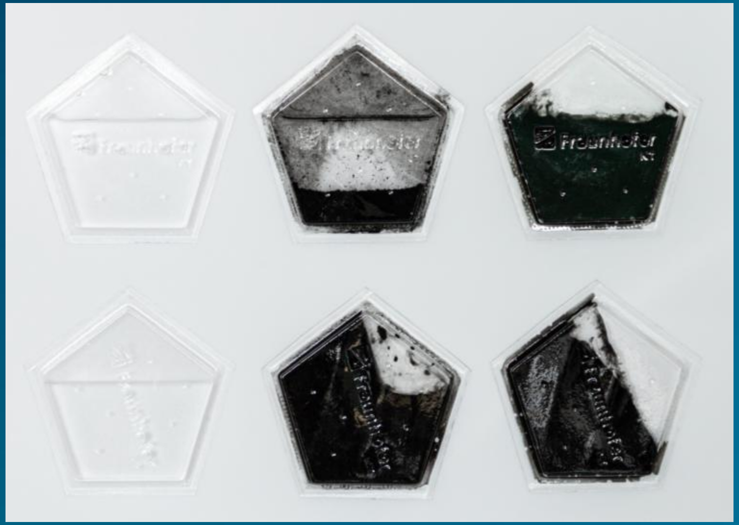


Christian Teicht, Moritz Walter, Florian Schwär, Sandra Pappert

International Energy and Environment Conference (IEEC) 2025

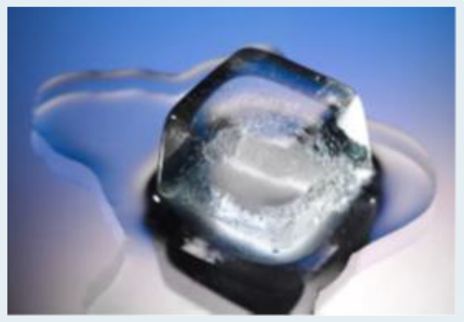
Calorimetry of Phase Change Materials (PCM) for Heat Storage Applications

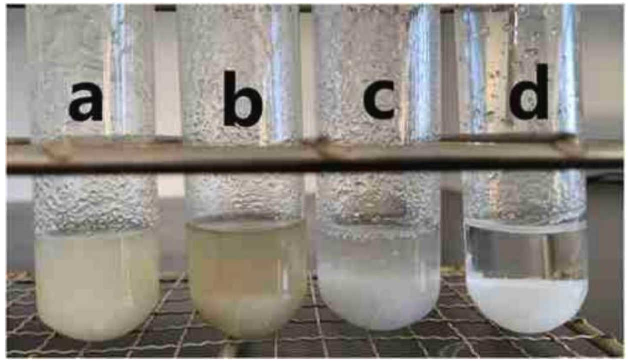
1. Motivation

Heat Storage with Phase Change Materials (PCM)

Latent heat storage: $dQ = \Delta h_{melt} * dm_{s \to l}$

- Salt hydrates as PCM[1]:
  - In general cheap and available
  - High heat storage density
  - Not flammable
  - **Likely to supercool**
  - **Phase segregation**





Phase segregation in salt hydrate PCM with varying gelling agent content.[2]

RAL Quality Mark: RAL-GZ 896 – Phase Change Materials

- Measurement (Salt Hydrates) T_m and Δh_{fl}:
  - T-history Calorimeter
  - Large Scale DSC
  - 3 Layer Calorimeter
    - Sample containment can be used for thermal cycling
- 3 Layer Calorimeter not well documented in literature (only gray literature[3]):

[1]Stephan, Peter (Hg.) (2019): VDI-Wärmeatlas. Fachlicher Träger VDI-Gesellschaft Verfahrenstechnik und Chemieingenieurwesen. Springer-Verlag GmbH. 12. Auflage 2019. Berlin: Springer Vieweg (Springer Reference Technik).
[2]Gao, Liqiang; Zhang, Xuelai; Hua, Weisan (2024): Preparation and thermal properties of sodium carbonate decahydrate as a novel phase change material for energy storage. In: Journal of Energy Storage 84, S. 110723. DOI: 10.1016/j.est.2024.110723.
[3]Laube, Andreas: The 3-layer calorimeter. Hg. v. Andreas Laube. w & a - wärme- und anwendungstechnische Prüfungen Andreas Laube. Online verfügbar unter http://wunda.tech/3-Schicht-Kalorimeter/, zuletzt geprüft am 14.05.2025.

Agenda

Investigation of the 3-layer calorimeter

1. Motivation
2. Introduction to the 3-layer calorimeter
3. Fraunhofer ICT version of the 3-layer calorimeter
    a) **Construction**
    b) **Testing**
    c) **Modeling**
    d) **Calibration**
4. Conclusion

