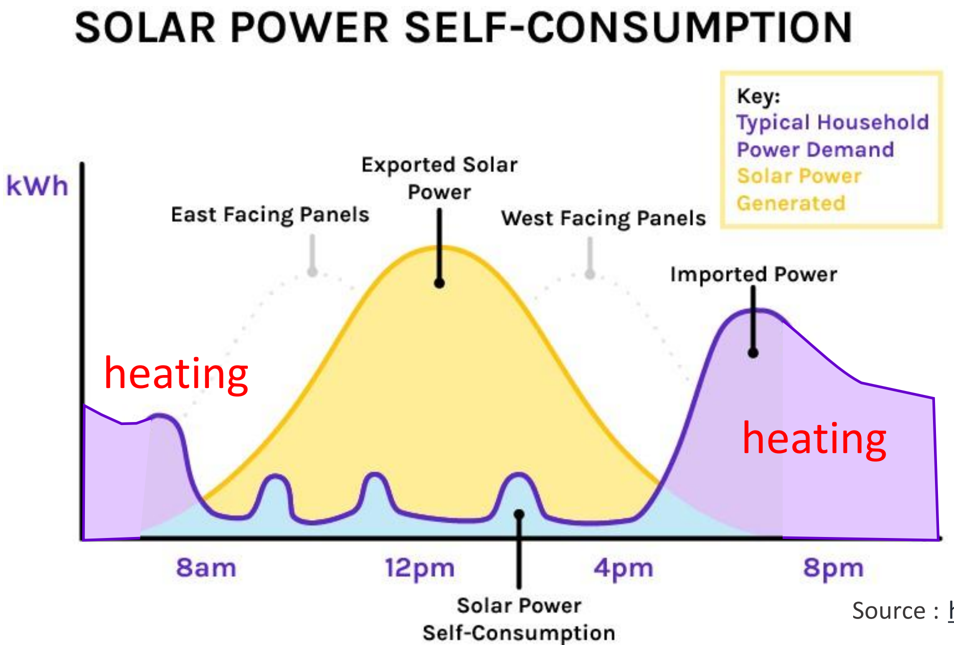
Introduction

Is solar energy optimal for heating needs ?

- In central Europe, heating & cooling represents:
  - 80% of the building energy consumption
  - 35% of the total energy consumption
- PV production peaks at periods of low heating demand.



The phasing mismatch can be solved by thermal storage and **PCM** is a solution

Source : https://www.mysolarquotes.co.nz/about-solar-power/residential/solar-power-self-consumption/

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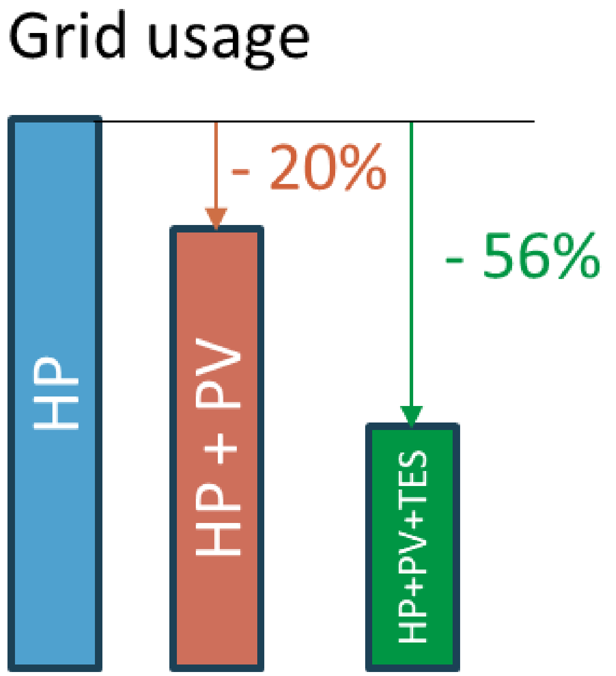
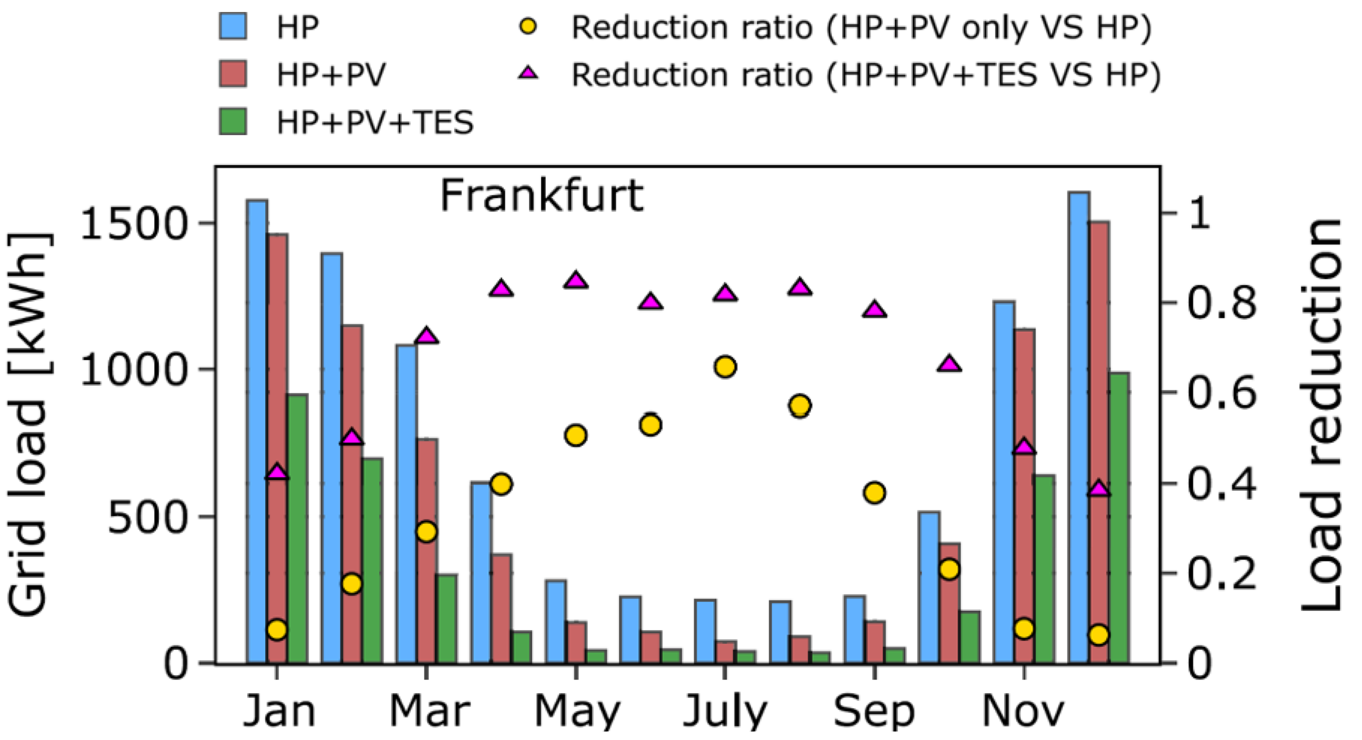
Simulation of a reference house in Frankfurt (*) : thermal storage <u>increases</u> the solar energy self consumption by <u>2.8x</u>

Hypothesis: The PV panels produce the annual required heating energy but at the wrong time
→ Calculation of the effect of Thermal Energy Storage (TES)



