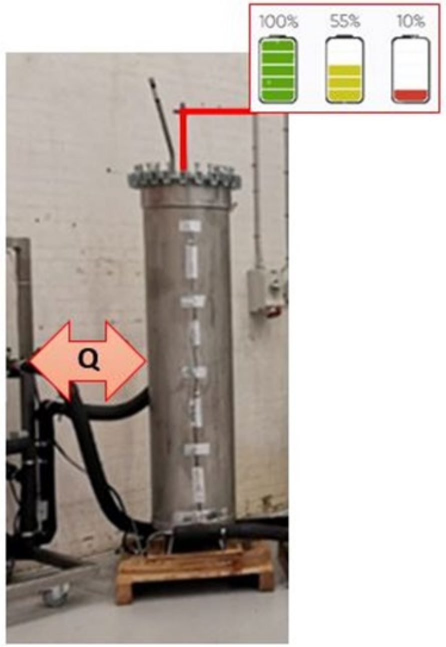
State of Charge Determination Utilizing Material Response in Compact Thermal Energy Storages

Report of intermediate results of work led by:

- Gerald Englmair, DTU, Denmark (for PCM)
- Reda Djebbar, NRCan, Canada (for TCM)

Gerald Englmair, PhD

Assistant Professor
Technical University of Denmark
Department of Civil and Mechanical Engineering (Construct)
Email: gereng@dtu.dk

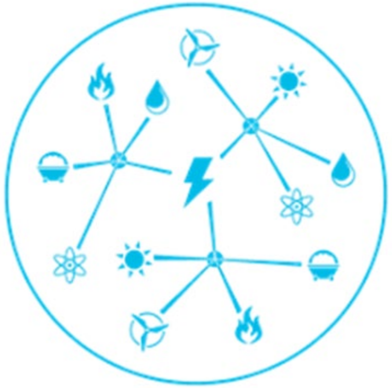


"Thermal battery" - schematic

Why state of charge (SoC) determination?

Storage integration into (digitalized) energy systems requires interaction with advanced (predictive) controls.

→ Reliable SoC determination potentially enables flexibility (reserve market access) of heating and cooling systems



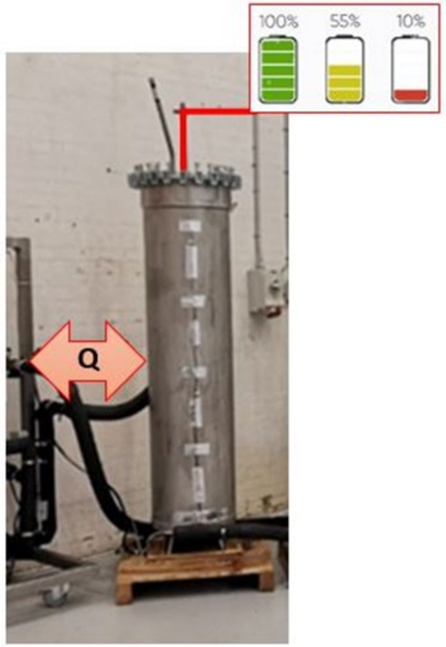
OUR DEFINITIONS:

Thermal Battery: A TES with instantaneous State of Charge determination

State of charge determination utilizes measurement techniques of **material bulk response**

State of charge is a **component level property** (analogy: electrical battery)

$$SoC = \frac{E(t)}{E_{max}} \%$$



"Thermal battery" - schematic

Survey on measurement techniques - Literature

Phase Change Materials (PCM)

magnetic_resoncance
x-ray_imaging
ultrasound
temperature
calorimetry
pressure
heat_flux
infrared_imaging
electrical_resistance
uv-vis_spectroscopy
acoustic_emission
fibre_bragg_gra ting

Thermochemical Materials (TCM)

volumetric_measurement
fibre_bragg_gra ting
electrical_resistance
thermogravimetry
calorimetry
radiography
temperature
x-ray_imaging
ph_value
spectroscopy
uv-vis_spectroscopy
heat_flux
vapour_pressure
magnetic_resonance
ultrasound
ir-spectroscopy
tcm_mass_vessel

Survey on measurement techniques - Institutions

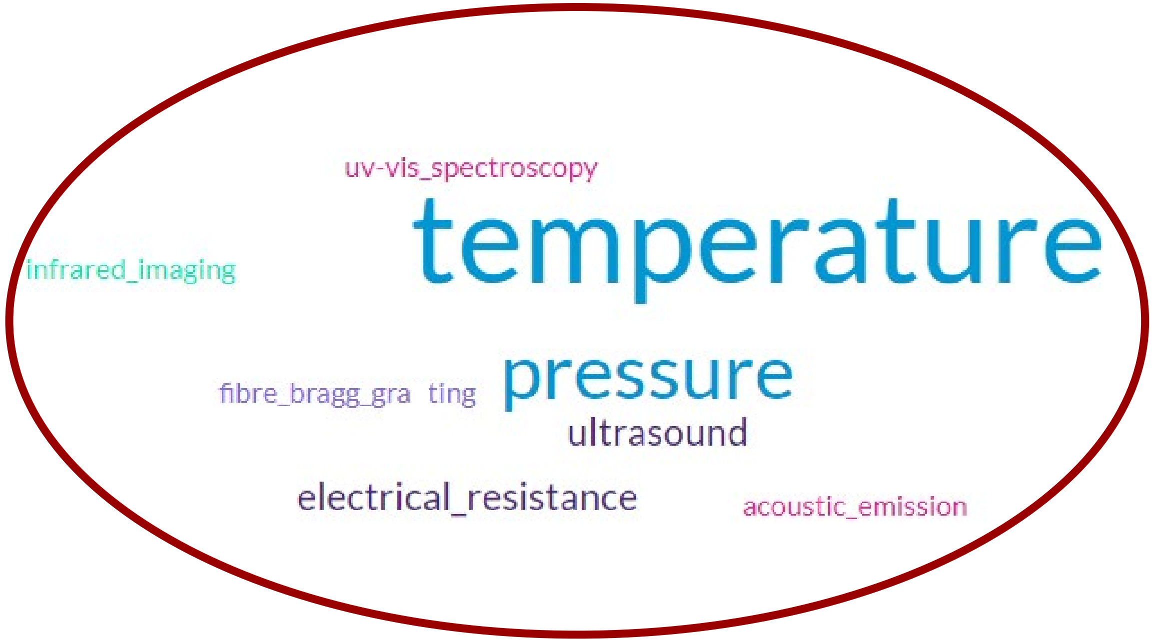
County	Institution	Field
Austria	AEE INTEC	TCM
Austria	University of Applied Sciences Upper Austria	PCM/TCM
Austria	TU Vienna	TCM
Canada	Dalhousie University (LAMTE)	PCM
Canada	Neothermal Energy Storage Inc.	PCM
Canada	NRCan	TCM
Denmark	Technical University of Denmark (DTU)	PCM
Germany	German Aerospace Center (DLR)	PCM/TCM
Germany	H. Mehling	PCM
Germany	University of Bayreuth	PCM
Germany	Fraunhofer ISE	PCM

