

Experimental Characterization of a Medium-Temperature Organic PCM Latent Thermal Storage for Residential Heat Pump Applications

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INTRODUCTION & AIM

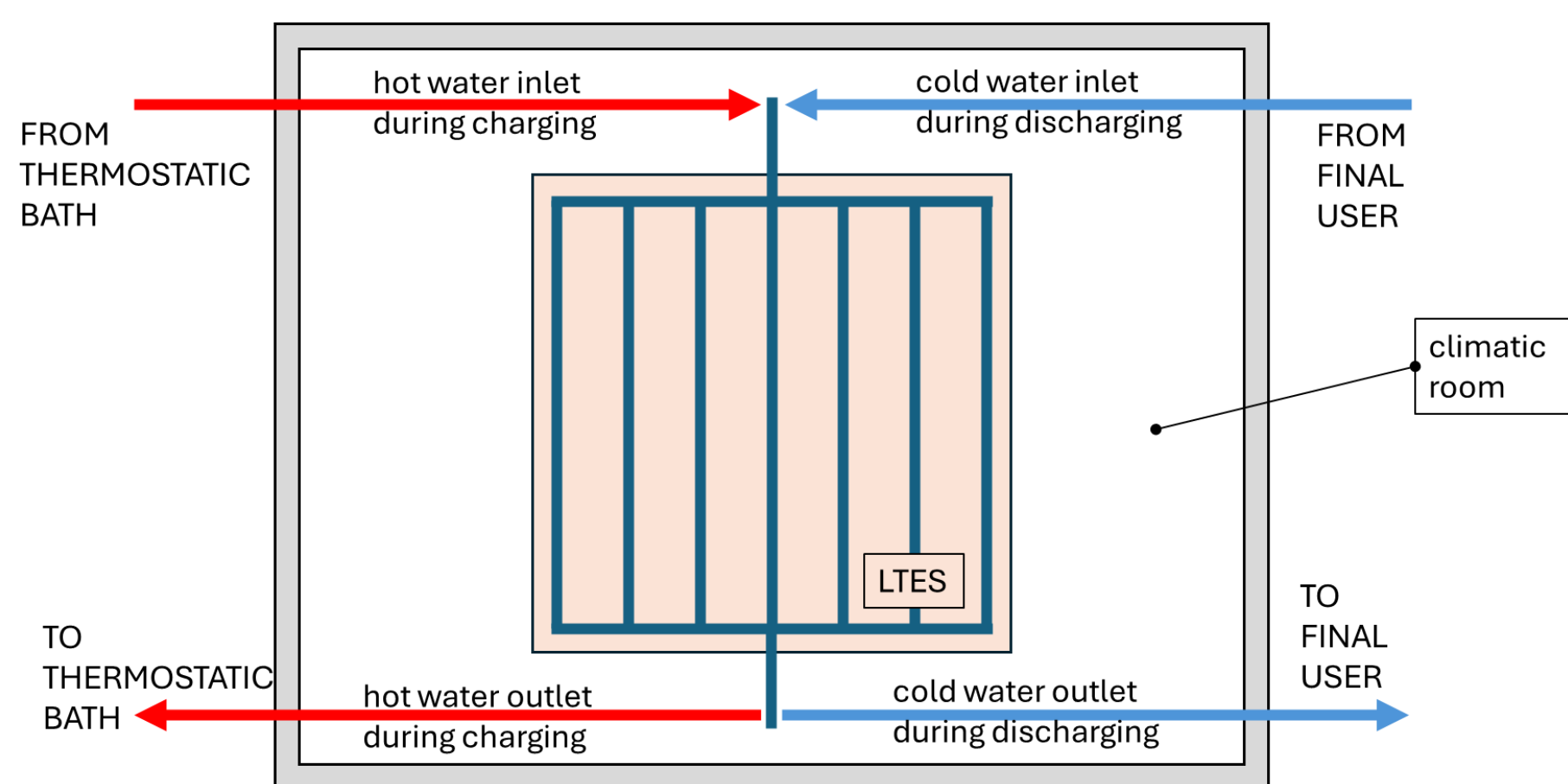
Latent thermal energy storage (LTES) based on phase change materials enables load shifting and improved integration of renewable electricity in residential heat-pump systems. However, real-scale performance strongly depends on operating conditions and on the internal thermal field evolution, while global indicators such as stored energy or average power alone do not fully describe the effective usability of the storage.

This work experimentally investigates a **0.1 m³ LTES filled with a commercial not flammable bio-based organic PCM and equipped with finned-coil heat exchanger**, with the objective of quantifying how **inlet temperature difference and water flow rate** influence:

- exchanged thermal power (heat pump to PCM and PCM to final user)
- stored and usable energy
- internal PCM storage temperature stratification

The study provides **application-oriented design insights for residential heat-pump integration**.

METHOD



A real-scale insulated stainless steel tank (430 × 520 × 440 mm) was filled with a **bio-based paraffin PCM (P48)** having a phase-change temperature close to **48 °C** (melting range 45–50 °C, latent heat ≈ 250 kJ·kg⁻¹, density ≈ 810 kg·m⁻³, and thermal conductivity ≈ 0.2 W·m⁻¹·K⁻¹).