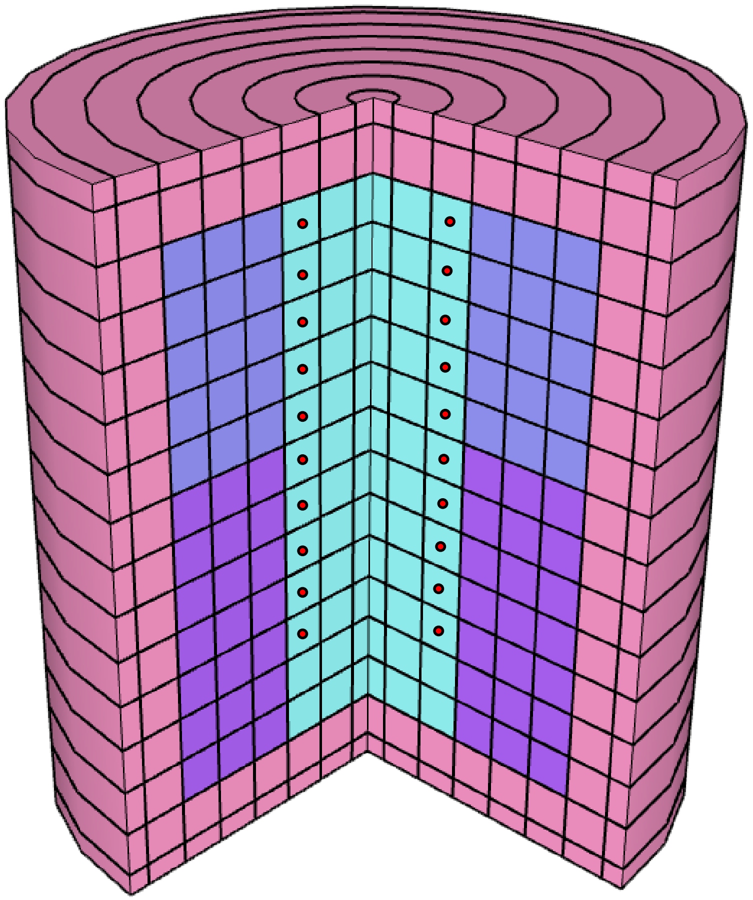


HP energy consumption decrease is small with PV and **significant with PV+TES**.

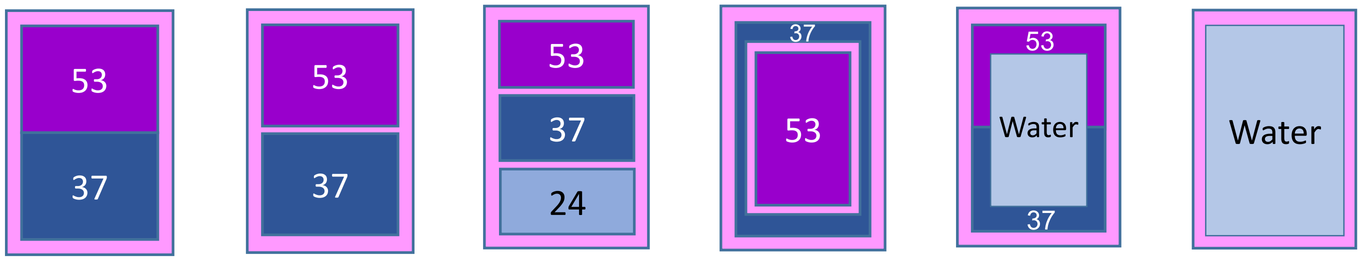
TES = $2m^3$ hot tank

(*) Li et al., University of Melbourne)

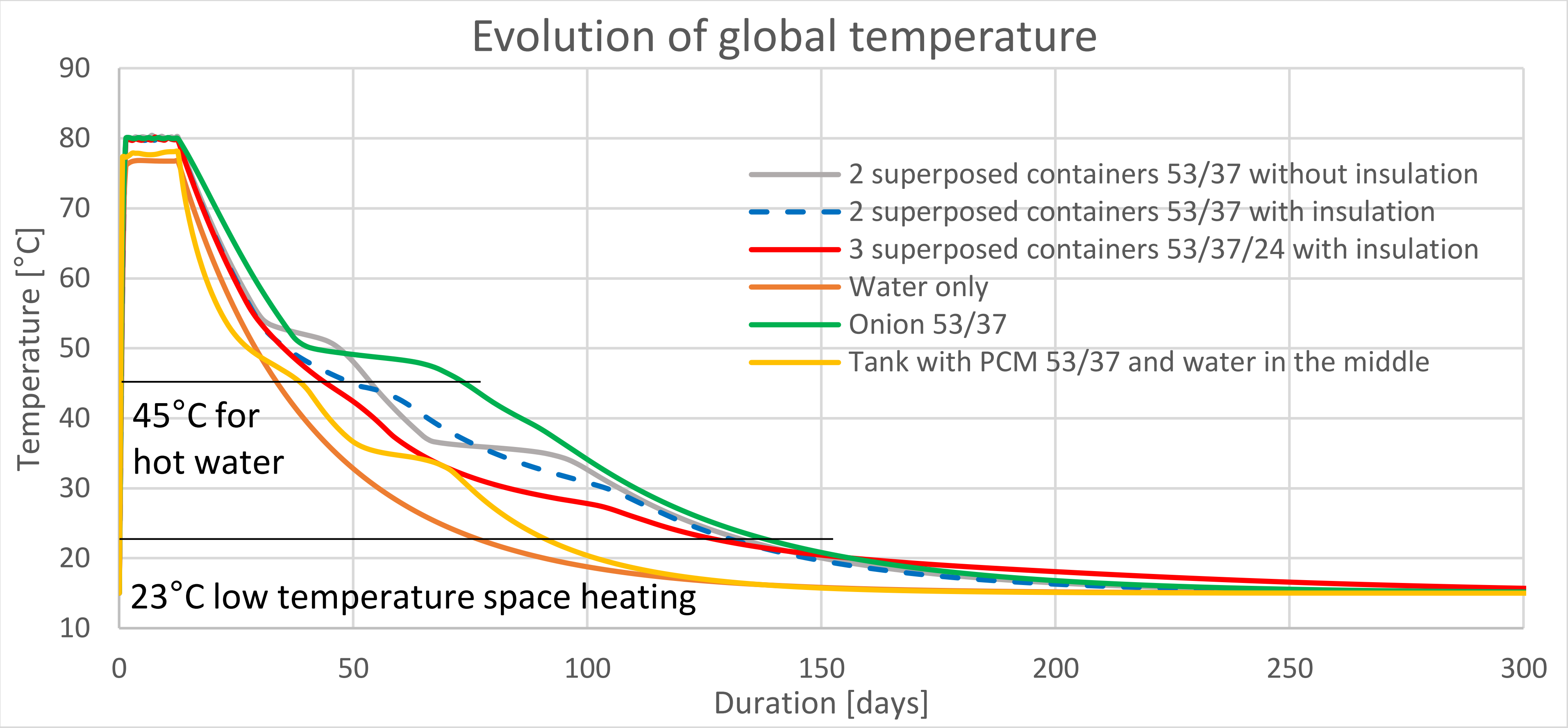
Tank structure simulations for TES



- Finite Elements simulation performed for cylinder structures with simplified annular cells
- 6 structures with 2-3 PCMs and water



TES for building heating and Domestic Hot Water (DHW): Storage temperature evolution during discharge