County	Institution	Field
Germany	ZAE Bayern	PCM
Italy	CNR	TCM
Netherlands	TNO	TCM
Norway	SINTEF Energy Research	PCM
Slovenia	NIC Slovenia	TCM
Spain	Universitat de Lleida (UDL)	PCM
Spain	University of the Basque Country	PCM
Switzerland	Lucerne University of Applied Sciences and Arts	TCM
UK	Birmingham University	TCM
UK	Swansear University	TCM

… 21 contributors in total

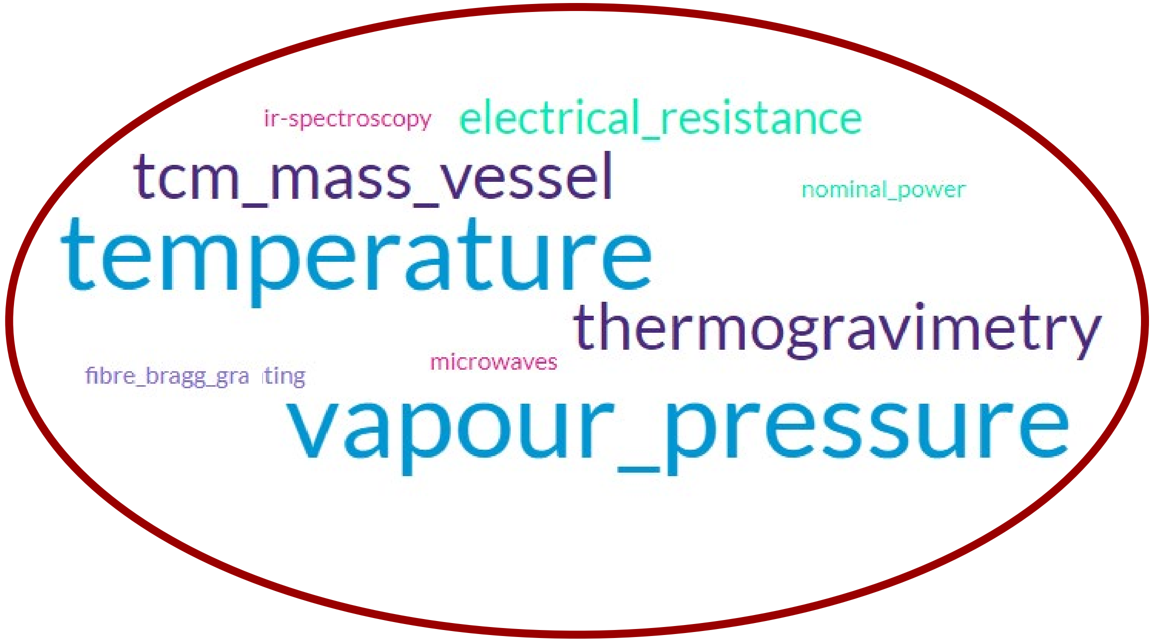
Measurement techniques – applied by Task experts (weighted)

PCM (25 studies)



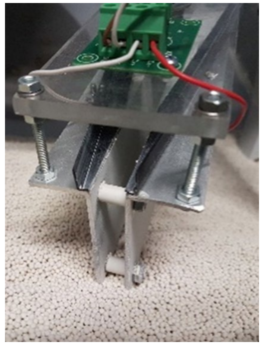
- Mainly PCM bulk temperature determination in labs for storage model development – component level.
- A couple of investigations in material labs

TCM (17 studies)



- Mainly investigations in the material labs
- A few component level investigations