Heat exchange is provided by a **seven-tube finned-coil heat exchanger with 12 passes per tube** and an effective heat-transfer area of approximately **2.6 m²**.

Charging and discharging tests were performed under boundary conditions representative of residential heat-pump operation:

- inlet temperature difference $\Delta T = 10, 15, 20$ K
- volumetric flow rate = **4–8 L min⁻¹**

•**end of the test:** exchanged thermal power < 0.5 kW

Thermal power and exchanged energy were calculated from water-side measurements, while the **internal thermal field** was resolved using **17 calibrated thermocouples** distributed throughout the PCM volume.

RESULTS & DISCUSSION

Below are all the operating conditions experimentally tested.

Flow rate	dT in	Charging time	E stored	Pmax charging	Discharging time	E released	Pmax discharged
[l min ⁻¹]	[K]	[min]	[kWh]	[kW]	[min]	[kWh]	[kW]
6	10	160	7.4	12	165	6.4	9.4
6	15	130	7.9	16	138	6.9	12
6	20	112	8.2	19	115	7.1	18
8	20	83	8.4	26	86	7.2	24
6	20	112	8.2	19	115	7.1	18
4	20	177	7.9	8.2	187	6.8	6.3

FUTURE WORK / REFERENCES

Future research will focus on:

- comparison with **inorganic PCM solutions**
- influence of **heat-exchanger surface distribution**
- development of **predictive models for usable energy and stratification**
- system-level optimization within **renewable-driven residential heat-pump operation**

1) EFFECT OF ΔT

At constant flow rate, increasing the inlet temperature difference strongly accelerates storage dynamics:

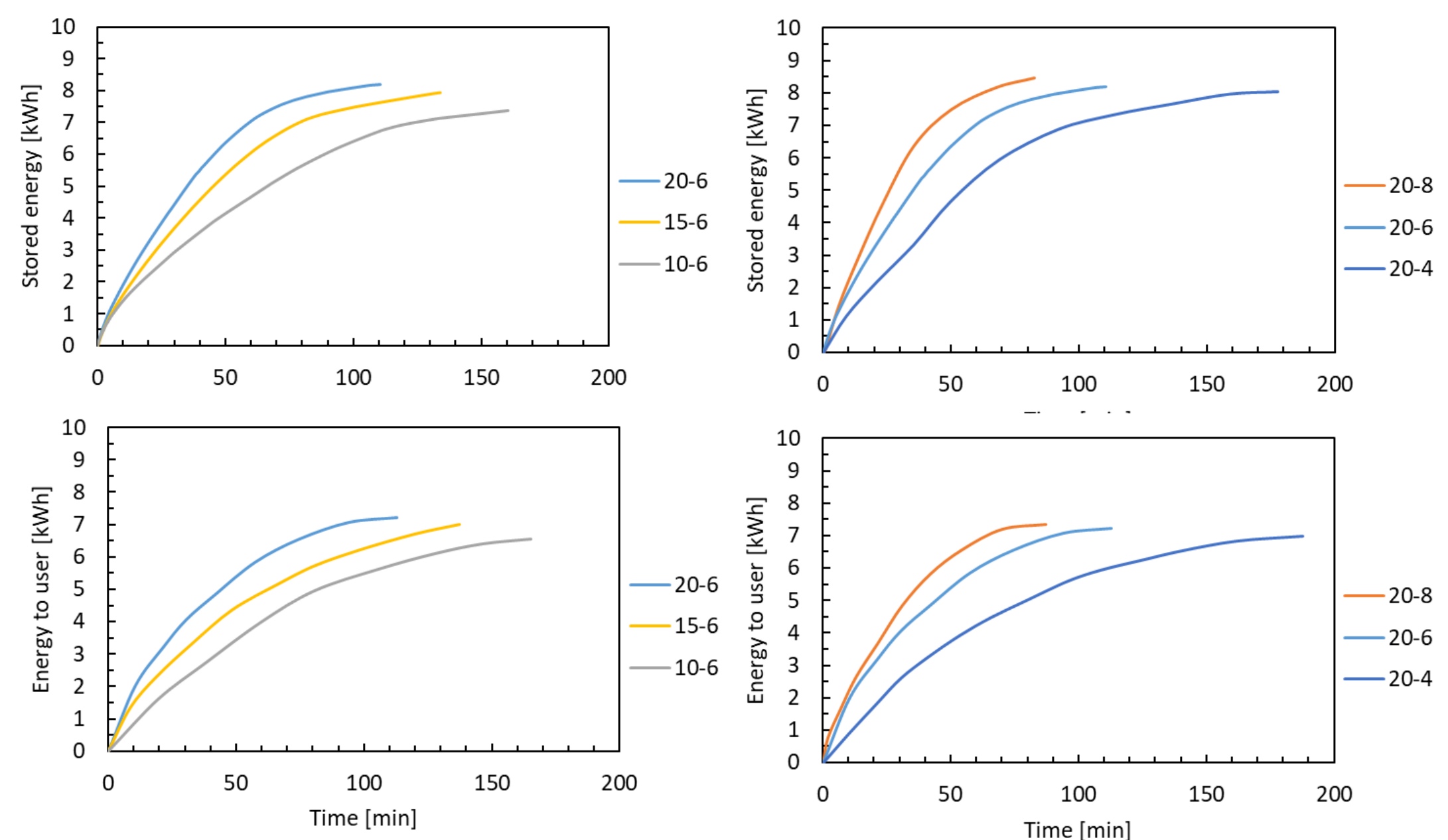
- operation time decreases (160 min → 112 min)
- peak thermal power rises (~12 kW → ~19 kW)