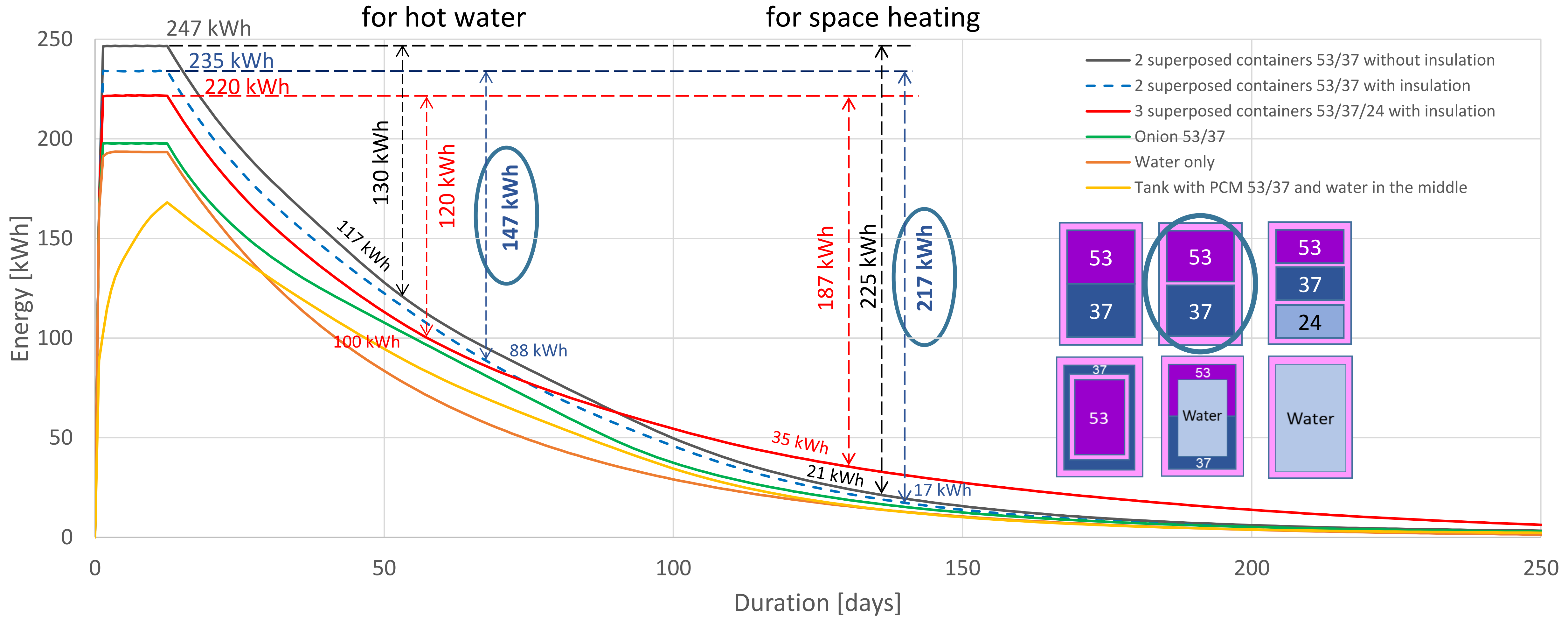


For all structures, minimal temperatures are:

DHW → **45°C**
Heating → **23°C**

Container = 2m high cylinder with radius of 0.67m

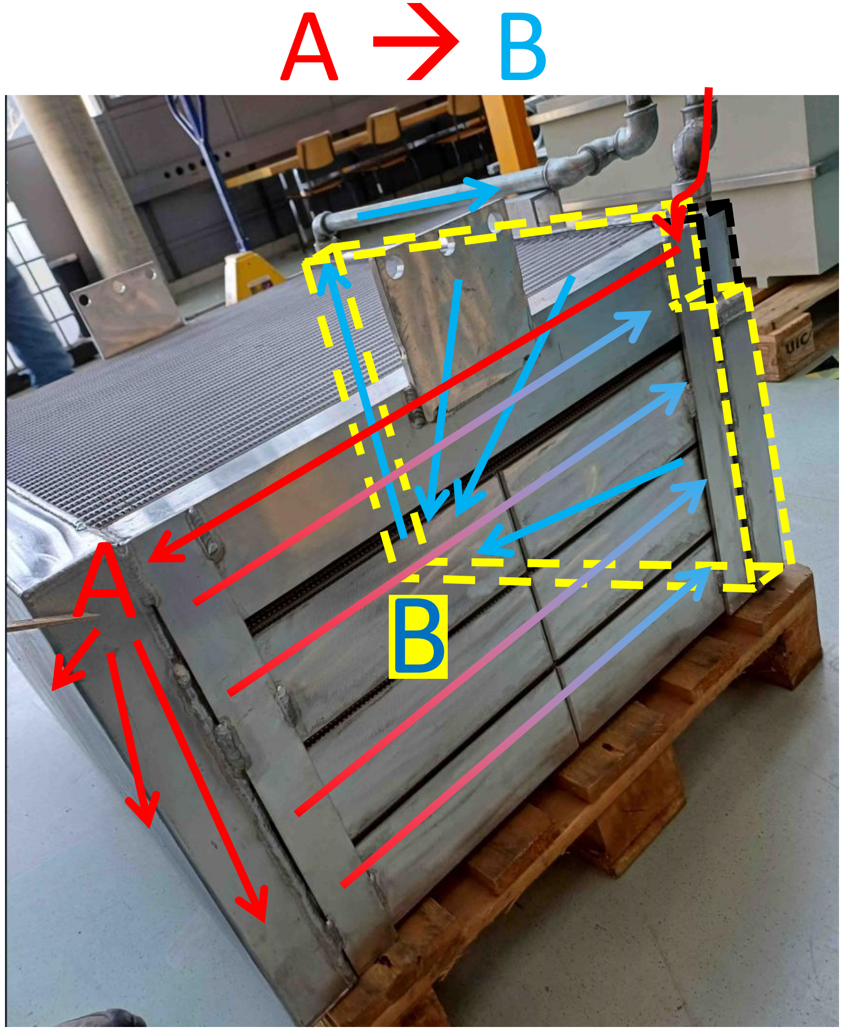
Thermal Energy discharge and structure selection