SoC determination – research classification

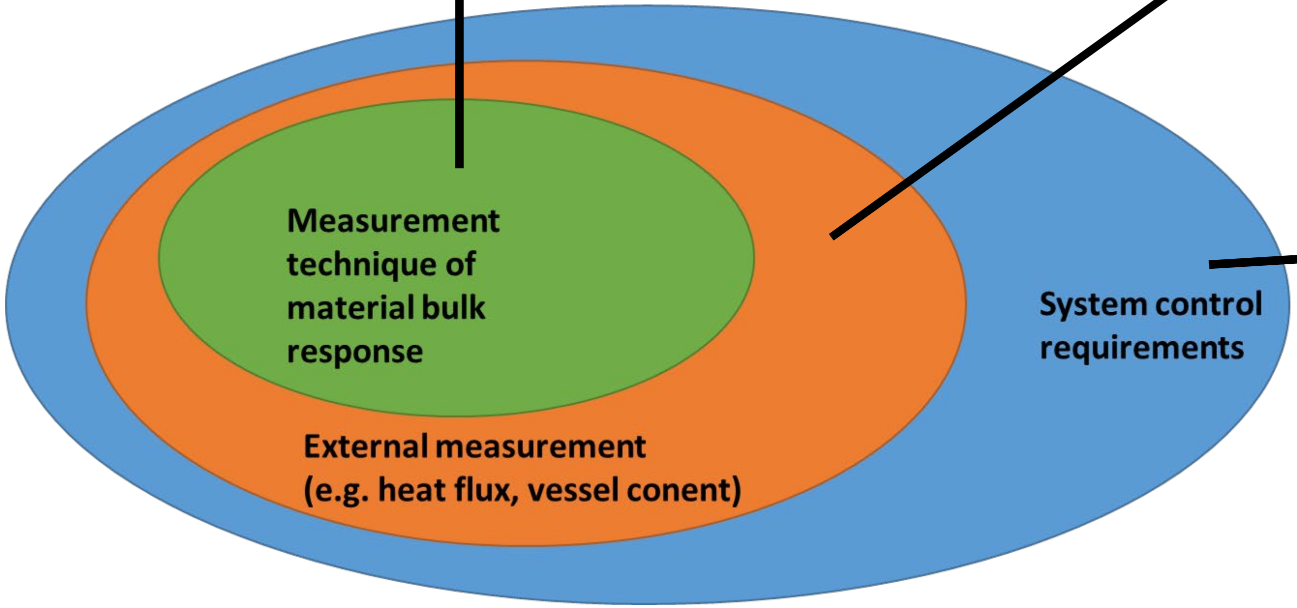


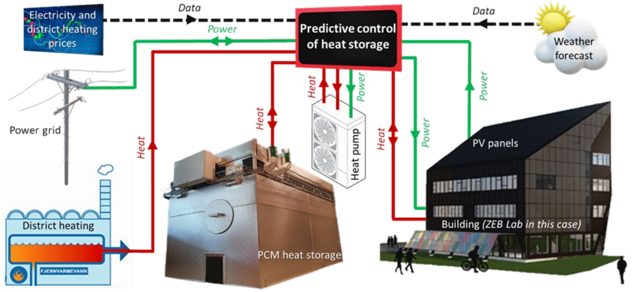
Source: FH Upper Austria

1. Material laboratory: Material response with charging/ discharging can be reproduced

Source: Technical University of Denmark

2. Pilot testing: Correlation of material response to heat flux
→ Calibration at test stand

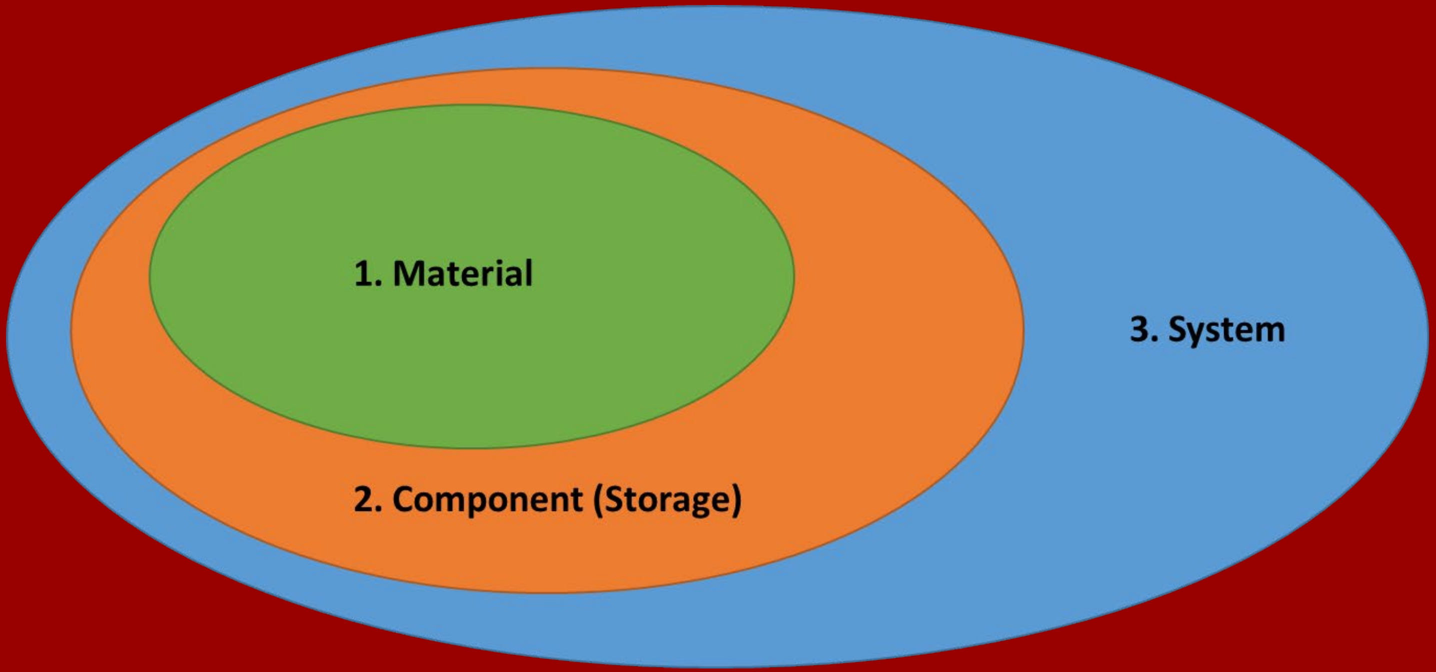




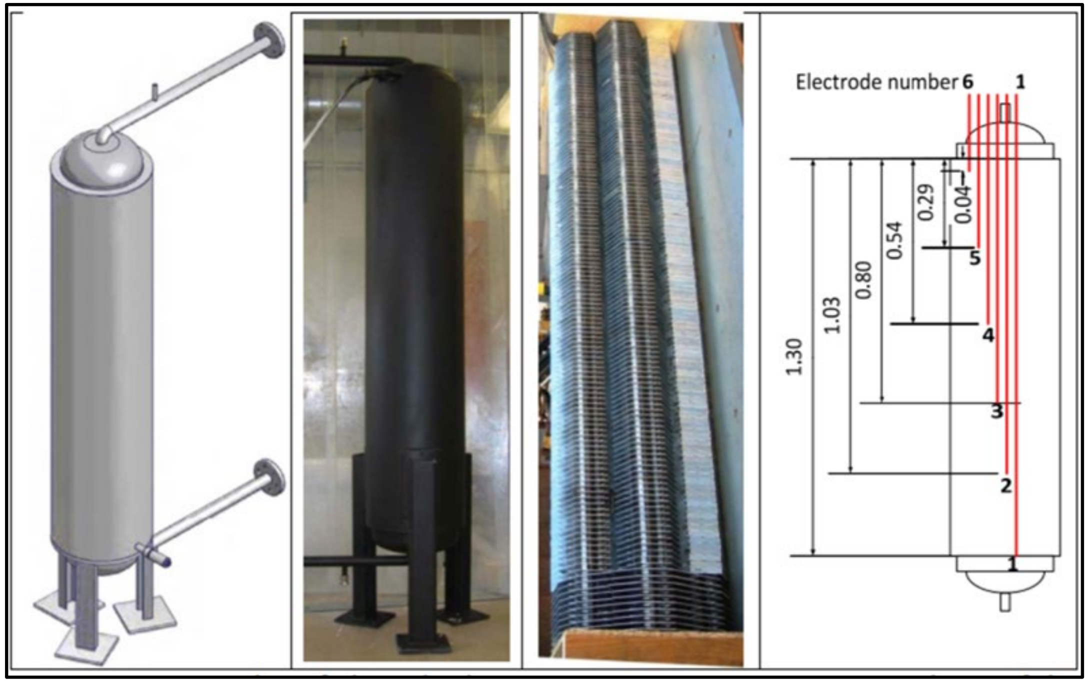
Source: SINTEF; https://www.sintef.no/en/projects/2021/presav-prediktive-styringsstrategier-til-aktiv-varmelagring-i-zeb-laboratoriet/

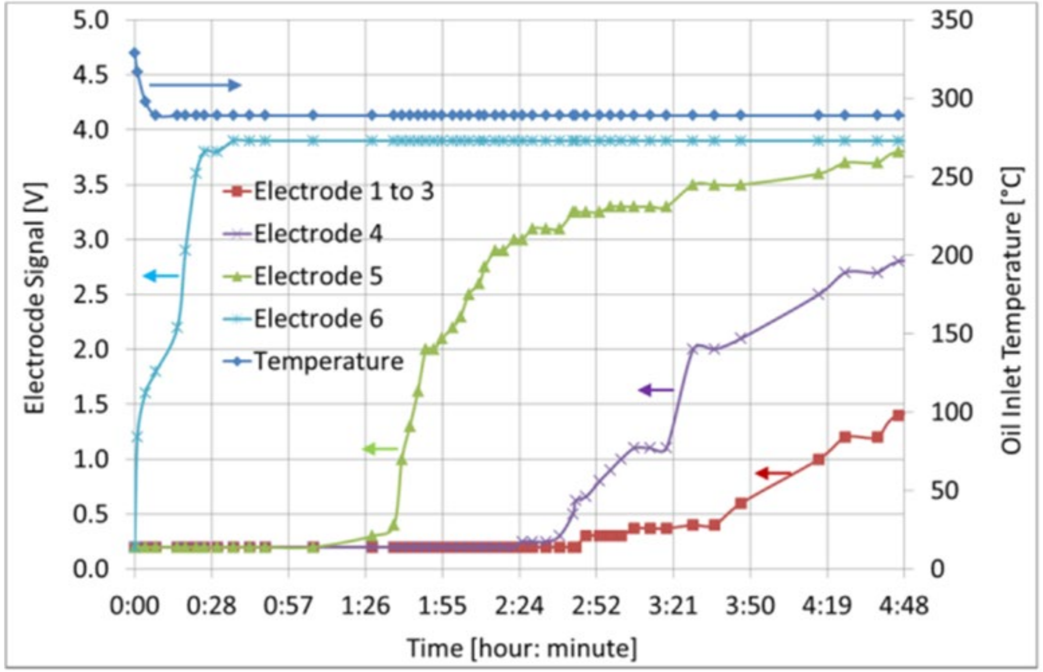