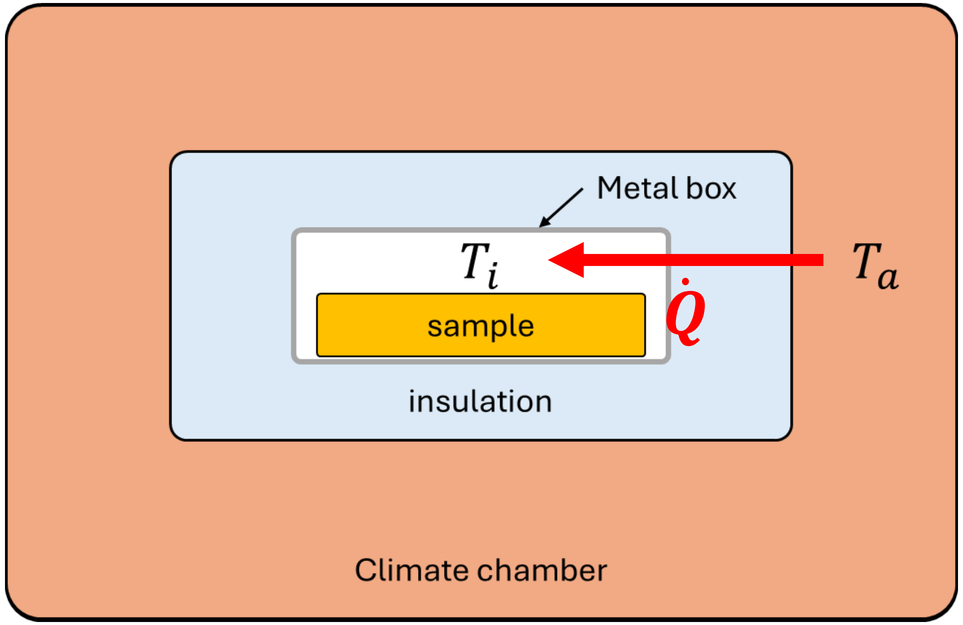
2. Introduction to the 3-layer calorimeter

Assumptions:

- Temperature inside calorimeter T_i is homogenious
- Temperature around calorimeter T_a is homogenious
- Thermal resistance of calorimeter R_{cal} is known
- Thermal capacity of calorimeter $C_{p,cal}(T_i)$ is known
- Sample temperature equals internal temperature of calorimeter $T_{sample} = T_i$

true?

how?

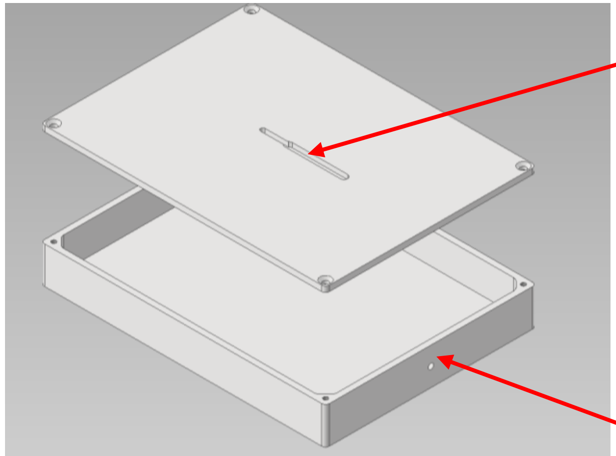


Measurement principle:

- Heat flow $\dot{Q}$ at T_i can be calculated from recorded temperatures
- Total thermal capacity $C_{p,total}(T_i)$ can be calculated from $\dot{Q}$ and $\dot{T}_i$
- Thermal capacity of sample $C_{p,sample}(T_i) = C_{p,total}(T_i) - C_{p,cal}(T_i)$