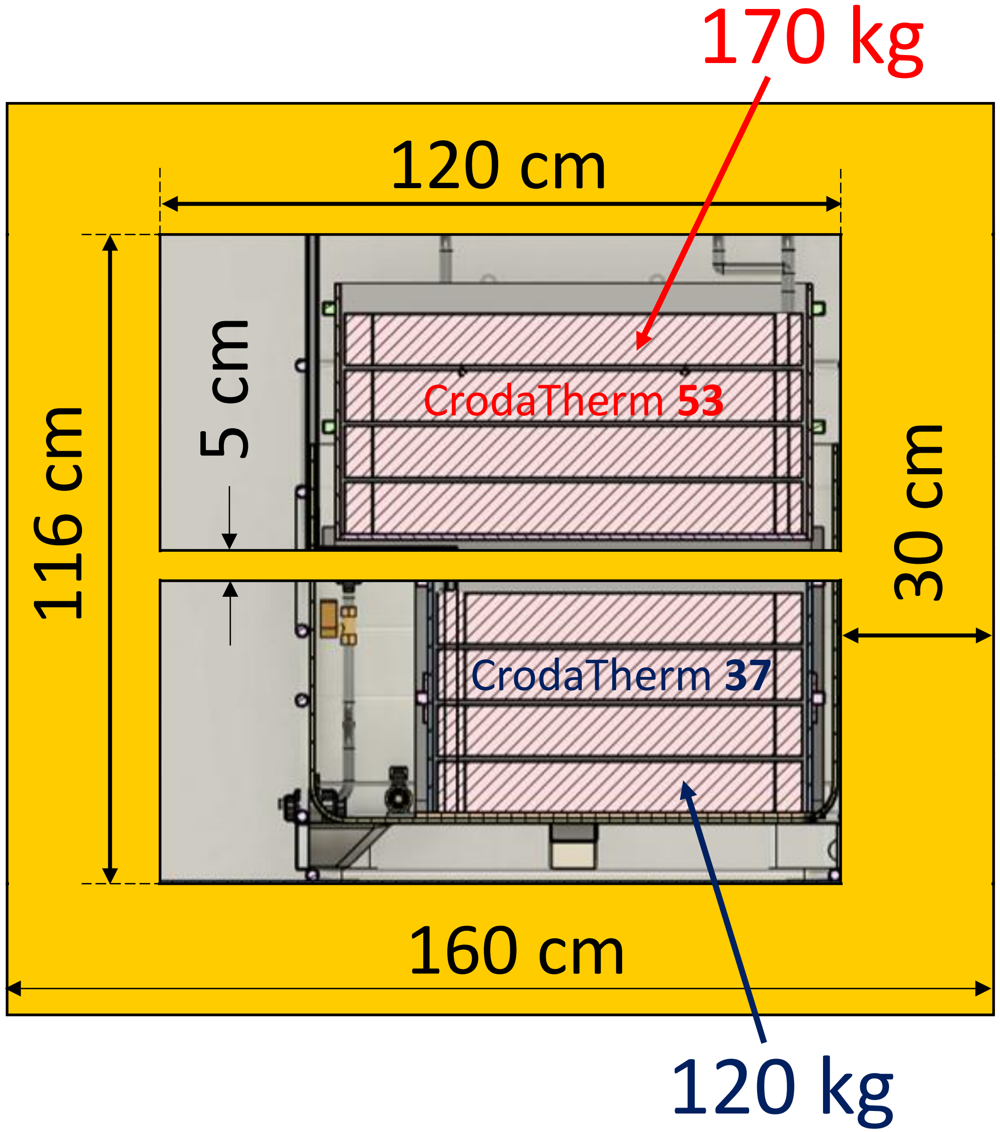


Structure : 2m of height with 0.67m radius	Storage for hot water	Storage for building heating
2 PCMs without intermediate insulation	130 kWh	225 kWh
2 PCMs with intermediate insulation	147 kWh	217 kWh
3 PCMs with intermediate insulation	120 kWh	186 kWh

1. **2 PCMs** are more efficient
2. Intermediate insulation allows to maintain longer a temperature > 45°C.