3. Reliable, instantaneous SoC determination enables CTES operation in flexible systems

Exemplary proof of concepts



PCM Material level – Electric resistance





Discharge of storage – containing sodium nitrate; $T_{melting}$ = 306°C.

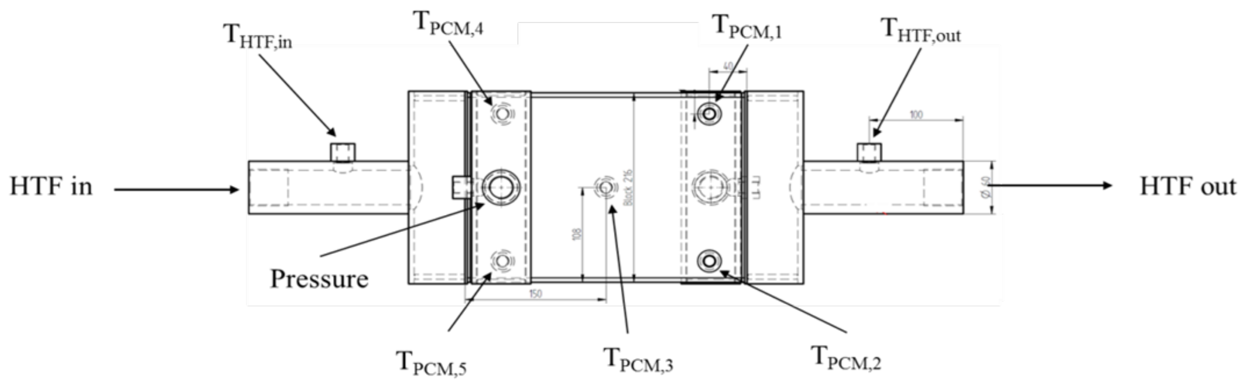
Thomas Bauer, Doerte Laing, Wolf-Dieter Steinmann. Deliverable 15.4: Feasibility of the new PCM measurement system based on the "electric resistance approach in the lab scale demonstrated. SFERA Project, 2012. Available here: https://dokumen.tips/documents/deliverable-report-154-feasibility-of-the-new-pcm-sfera-deliverable-report.html?page=1