Fraunhofer ICT version of the 3-layer calorimeter

a) Construction



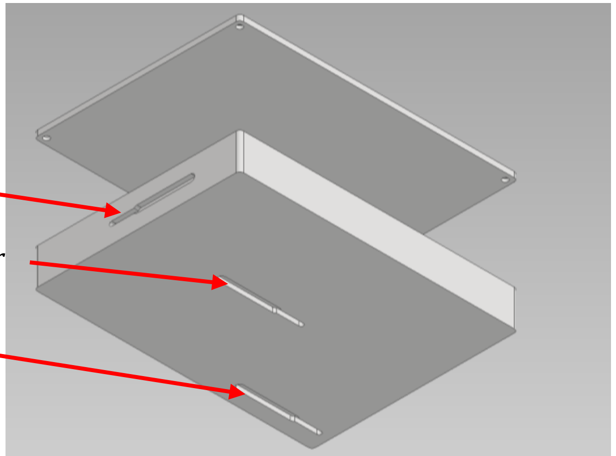
inside top: $T_{i,1}$

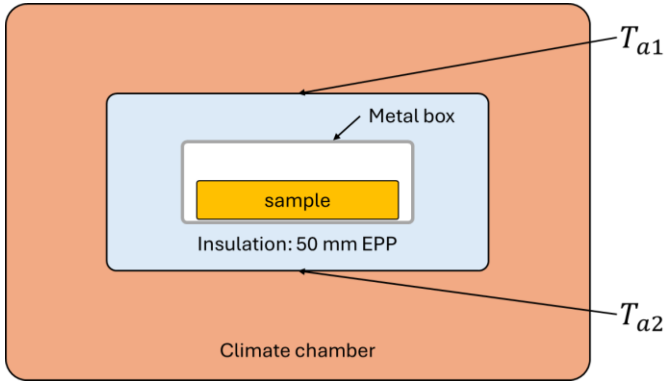
inside side: $T_{i,2}$

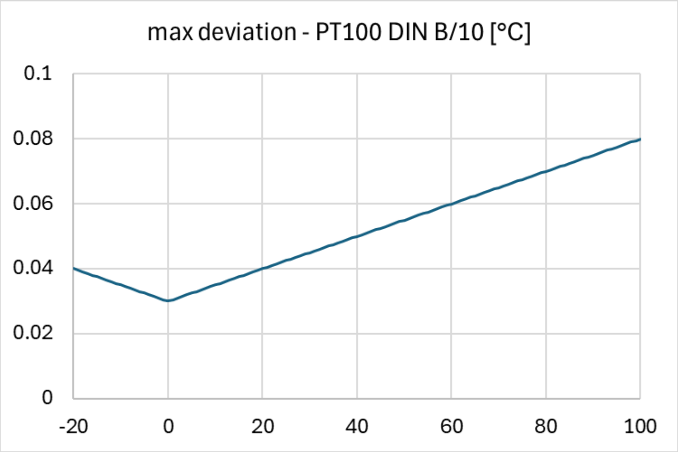
inside bottom (heater): $T_{i,heater}$

inside bottom corner: $T_{i,3}$

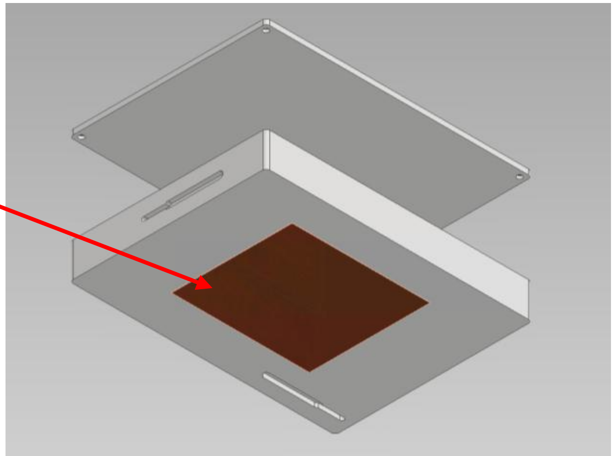
inside sample: $T_{i,sample}$







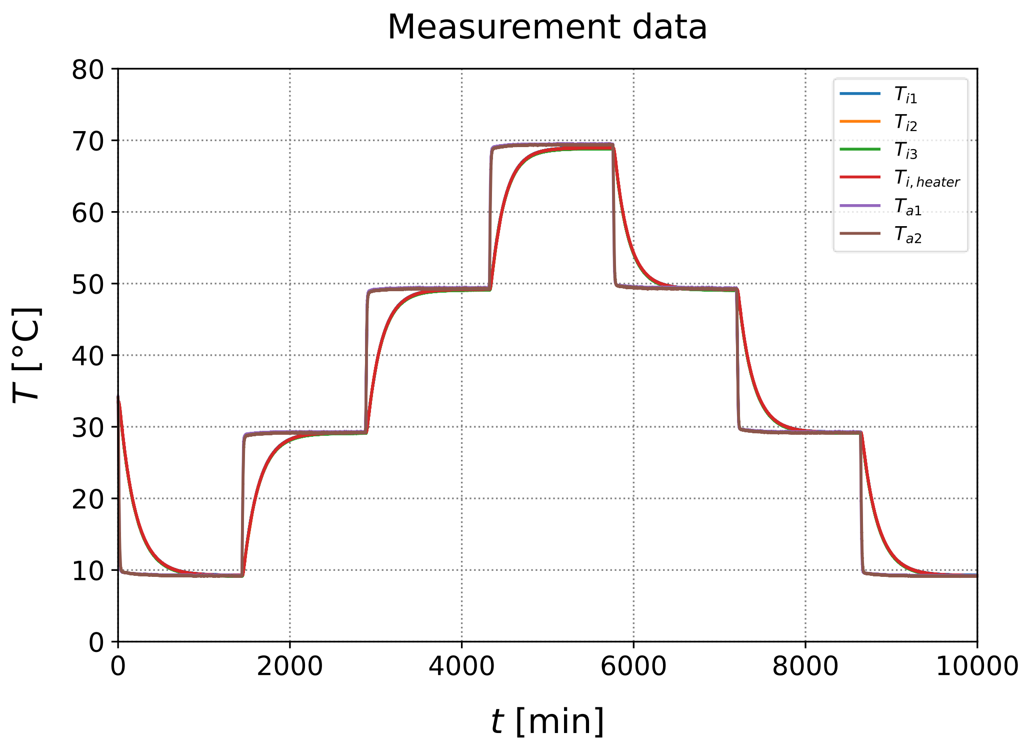
Foil heater



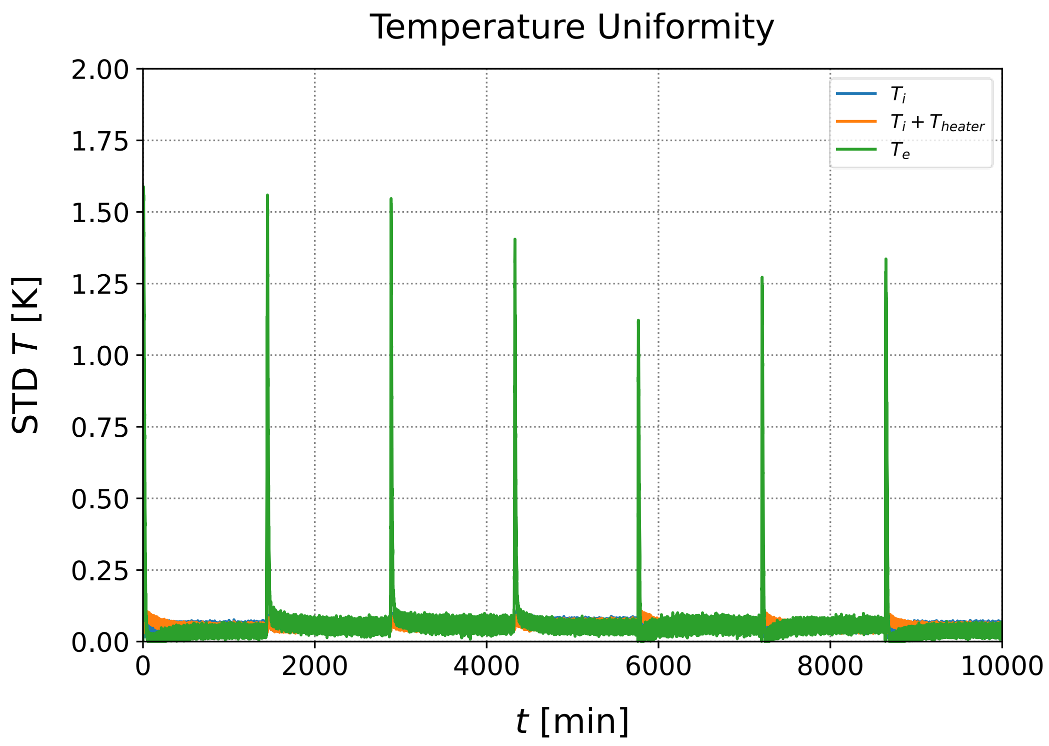
Fraunhofer ICT version of the 3-layer calorimeter