PCM tank design for DHW and building heating





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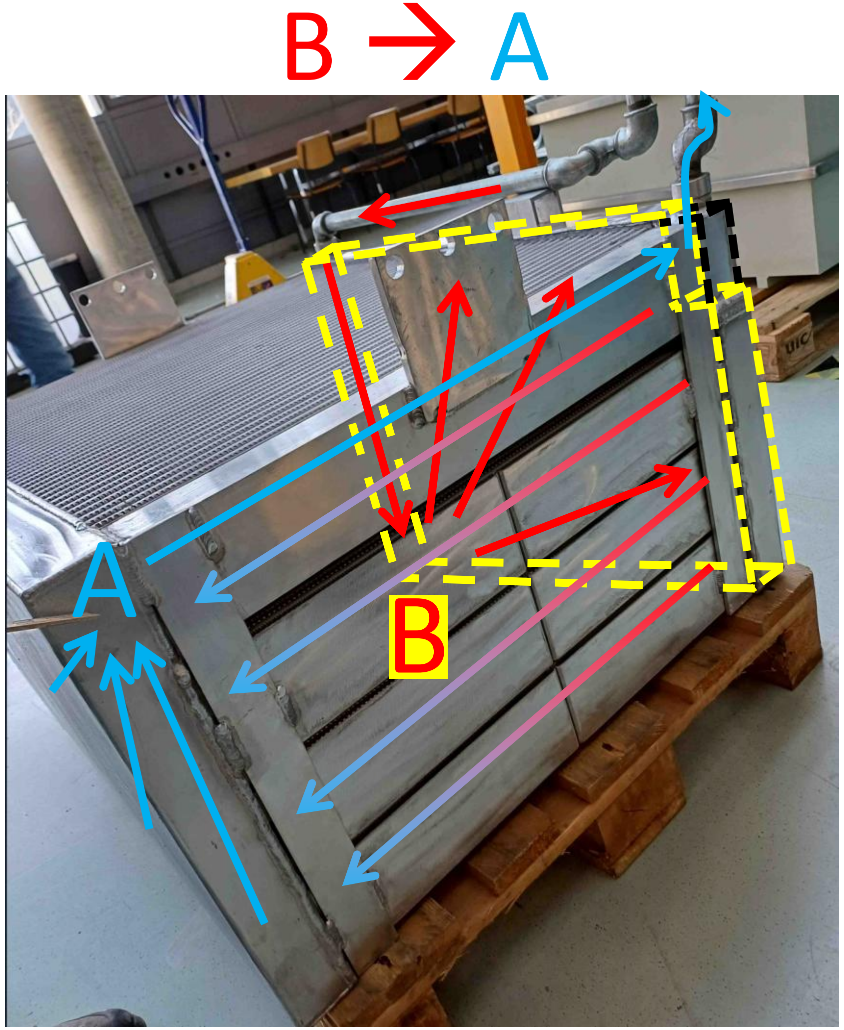
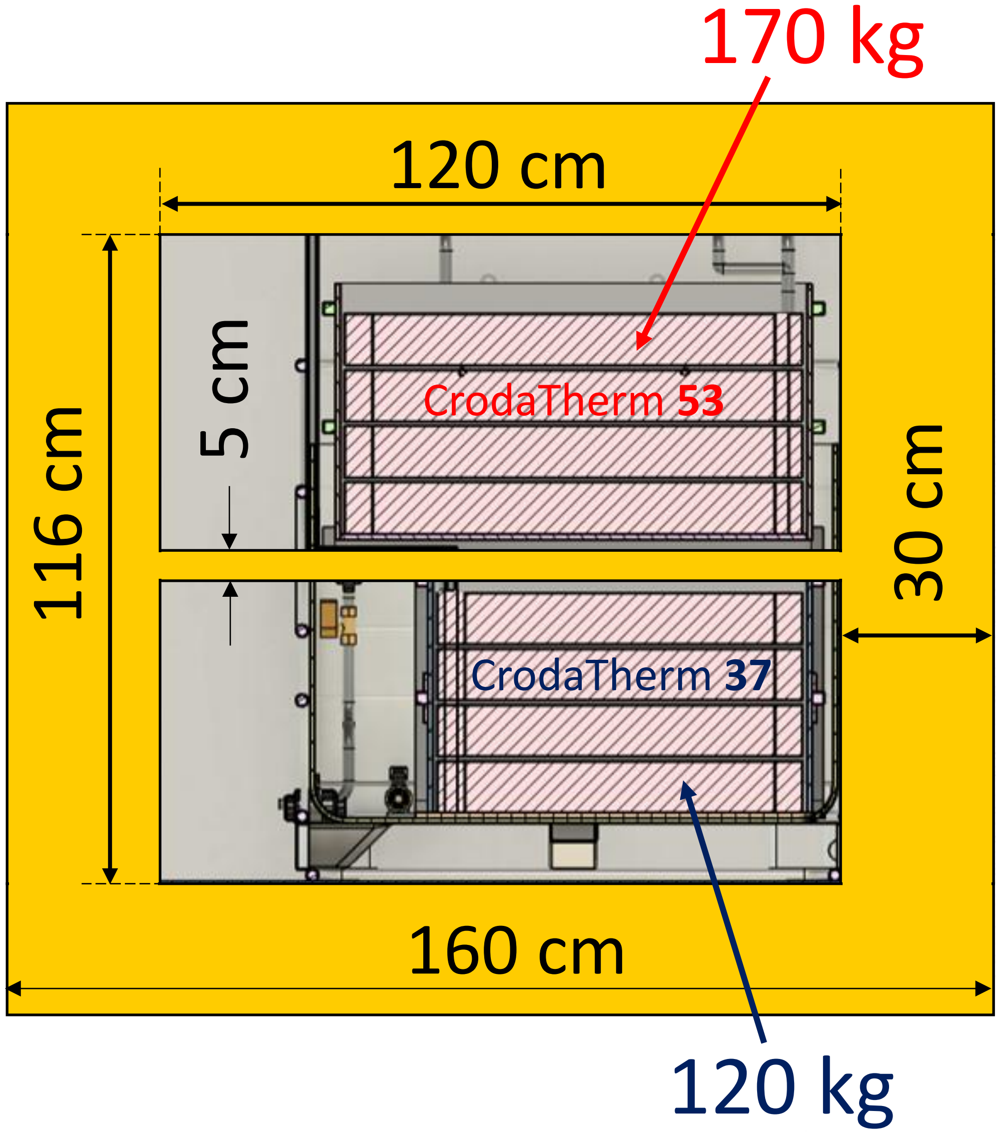
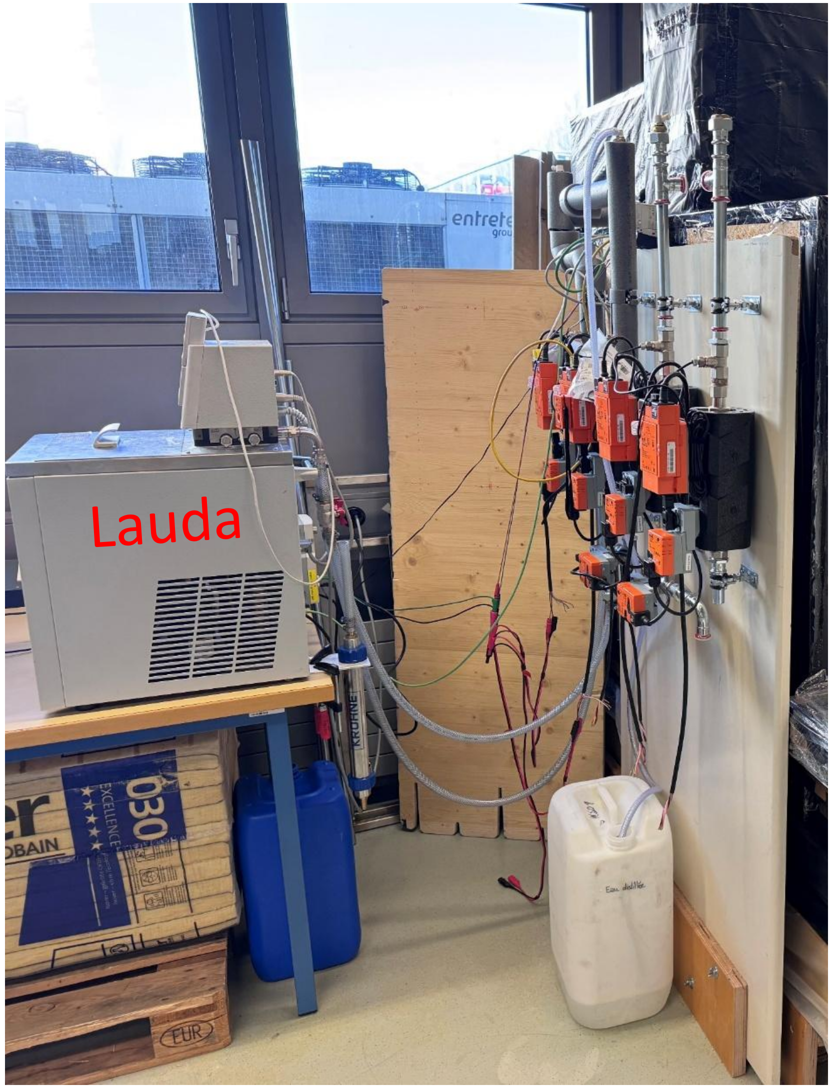
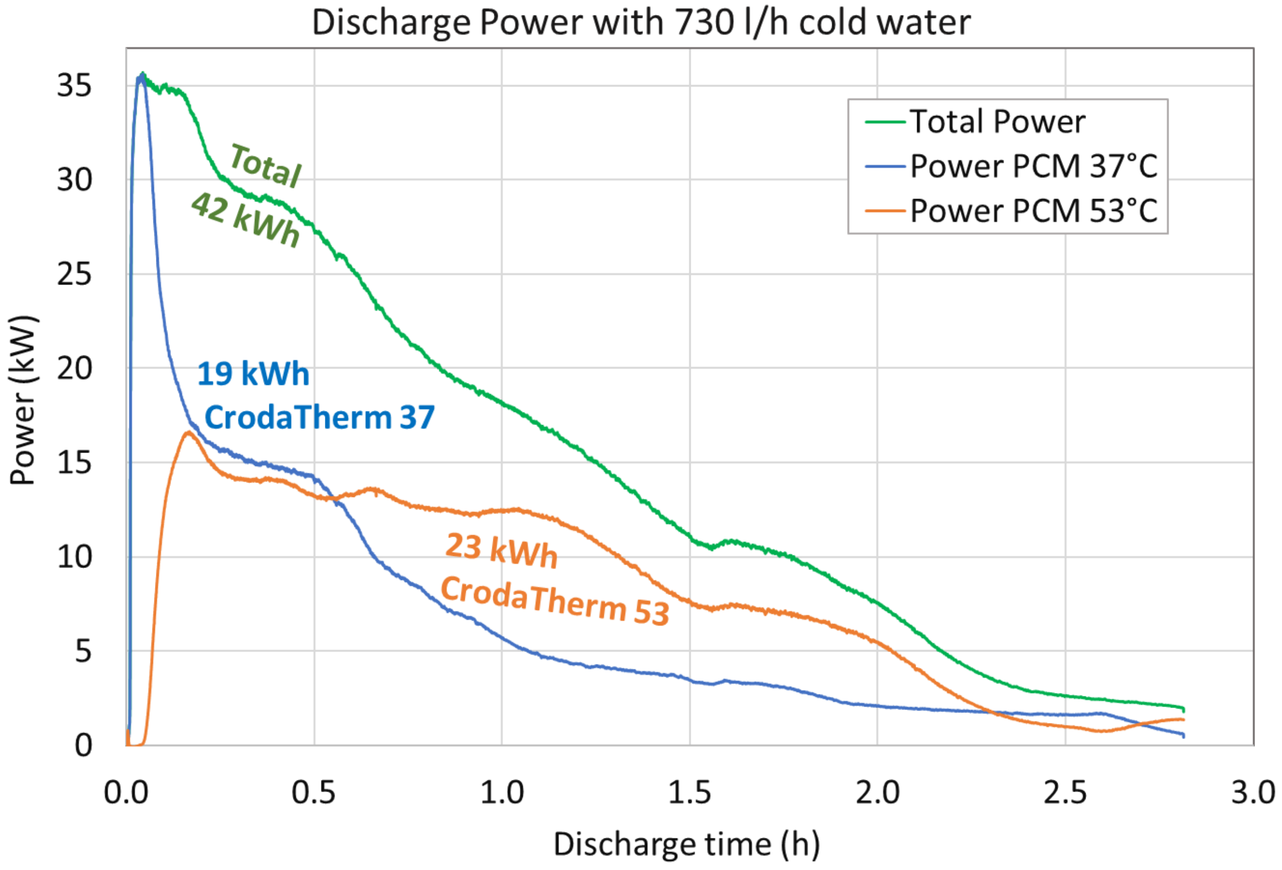




Measurement and controlling system



TES thermal characteristics



Serial discharge of the battery with 18°C Water

PCM 37

Parameter	Value
Capacity (20-60°C)	**19 kWh**
Power (Water 9°C → 50°C)	**30 kW**
Stability after 100 cycles	Power -1% Storage +2.2%

PCM 53

Parameter	Value
Capacity (20-60°C)	**23 kWh**
Power (Water 18°C → 60°C)	**32 kW**