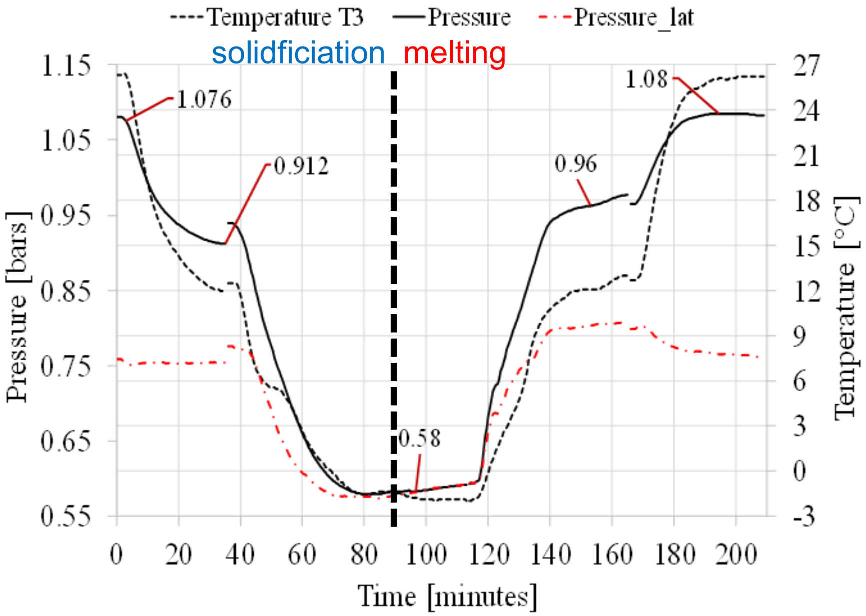
Laing, D., Bauer, T., Breidenbach, N., Hachmann, B., & Johnson, M. (2013) Development of high temperature phase-change-material storages. Applied Energy, 109, 497-504. doi: 10.1016/j.apenergy.2012.11.063.

DLR

Expert: Maike Johnson

PCM Material level – Chamber pressure





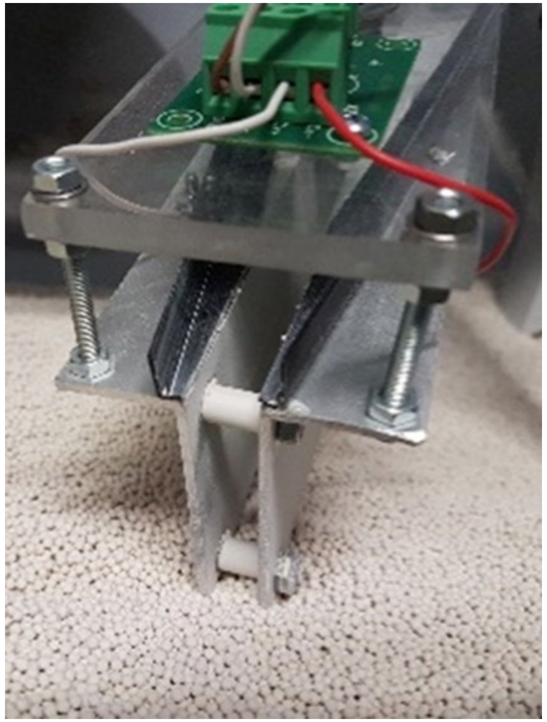
Discharge of storage – containing paraffin; $T_{melting}$ = 4°C

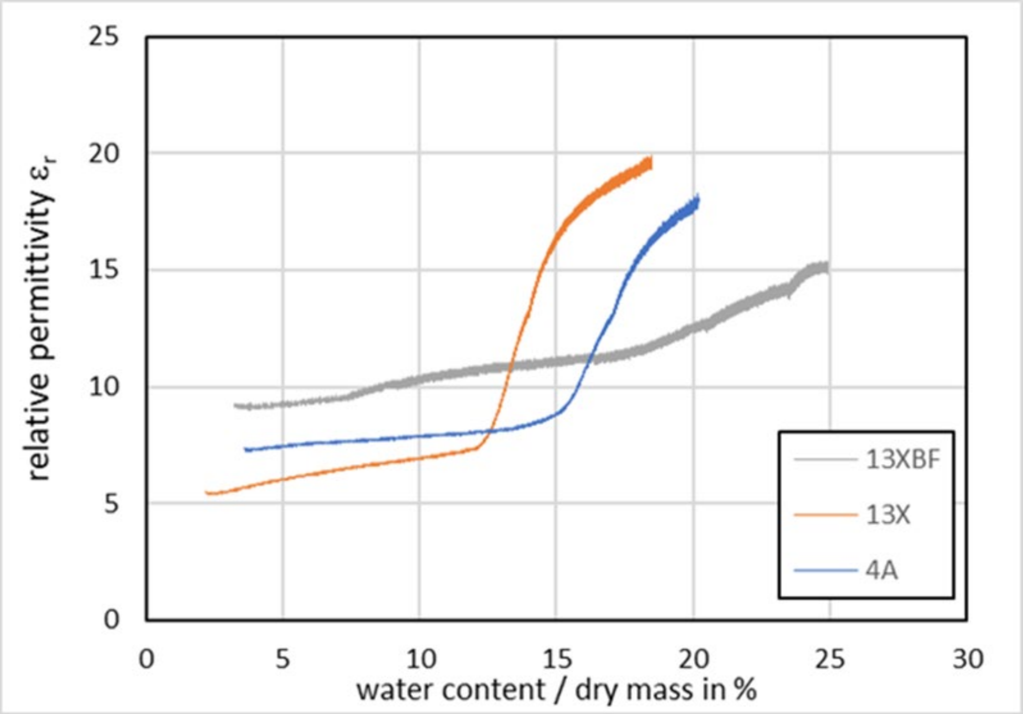
Zsembinszki, G., Orozco, C., Gasia, J., Barz, T., Emhofer, J., and Cabeza, L.C., "Evaluation of the State of Charge of a Solid/Liquid Phase Change Material in a Thermal Energy Storage Tank", Energies, 13, 1425, 2020.