b) Testing – heating / cooling without phase transition **(sample = water, 111 g)**

Temperature profiles



Temperature deviations inside and outside the calorimeter

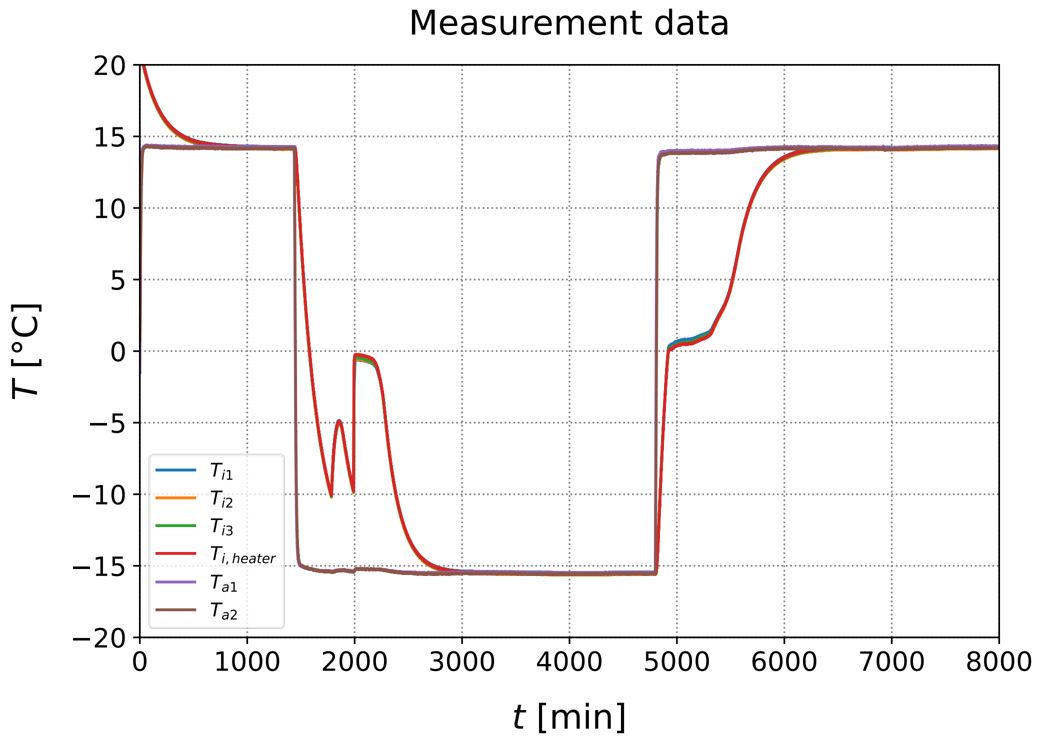


Fraunhofer ICT

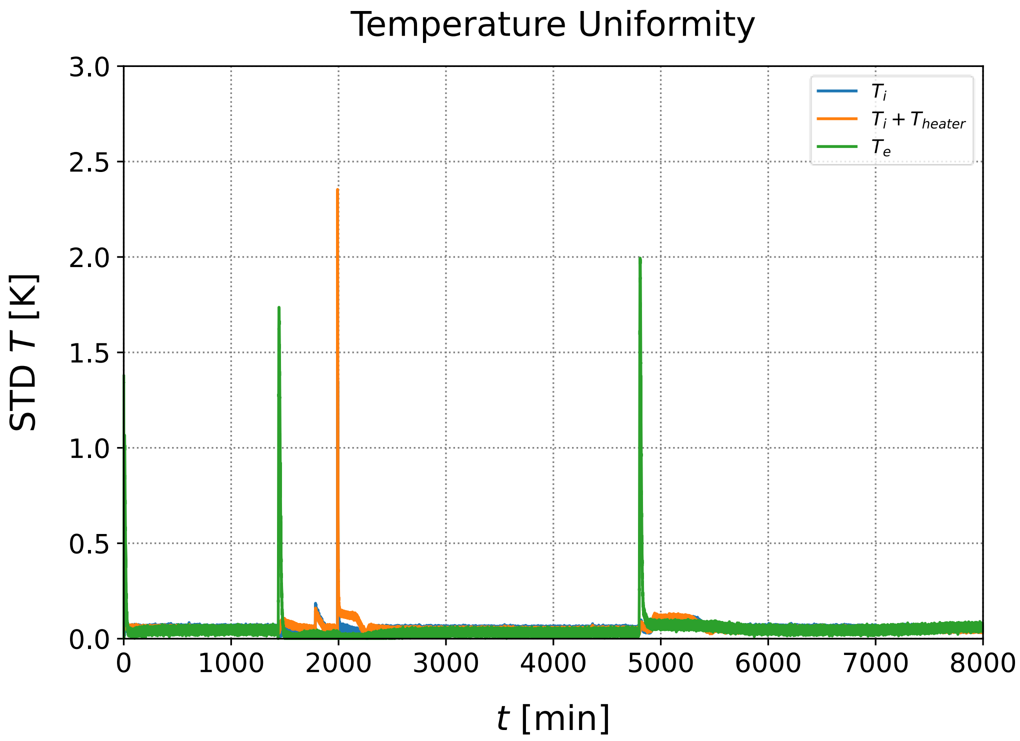
Fraunhofer ICT version of the 3-layer calorimeter