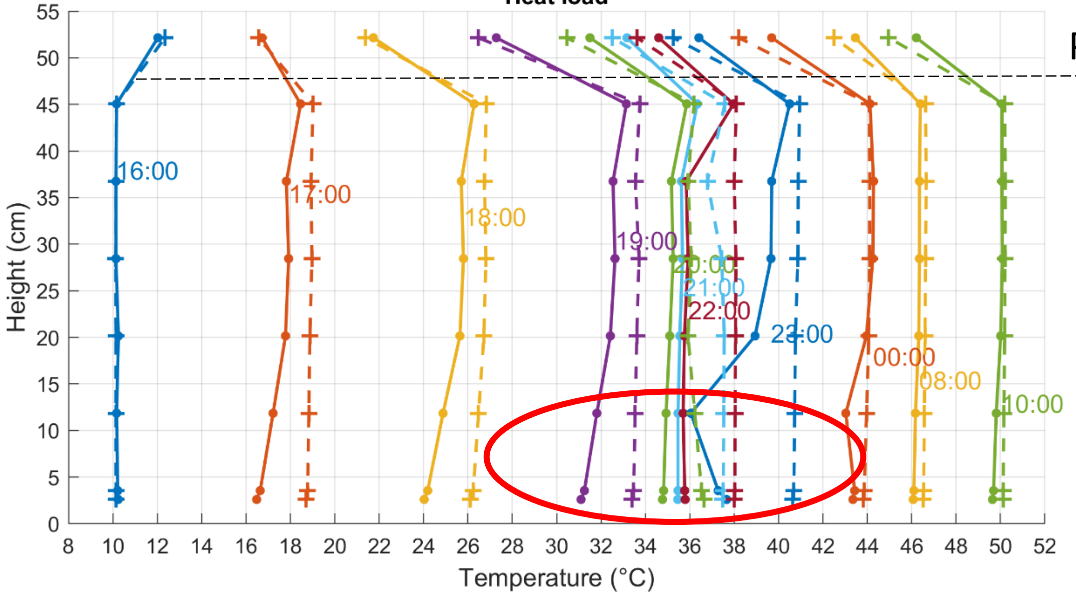
Total battery

Parameter	Value
Capacity (20-60°C)	**42 kWh**
Power (Water 18°C → 60°C)	**35 kW**
Power after plate heat-exchanger	**28 kW**