Universitat de Lleida

Experts: Gabriel Zsembinszki, Emiliano Borri

TCM material level – Capacitive sensor applied to Zeolite

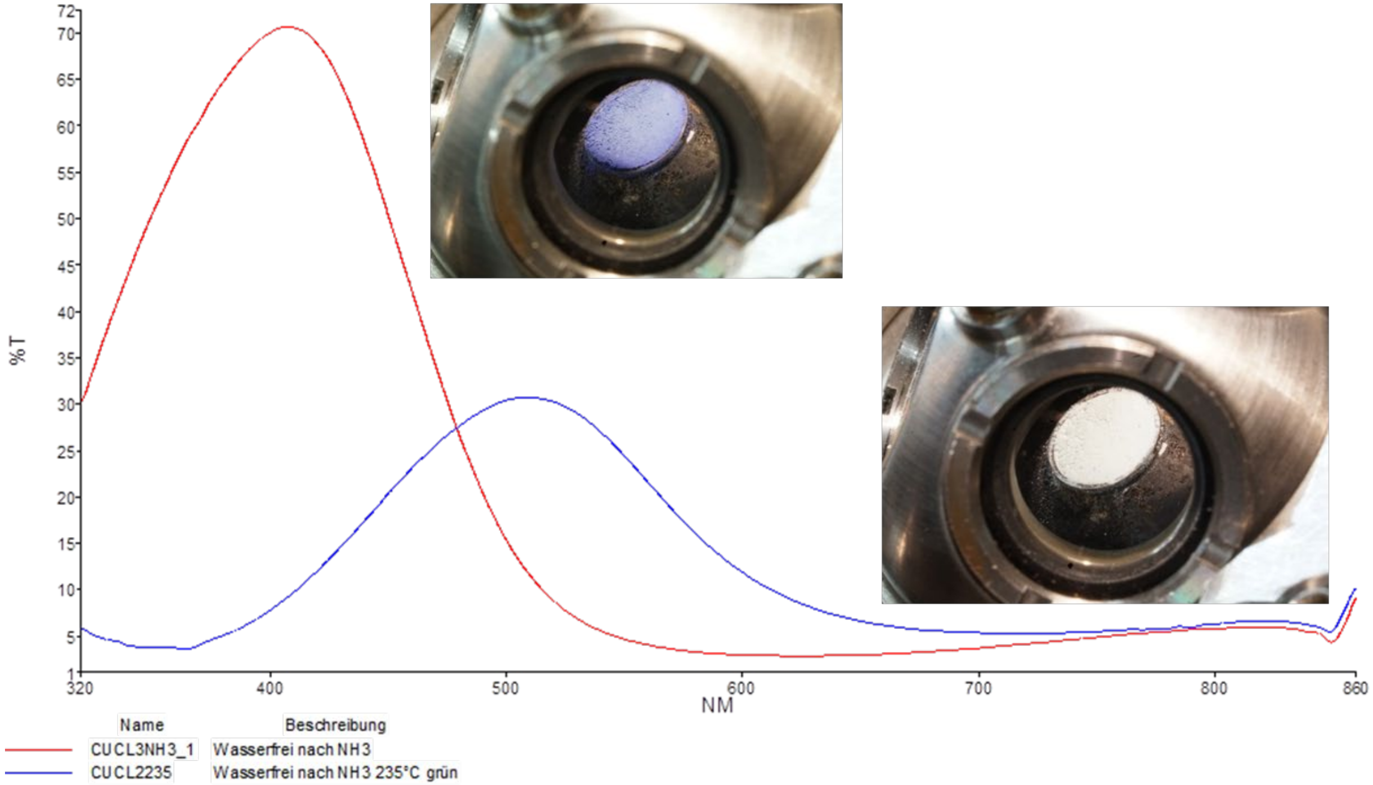




Zettl, B., Kirchsteiger, H., Issayan, G., Wagner, W., " Development of a virtual sensor for state of charge (SOC) evaluation of TCM Energy Storage", Proceedings of Eurosun 2022

Experts: Bernhard Zettl, Gayaney Issayan

TCM material level – UV reflectance



Spectral comparison of solid $CuCl_2$ (blue line) and solid $CuCl_2 \cdot x\ NH_3$ (red line)

Measured in diffuse reflectance with a Perkin-Elmer Lambda 900 UV-vis-NIR spectrometer

aws Prototypenförderung für Universitäten und Fachhochschulen:

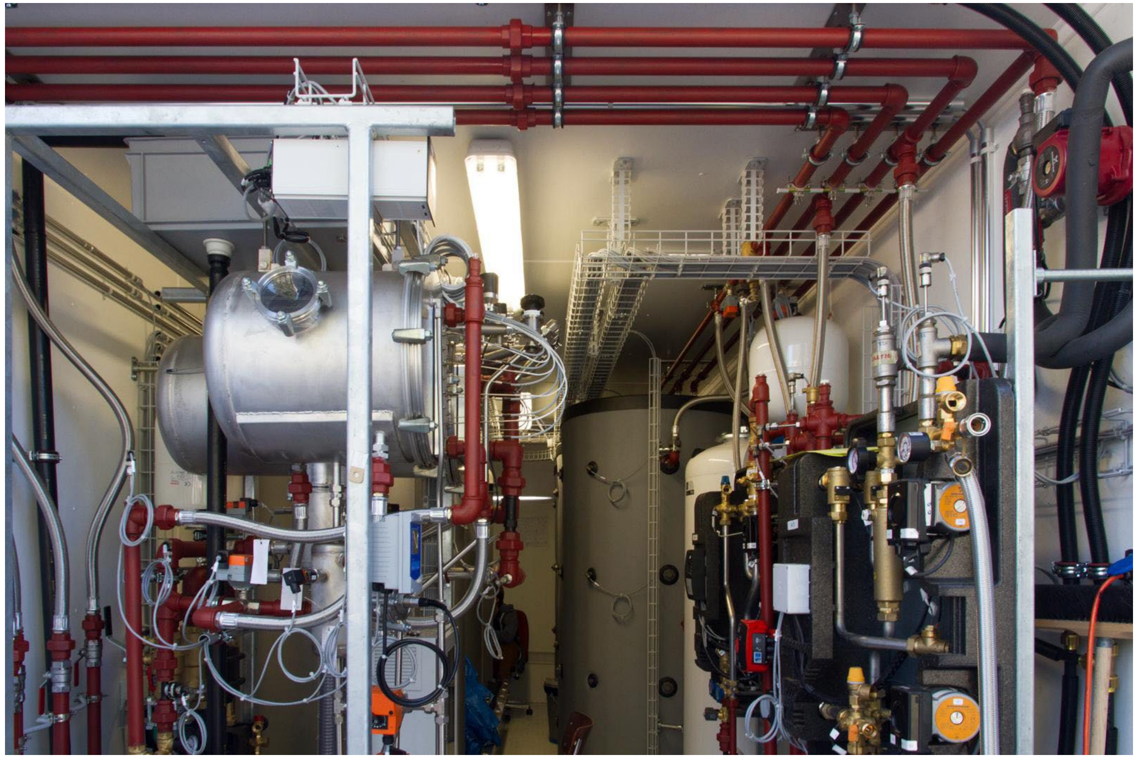
P2409836

Austrian patent filed 12.9.2023:

A 50736/2023

Experts: Peter Weinberger, Jakob Smith, Jakob Werner

TCM Component level – level in tank



The **aqueous sodium hydroxide** heat storage system is designed as a closed transported system consisting of the heat and mass exchanger and the tanks containing the charged and discharged sodium hydroxide and water.

By knowing how much concentrated sorbent is left (level in tank), the state of charge is known.

B. Fumey, R. Weber, P. Gantenbein, X. Daguenet-Frick, Sascha Stoller, Reto Fricker, V. Dorer, Operation Results of a Closed Sorption Heat Storage Prototype, nergy Procedia, Volume 73, 2015, Pages 324-330.

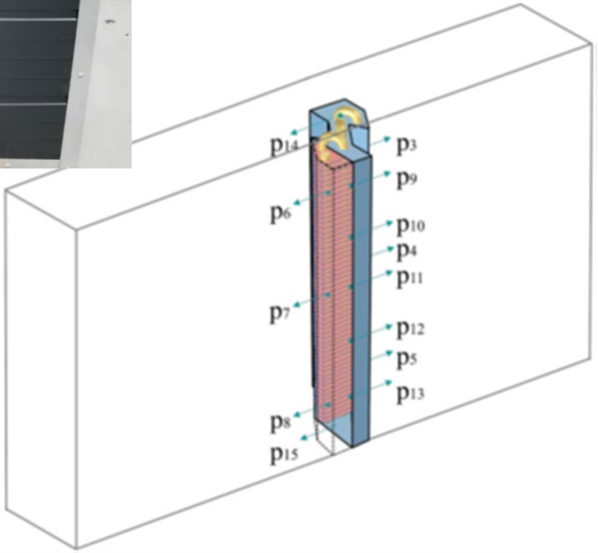
HSLU Hochschule Luzern

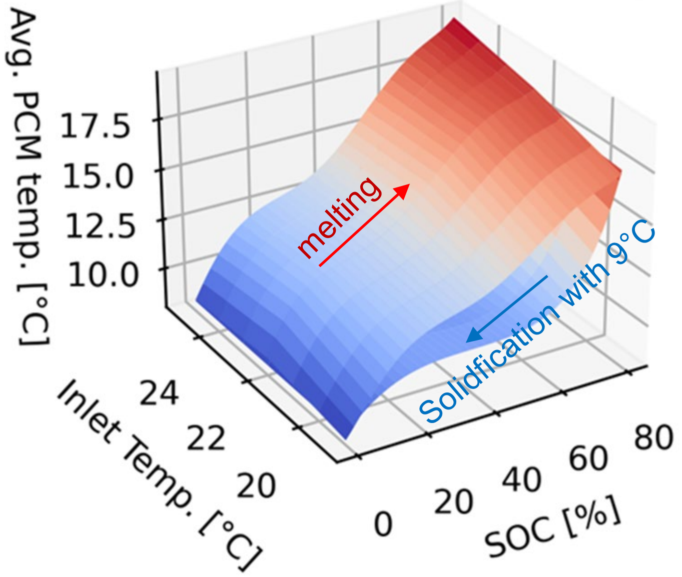
Expert: Benjamin Fumey

PCM Component level – Bulk temperature

Innovation Fund Denmark

Cool-Data



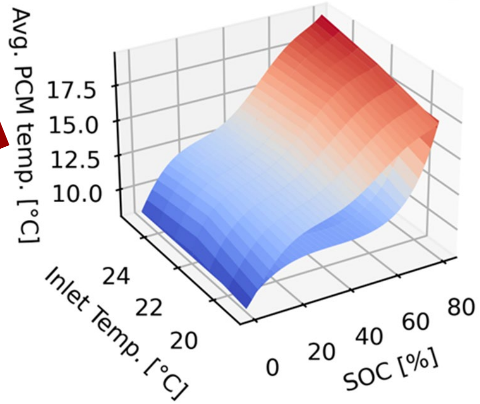


Correlation of PCM bulk temperature to SoC – storage containing salt hydrate; $T_{melting}$ = 15 °C

