FLEXIBLE (SERVER) ROOM COOLING WITH COMPACT COLD STORAGE

Summary

Latent Thermal Energy Storage (LTES) utilizing phase change materials (PCM) can serve as an asset for flexible cold supply for buildings as well as for industry in the range of 10-20 ºC. The measured energy storage density in previous research was 5 times higher in comparison to water tanks. This storage solution is also relevant for solar cooling. PCM cold storage for flexibility market access and more reliable cooling systems will be investigated. The main objective is to optimize LTES by enhancing their controllability. For this purpose, a 130-kWh pilot PCM cold storage for safer and flexible server cooling was taken into operation. Data will be monitored and analyzed – serving as basis for a Digital Storage Twin to improve system control. Besides demonstration and learning from practice, development of a state-of-charge (SoC) determination technique is in focus. SoC detection, i.e., a determination of the remaining capacity available in thermal energy storage, is crucial for optimized storage operation via thermal power control. Laboratory experiments will elucidate the optimal measurement technique for large PCM cold storage based on acoustic methods.

Keywords: Thermal Energy, cold storage, phase change materials, flexible cooling.

1. Introduction

The main advantage of phase change materials (PCMs) is the high storage density in small temperature intervals. Ice water storage tanks have been efficiently applied as constant low-temperature heat source (0 °C) in heat pump systems, leading to a higher performance for building applications . For cold storage application, two groups of materials are considered: a) Inorganic PCM (water, salt hydrates, eutectic mixtures); b) Organic PCM (paraffin and fatty acids). (Cabeza et al., 2011). Zhu et al., 2023 have shown that both salt hydrates and paraffinic products can be utilized for PCM cold storage with a resulting energy storage density five times higher than with water tanks. However, paraffinic products were found to perform better in terms of heat transfer.

Both, data center cooling and (solar) domestic cooling are important applications for compact thermal energy storage utilizing PCM (Van Helden et al., 2023) – where storage temperatures in the range of 10-20 °C are required. Cold storage for server room cooling (small and medium-sized data centers) aims to provide operation flexibility of compressor-driven chillers and to cover a constant cooling demand for several hours to increase cold supply security. The International Energy Agency has estimated that data centers used between 220 and 320 TWh of electricity (IEA, 2023).

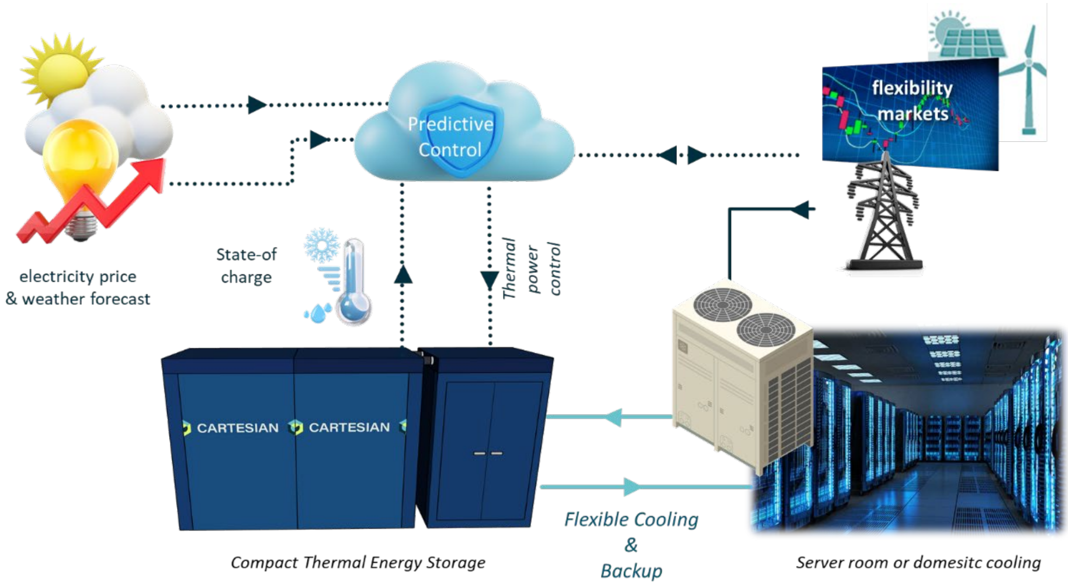
The integration of PCM cold storage in server room cooling systems has several advantages: For example, reduction of cooling electricity costs load shifting, reduction of investments costs in chiller through peak shaving as well as additional revenue streams by participating in power reserve markets with energy flexibility. This leads to more climate-neutral heating and cooling systems by providing thermal comfort and climate neutral processes while reducing Europe’s dependence on fossil fuels. Also, decentralized thermal storage potentially enhances the electrical grid resilience.