Frischwasserstation

Temperature profile during heating/cooling

10°C → 50°C



PCM Level

Figure 3: Heat load, 10 to 50°C

exit
entrance

Flow
890 l/h

50°C → 16°C

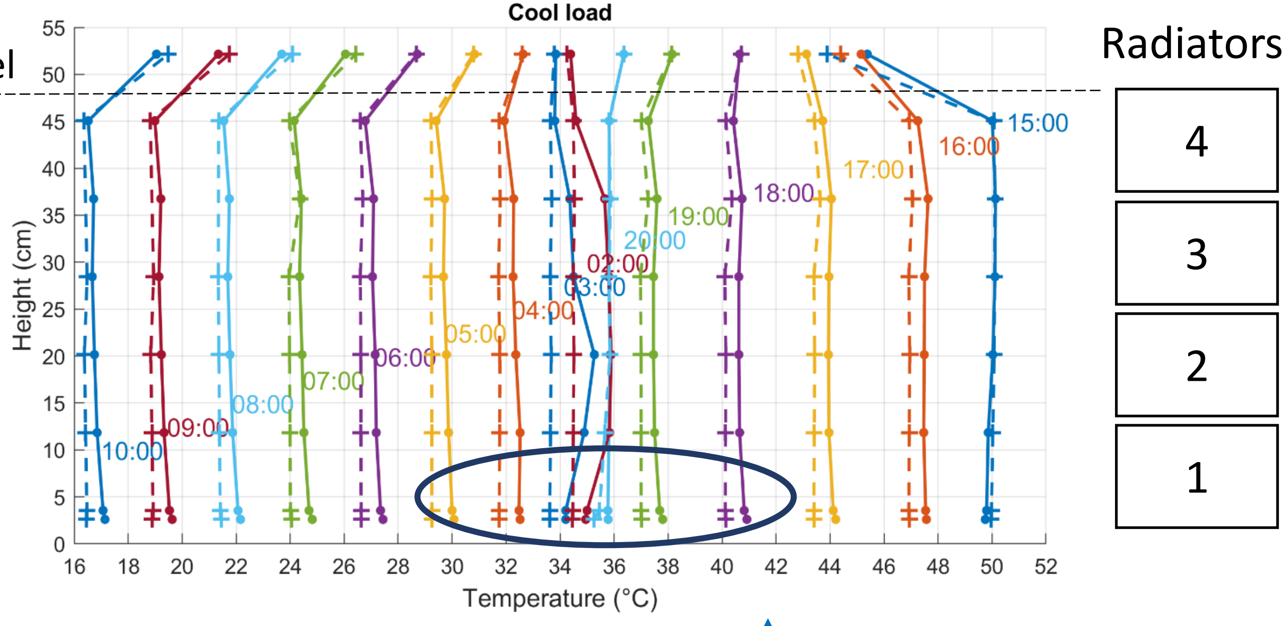


Figure 4: Cool load, 50 to 16°C

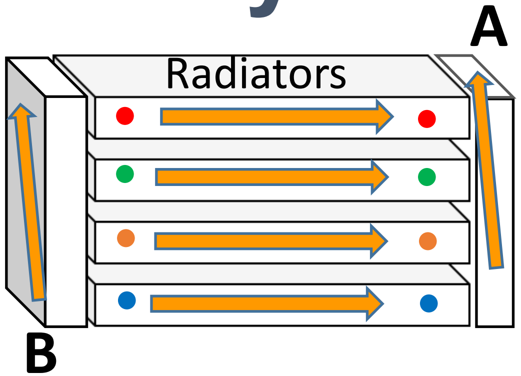
exit
entrance

Flow
890 l/h

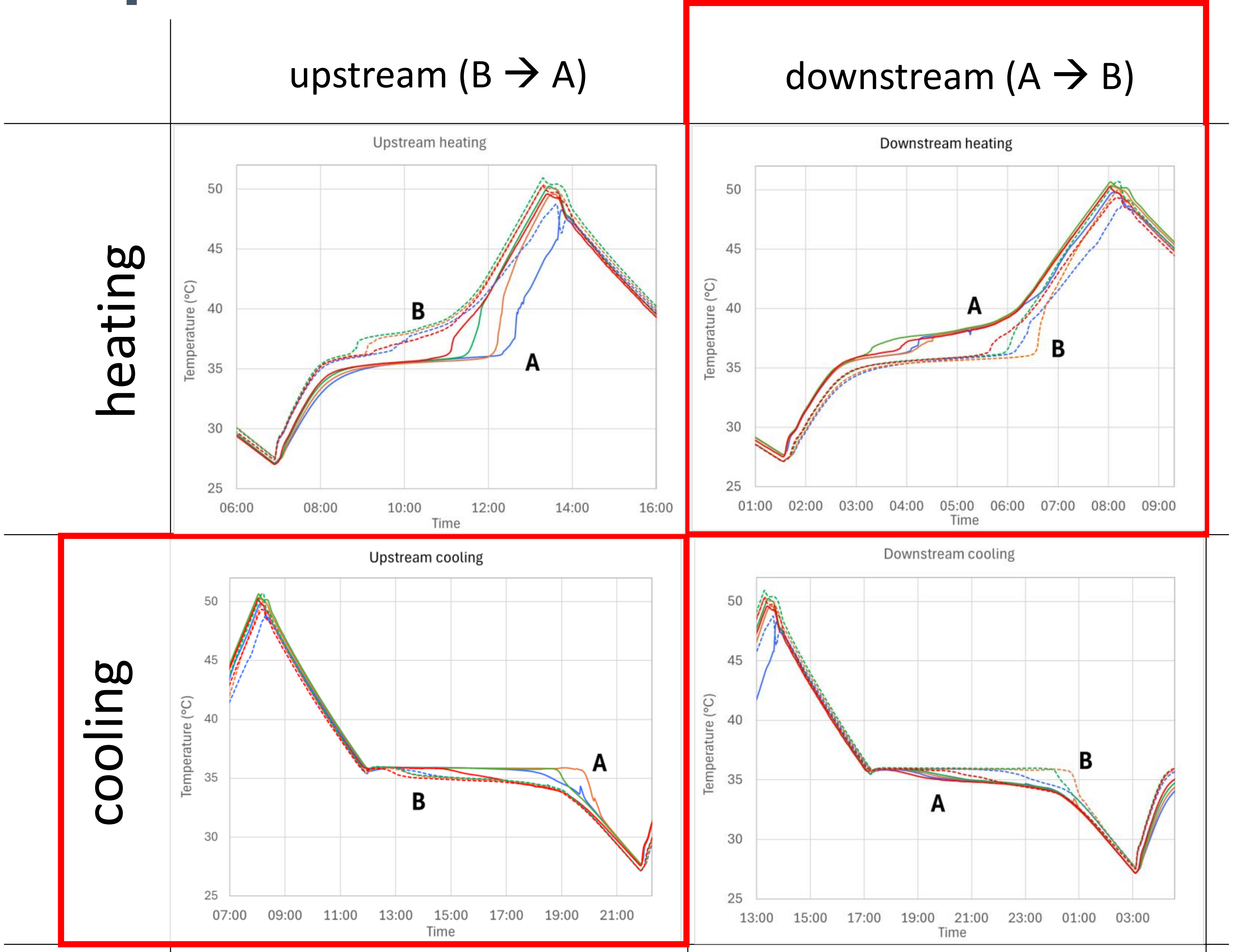
The temperature inside the container is uniform.

The lower radiator heats up slower and the cools down faster.

Efficiency weakly dependent on the flow direction



- **Flow direction** (890 l/h):
  - No effect for cooling
  - Upstream heating a little bit slower for the lower radiator
- **Position**:
  - Due to high flow rate the Upper radiator is always the fastest
  - Lower radiator is the slowest for heating, and 2nd fastest for cooling



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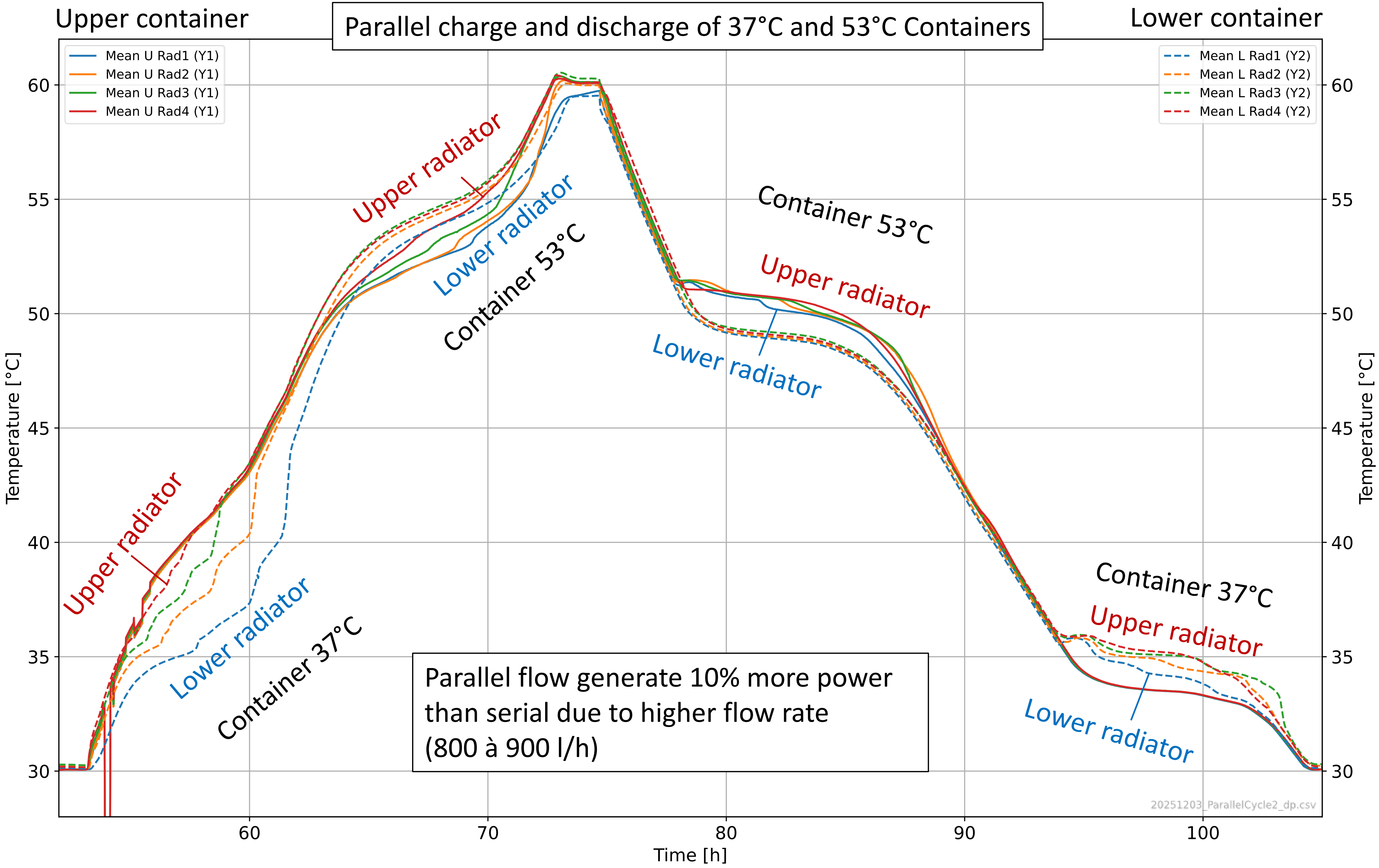
Parallel charge and discharge of 37°C and 53°C Containers



Parallel flow generate 10% more power than serial due to higher flow rate (800 à 900 l/h)

Thermal storage: better than Heat Pumps to reduce CO_2 emission of old buildings with oil heating

PV + HP are 3x more costly than
thermal solar panels + thermal storage

Solution	Oil heating with no renewable energy	50m² PV + HP	50m² thermal panels + 10kWh TES storage
Investment Costs (€)	------	**69’000.-**	**22’000.-**
CO_2 production (kg/year)	**3’300**	**261**	1’434
CO_2 reduction (kg/year)	------	3’039	1’866

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CO_2 reduction (kg/year)	------	3’039	1’866
CO_2 reduction per invested Euro (g/€ year)	------	**44**	82