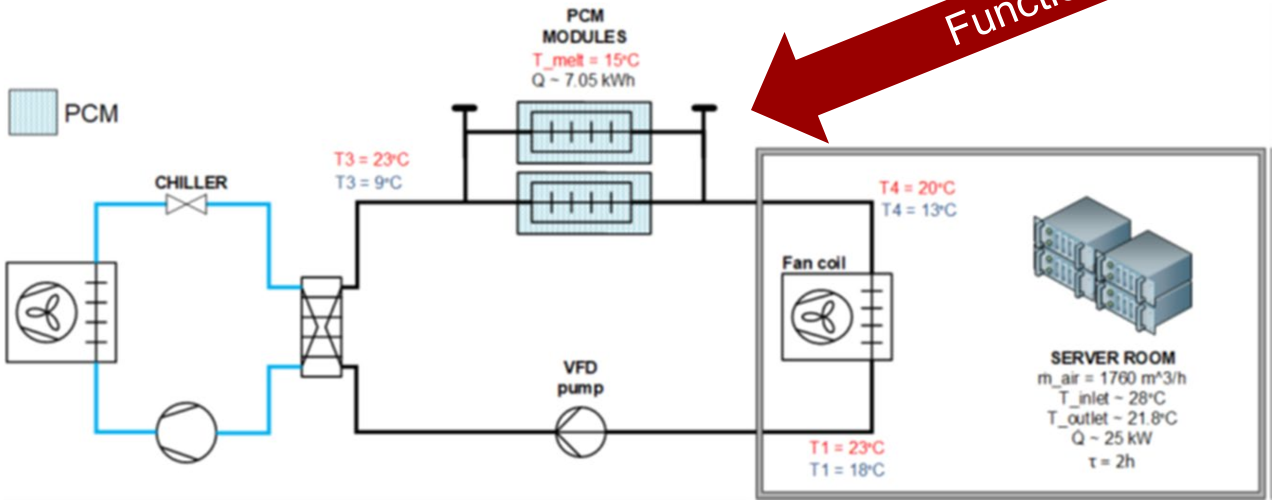
Zhu, Y., Englmair, G., Huang, H., Dragsted, J., Yuan, Y., Fan, J., & Furbo, S. (2023). Numerical investigations of a latent thermal energy storage for data center cooling. Applied Thermal Engineering, 236 Part B, [121598]. https://doi.org/10.1016/j.applthermaleng.2023.121598 https://cool-data.dtu.dk/

Expert: Gerald Englmair

System level: Data driven models (research)



Functions



Innovation Fund Denmark

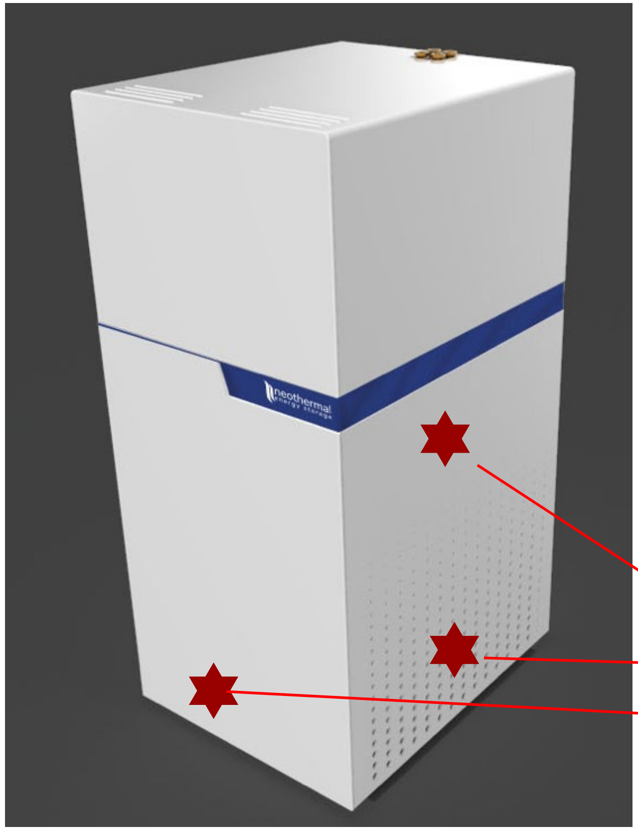
Cool-Data

Server room cooling model to develop a predictive system control algorithm

Zhu, Y., Englmair, G., Huang, H., Dragsted, J., Yuan, Y., Fan, J., & Furbo, S. (2023). Numerical investigations of a latent thermal energy storage for data center cooling. Applied Thermal Engineering, 236 Part B, [121598]. https://doi.org/10.1016/j.applthermaleng.2023.121598
https://cool-data.dtu.dk/

Expert: Gerald Englmair

System application:
PCM heat storage control based on SoC determination



Internal temperature sensors in selected locations (result of control system development)

Storage containing salt hydrate composite; $T_{melting}$ = 58 °C

Based on internal temperature distribution, the following **operation states** are determined:

- **Full cell charge (100% SoC)**
- **Partial cell charge (50-100% SoC)**
- **Nucleation activiation required (≤ 50%)**
- **Cell depleted (0% SoC)**

Utilizing stable supercooling of Sodium Acetate Trihydrate

Source: Neothermal energy storage Inc.; Further information available at https://neothermal.ca/

neothermal energy storage

Expert: Louis Desgrosseillers

Preliminary conclusions

(Final report in fall 2024)

State of charge determination utilizes measurement techniques of **material bulk response**

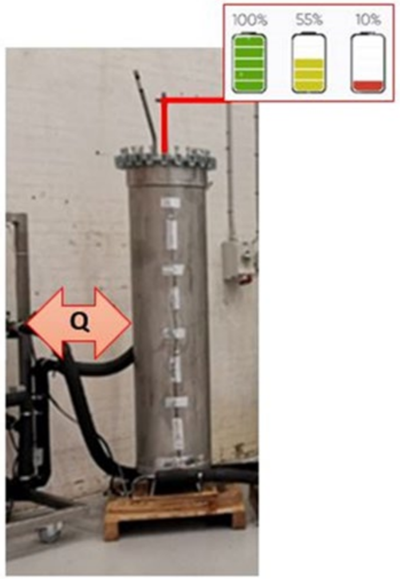
State of charge is a **component level property** (analogy: electrical battery)

Its reliable determination in storages is a prerequisite for **flexible system operation**

PCM: The combination of bulk temperature and heat flux measurement is common in the lab.
→ Novel techniques are potentially less complex in their application (once developed)

TCM: Common: a) Adsorbate content of sorption material; b) Mass of reactants in closed vessels.
→ Novel techniques (non-intrusive) for large & high temperature solutions are important

Interdisciplinary, applied research is needed to **bridge material science and system engineering**



"Thermal Battery"