2. Pilot installation for flexible server room cooling

A PCM cold storage pilot (Fig. 1a) with approximately 130 kWh capacity was installed in an existing server room cooling facility. To increase the flexibility of chillers connected to water/air heat exchangers in the server room (baseload approximately 50 kW) – PCM with melting temperature of 15–16°C is used. The goal is to cover cooling demand for approximately 2 hours and in this way to maximize the utilization of solar and wind electricity from the grid, while increasing cold supply security and more constant electrical chiller operation.

The pilot was installed in March 2026 and will be operated to demonstrate how thermal energy storage reduces system costs through flexibility. Also, the operation behavior regarding optimized operation of electric chillers (e.g. considering electricity prices) as well as maximal usage of free cooling via dry cooling towers will be investigated.

a) 



b)

Fig. 1: a) PCM cold storage prototype including hydraulic skid; b) Schematic overview of system operation – PCM storage will serve for more flexible operation of electric chillers and to maximize free cooling.

As shown in Fig. 1b, monitoring and controlling the system in relevant environment will provide essential operational data to better operate PCM cold storage. To understand how and when to best charge/discharge the cold storage, continuous collection and forecasting of electricity price and heat demand data are needed. The integration of State of Charge Determination and Thermal Power Control is the basis for optimal storage operation. Model predictive control is an advanced process control method suitable for processes with integrated thermal energy storage, which requires monitoring systems to give an accurate estimate of the SoC of the cold storage. Data-driven algorithms could have the potential to act upon the required thermal output, based on a reliable charge determination. With the gathered monitoring data, a digital twin will be created – allowing simulation of different system scenarios and optimal component sizing (chillers, PCM cold storage, etc.).

The knowledge gathered from pilot testing will be used by industrial project partners to develop products – Compat Thermal Energy Storage and system controller.

3. Reliable state of charge determination as key for system operation

Thermal storage can serve as an asset in centralized heat supply for buildings (water tanks, water pits) as well as in decentralized (solar) cold and high-temperature storage (e.g., PCM) for industry. Charge detection is crucial for optimized storage operation schedulers (supported by artificial intelligence) linked to electrical and thermal grids. Thus, an instant and reliable measurement technique would pave the way for optimal operation of grids coupling different energy sectors – including power to heat and waste heat utilization from industry.

The state of charge of electrical batteries can be reliably detected via voltage or current measurements. For latent thermal energy storage, however, charge determination is based on heat flux or temperature measurements, which have several shortcomings (IEA ES Task 40, 2025):

- Temperature readings are punctual and cannot represent a larger volume
- Liquid and solid fractions change during PCM storage operation. During latent phase transformation, temperature readings don´t correlate to the storage´s energy content
- Heat flux measurements are expensive and heat loss determination is difficult

From a control perspective, the ideal sensor measures instant, not single points and is applicable for latent storage with volumes of a few liters to thousands of cubic meters.

In our research we are investigating different parameters directly linked to acoustic bulk response such as speed of sound and acoustic wave dispersion in vessels containing liquid and solid PCM. The focus is on potential low-cost technology. A 10- liter test setup for acoustic wave dispersion connected to a constant temperature heat source (Fig. 2a) has already been built and is currently tested for different parameters (Fig. 2b). When a proof of concept is achieved, there is an opportunity to implement the developed measurement technique in the pilot PCM cold storage. Obtained results will contribute to activities in IEA ES Task 47 on "Components for Thermal Energy Storage" – which is also the best platform for gaining knowledge/ overview of new approaches in ongoing research.

a)

b)

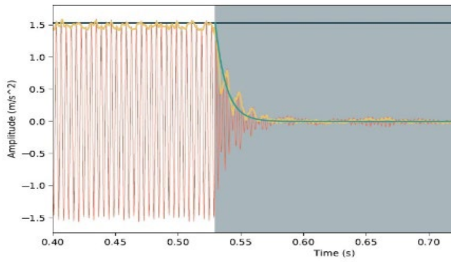


Fig. 1: a) State of charge determination test setup with cold/heat source to solidify/melt the phase change material in the 10-liter vessel. b) Exemplary data obtained from the tests: Step response.

4. References

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