Conclusion

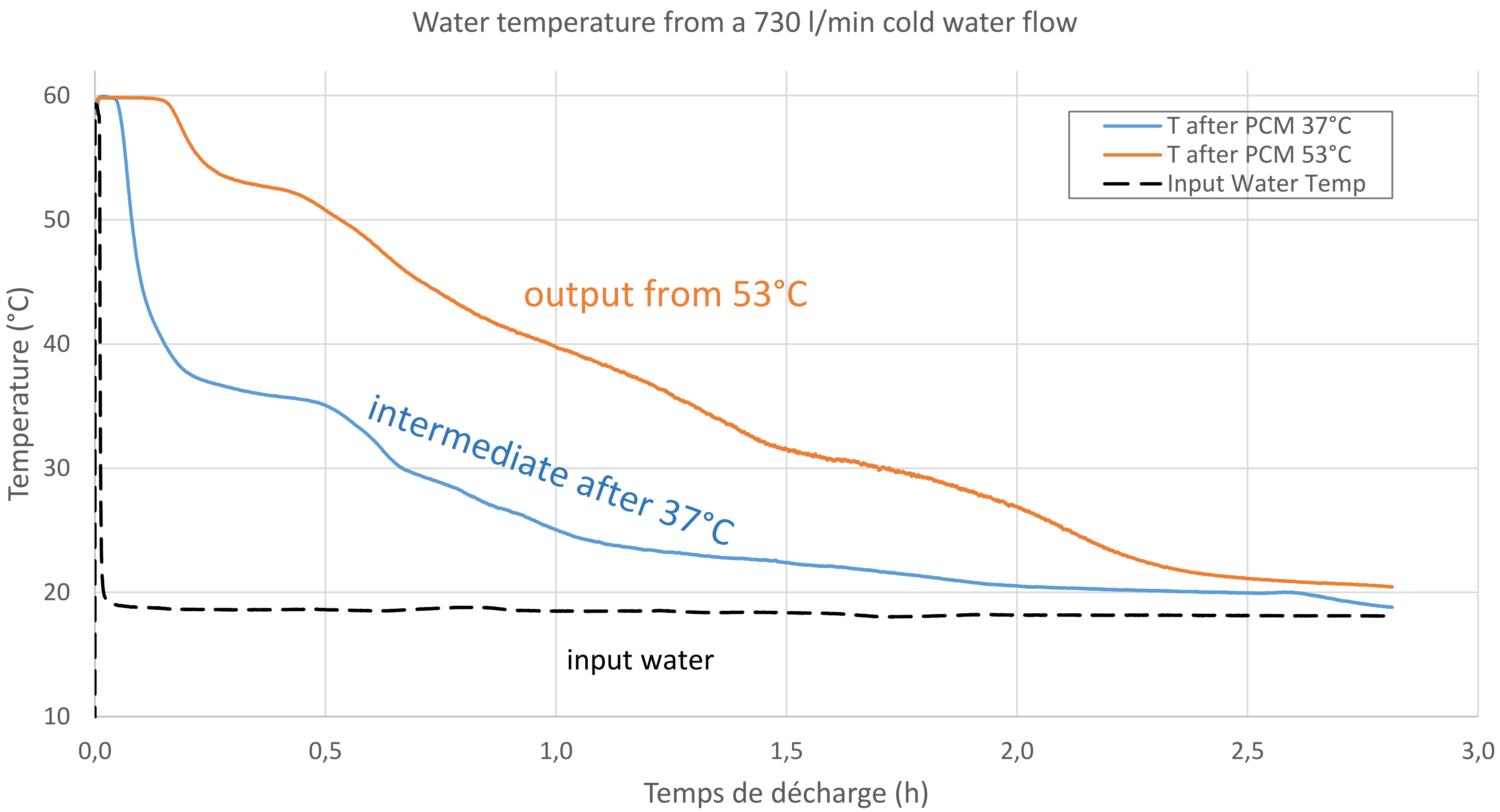
- We develop a TES demonstrator with 2 PCMs of T_m = 37°C and 53°C.
- The structure has a **storage capacity** of **42 kWh** with a discharge **power** up to **35kW**.
  - PCM Heating more efficient in the upper radiators and PCM cooling slightly faster in the lower radiators
  - **Direct heating** of cold water can produce DHW with no risk of legionella bacteria (Frischwasserstation)
- **Ideal for renovations** with solar thermal energy, avoiding the use of a HP and reducing significantly CO_2 emissions.

Wo ist das Problems ?

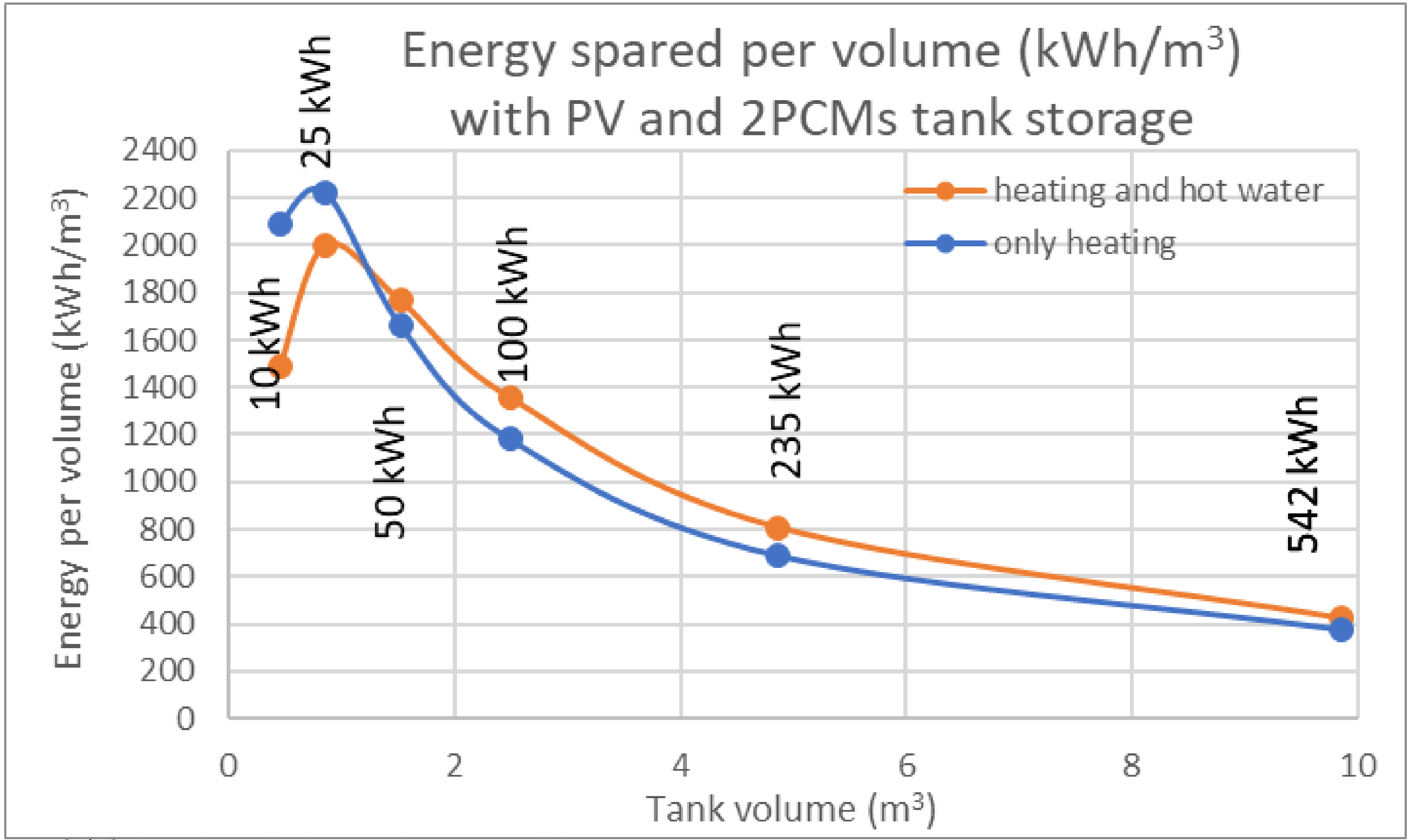
nur da !!!

outlook

Temperature during serial discharge with cold water



Energy spared per volume with TESS when 90 m^2 PV are already installed



Optimum is placed around 10-25 kWh

Décharge du bac supérieur (PCM 53)

L'isolation interbac de 5cm fait un excellent travail