b) Testing – heating / cooling with phase transition **(sample = water, 111 g)**

Temperatures



Temperature deviations inside and outside calorimeter

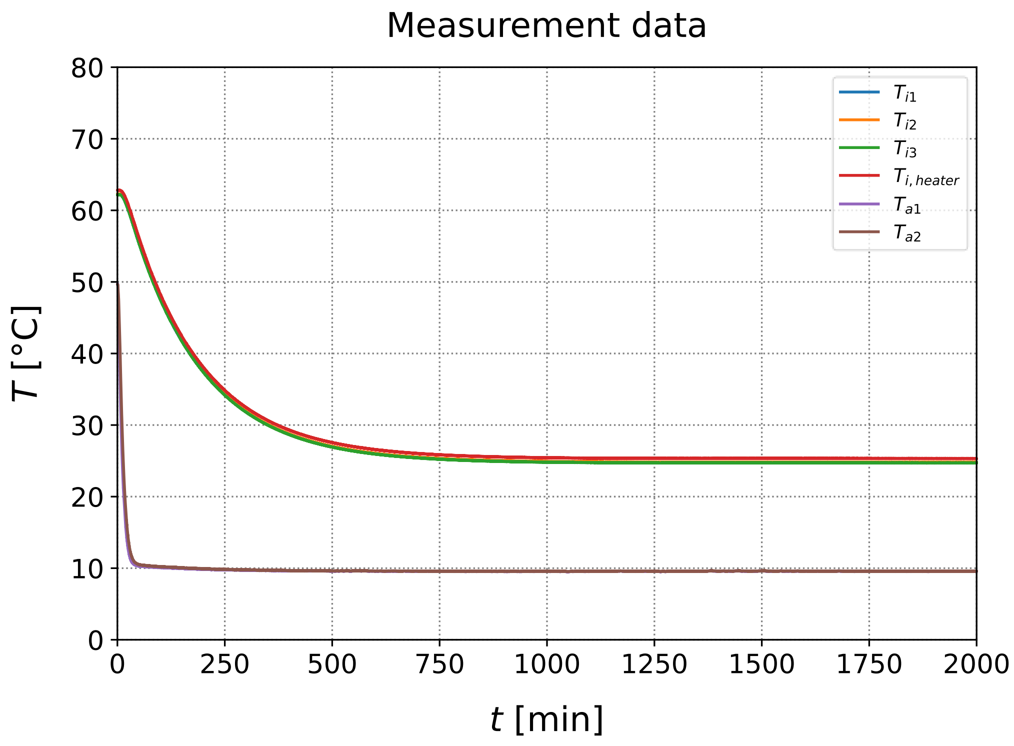


Fraunhofer ICT

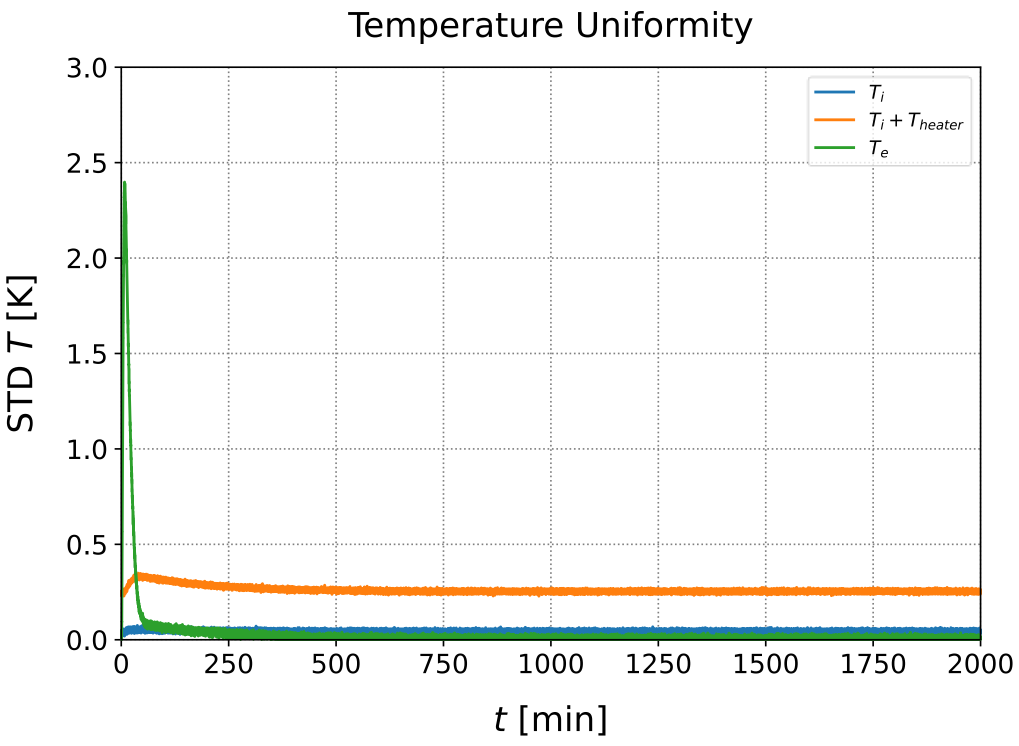
Fraunhofer ICT version of the 3-layer calorimeter

b) Testing – heating / cooling without phase transition with heater **(P = 1 W, sample = water, 111 g)**