2) EFFECT OF FLOW RATE

At fixed $\Delta T = 20$ K, increasing the water flow rate significantly enhances heat-transfer intensity.

- operation times are reduced by **up to 50 %**
- maximum thermal power increases by approximately a factor of three.

Similar trends are observed during discharging, confirming the dominant role of thermal driving temperature on dynamic behavior.



INTERNAL TEMPERATURE FIELD & STRATIFICATION

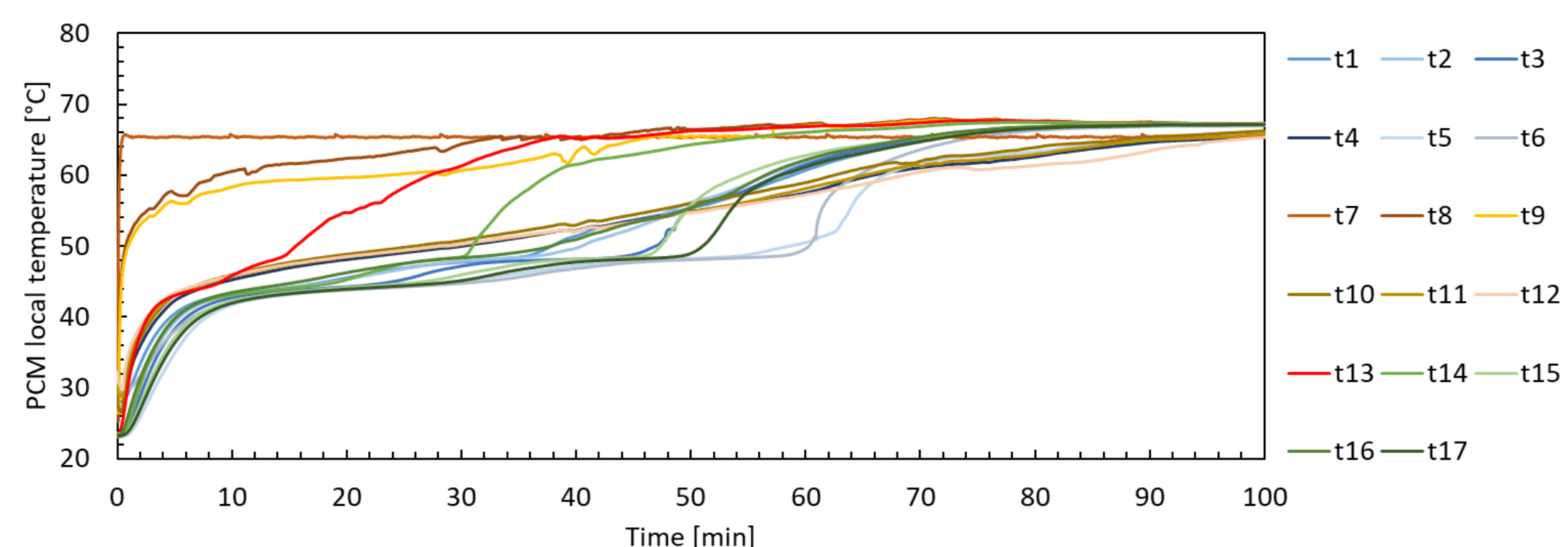
Temperature measurements reveal a **strongly non-uniform thermal field** governed by the interaction between water-side convection and PCM-side conduction.

More aggressive operating conditions increase thermal non-uniformity.

Higher ΔT and **flow rate** lead to:

- larger **maximum internal temperature differences**
- higher **spatial temperature standard deviation**
- reduced time available for conductive homogenization inside the PCM

As a result, **thermal power enhancement inherently amplifies temperature stratification**, which may limit the fraction of effectively usable stored energy.



CONCLUSION

The experimental analysis of a real-scale latent thermal energy storage with **organic PCM and 12-pass finned-coil geometry** demonstrates that **operating conditions strongly govern dynamic performance while only marginally affecting total storage capacity**. Increasing inlet temperature difference or water flow rate significantly enhances **peak thermal power** and shortens charging and discharging times, but simultaneously **amplifies internal temperature stratification** and can reduce the **fraction of usable discharged energy**.

These results reveal a fundamental **trade-off between power density, thermal uniformity, and energy usability**, showing that optimal operation for residential heat-pump integration does not correspond to maximum thermal power.

Real-scale PCM storage design must therefore rely not only on **global energy metrics** but also on **spatially resolved thermal-field analysis** to ensure reliable and application-oriented performance.