Temperature profiles



Temperature deviations inside and outside the calorimeter



Fraunhofer ICT version of 3 layer calorimeter

c) Modeling

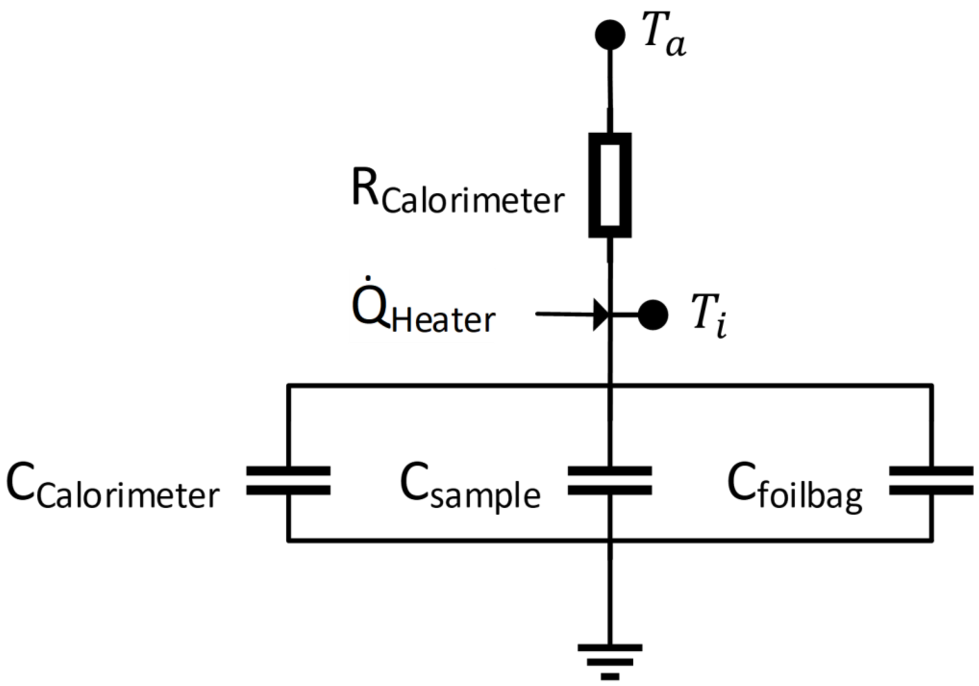
3 layer calorimeter is modeled as thermal node model:

$$\dot{T}_i = \left(\frac{T_a - T_i}{R_{cal}(T)} + \dot{Q}_{heater}\right) \cdot \frac{1}{C_{sample(T)} + C_{Cal}(T) + C_{foilbag}(T)}$$

Stationary $\dot{T}_i = 0$:

$$\frac{T_a - T_i}{R_{cal}(T)} + \dot{Q}_{heater} = 0$$

$$R_{cal}(T) = \frac{T_i - T_a}{\dot{Q}_{heater}}$$

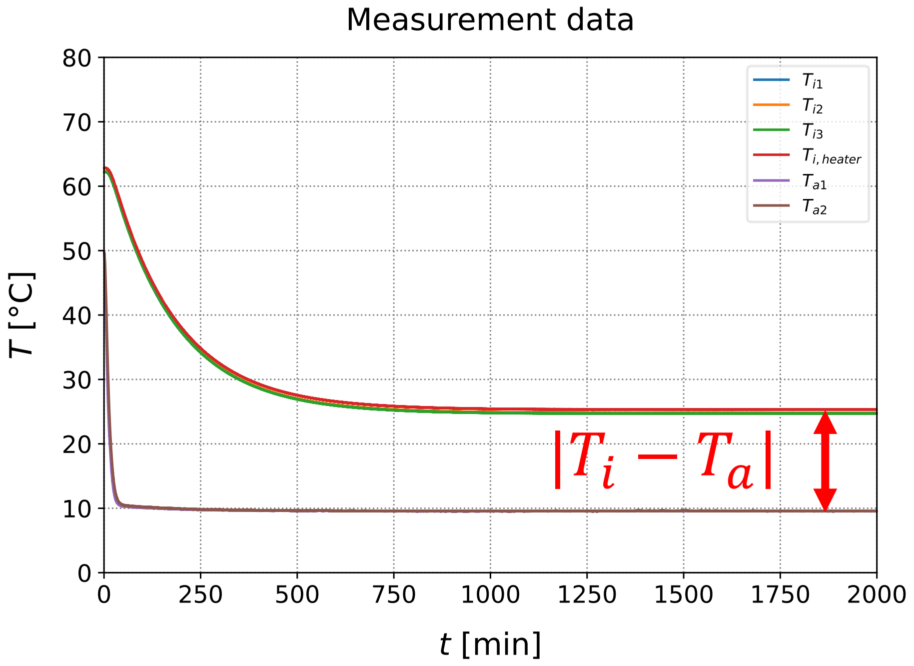


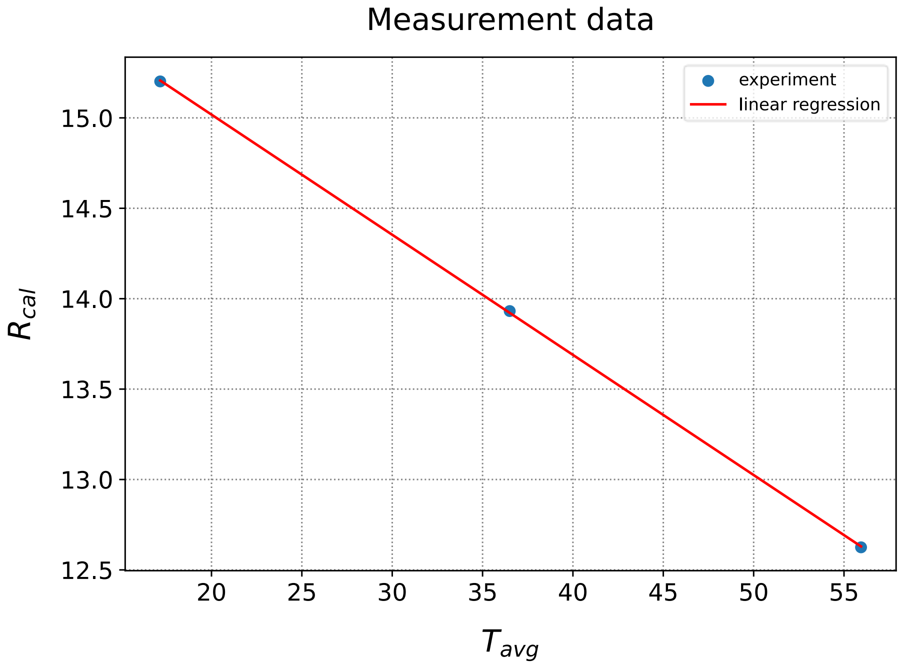
Fraunhofer ICT version of 3 layer calorimeter

d) Calibration – Thermal Resistance

Thermal Resistance

$$R_{cal}\left(\frac{T_i + T_a}{2}\right) = \frac{T_i - T_a}{\dot{Q}_{heater}}$$

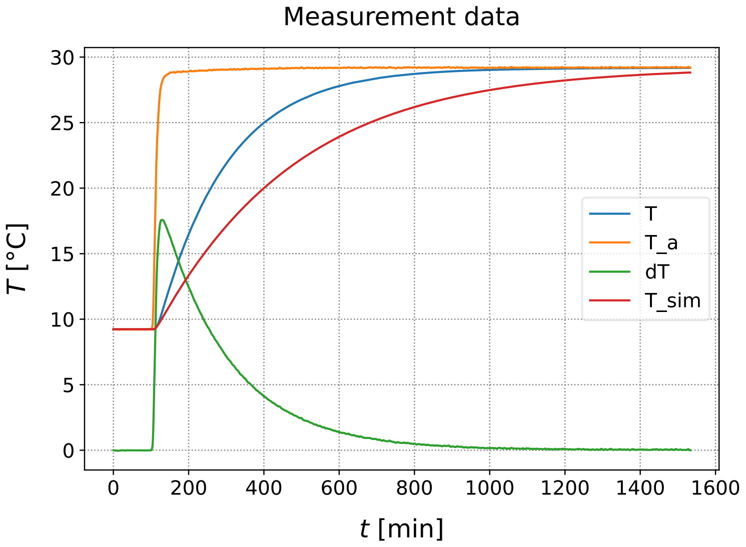


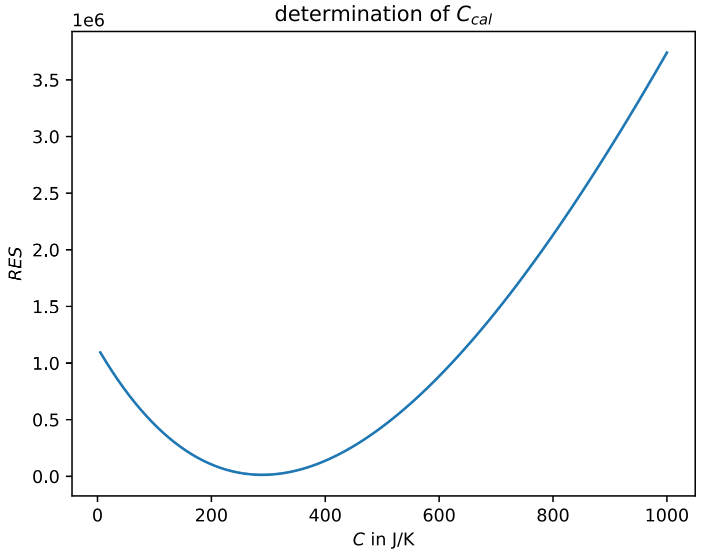


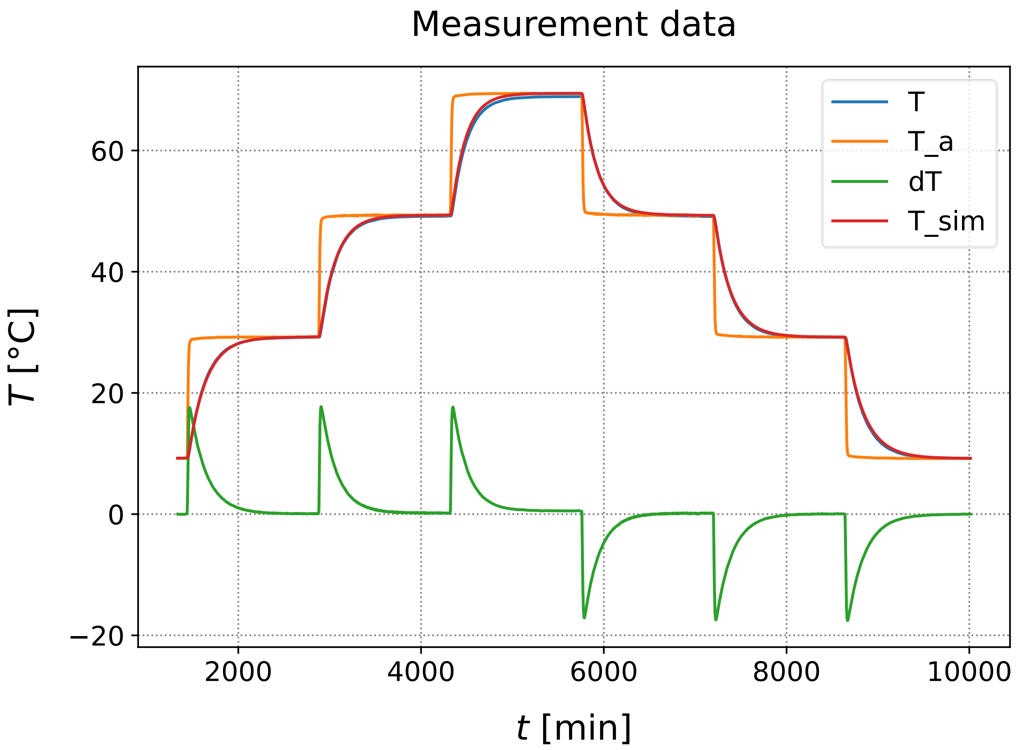
Fraunhofer ICT

Fraunhofer ICT version of 3 layer calorimeter
d) Calibration – Thermal Capacity

Procedure:
- Differential equation for the calorimeter is solved numerically.
- Deviation from simulation results is minimized by adjusting C_{cal}.
- All measurements without phase change are used in this procedure.
- Thermal capacity determined as 289.2 J/K.







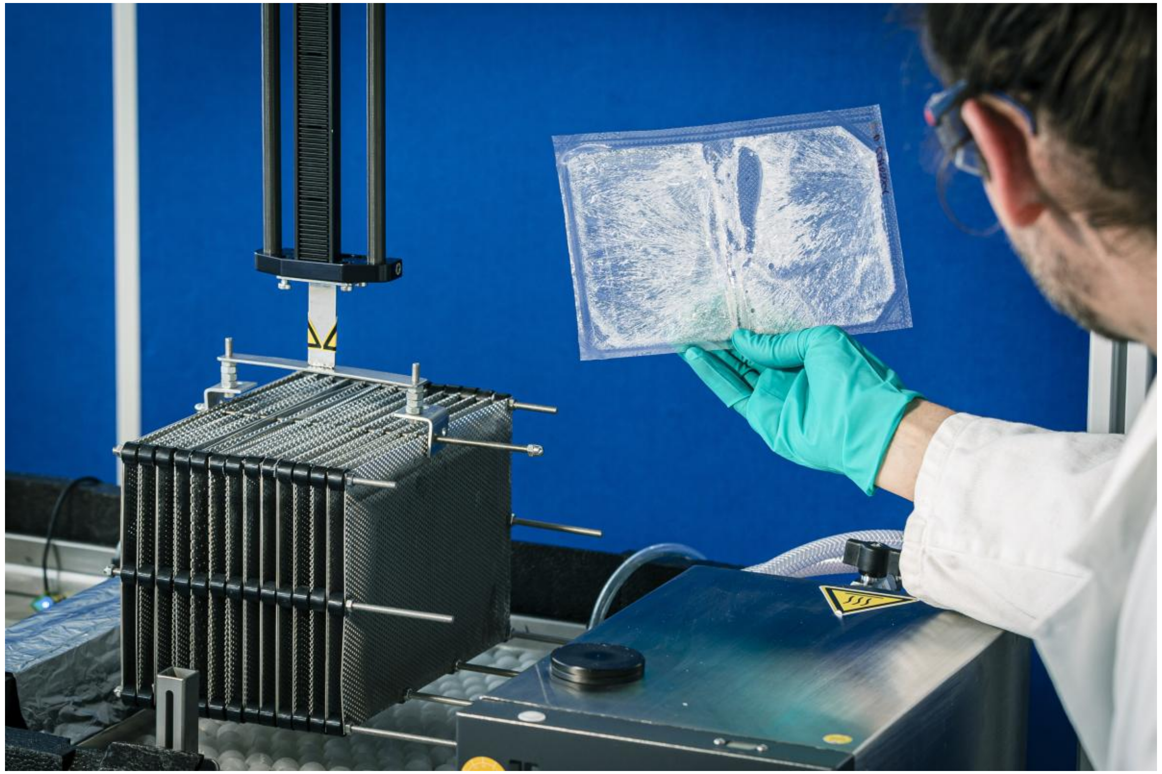
Results and Outlook

Results:

- Temperature uniformity was demonstrated
- Electrical heater was implemented for calibration
- A two-step calibration procedure was developed
- The 3-layer calorimeter is suitable for thermal cycling investigations of salt hydrate-based PCM

Ongoing Work:

- Statistical analysis of measurement uncertainty
- Validation with reference PCM
- Improving accuracy using advanced modeling methods
- Reducing the number of sensors



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