MULTI-PCM THERMAL ENERGY STORAGE SYSTEM FOR HOT WATER AND SPACE HEATING: DESIGN, SIMULATION AND MEASUREMENTS

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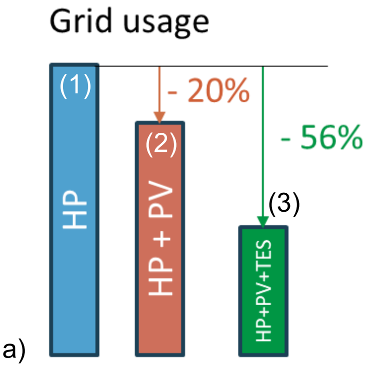
Introduction

To address climate change, massive investments have been made in solar energy production; however, it has a phase mismatch with the buildings' thermal needs that correspond to 80% of their energy consumption [1]. A study by Li et al. (2022) [2] evaluated how combining photovoltaic (PV) with Thermal Energy Storage (TES) can alleviate this mismatch for a typical single-family house using a Heat Pump (HP). For Frankfurt, their results show that PV sized to match annual building consumption reduces grid energy use by about 56%, while integrating both PV and TES.



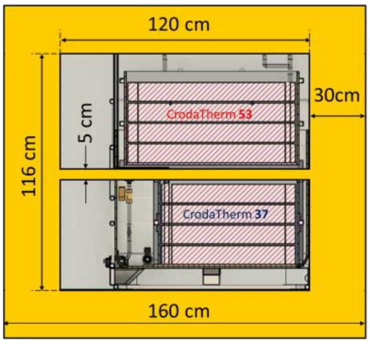


Figure 1: a) Annual grid energy use of the HP of a reference single-family house in Frankfurt for three cases: (1) without solar power, (2) with PV panels and (3) with the addition of TES. The results show that solar power becomes truly effective only when coupled with TES. b) Schematic of the PCM storage structure that was simulated, built and experimentally characterized to enhance the solar power usage with air-water HPs.

Our approach employs multiple Phase Change Materials (PCM) [3] [4] as thermal storage for both Domestic Hot Water (DHW) and space heating and integrate them in the insulated structure of Figure 1b). This enables night and winter heating using air-water HPs powered primarily by solar energy at their highest CoP. Finite elements simulations were used to compare storage configurations, leading to the construction of an optimized ~1 m^3 PCM tank with phase changes at 37°C (heating) and 53°C (DHW), whose performance is presented below.

Simulation

An annual simulation was conducted to assess the optimal utilization of solar energy for a reference house of two apartments located in Fribourg (CH) for the years 2022–2023. The building complies with the Swiss Minergie-P standard. It has external walls with a U-value of 0.15 W/m^{2}K and 90m^2 of south-facing PV panels. Thermal storage performance was modelled using ANSYS, while the reference energy demand was determined using the LESOSAI software.

Three 2.6m^3 configurations were evaluated: two of them used 2 PCMs (37-53°C) with/without intermediate insulation and the last one used 3 PCMs (24-37-53°C) separated by an insulation. As shown in Table 1, the 2 PCMs tank with intermediate insulation showed the largest storage capability during the cold season. This is due to due to the minimal volume loss for the insulation between both PCM zones and the weak heat transfer through it, what is particularly advantageous for DHW.

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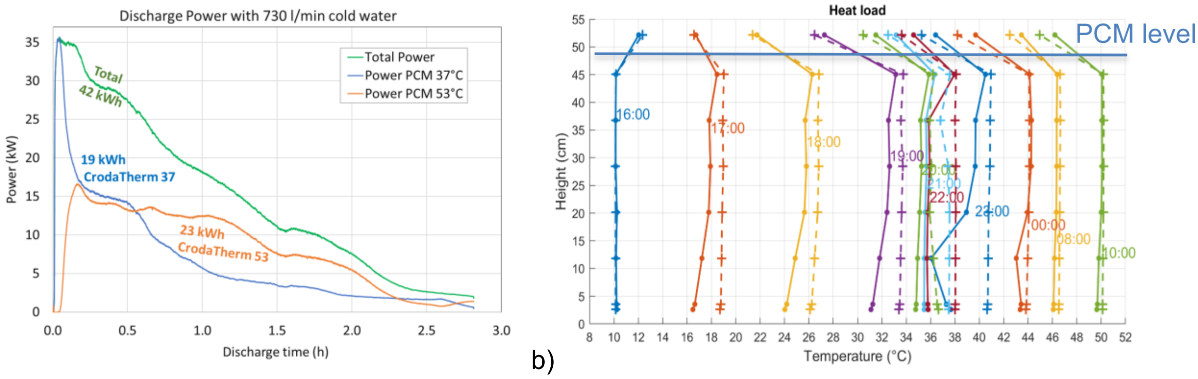
Table 1; Three PCM configurations and their storage capacity for DHW and space heating

Structure	DHW storage	Space heating storage
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	187 kWh

Further simulations as a function of the storage size showed that thermal autonomy can be achieved for capacities > 542kWh. However, the reference house being highly insulated, only 3,700kWh are saved, while a 50kWh storage system would still provide a savings of 2,500kWh, demonstrating that relatively small PCM storage units can substantially reduce heating demand in well-insulated buildings.

Measurement results

The structure of Figure 1b) has been realized with 4 radiators in 2 PCM tanks and 30 cm insulating layers with 0.03 W/(m K) conductivity. Thermal storage is performed by 370 liters of PCM: CrodaTherm 37 and 53 and 260 liters of water. After having heated both tanks to 60°C, a discharge with 730 l/min cold water showed 42kWh of thermal storage and a maximal power of 35kW (Figure 2a). The stability of the thermal performance was attested by 100 cycles with 1% power and 2.2% energy fluctuations.



a) b)

Figure 2: a) The serial discharge shows a 19kWh discharge of CrodaTherm 37 followed by the 23kWh CrodaTherm 53 discharge. b) PCM temperature profile during loading of the lower tank. The dashed and solid lines respectively close to the water entrance and exit show slightly higher performances of the upper radiators.

The temperature of the whole PCM remains the same during several hours (un)loading during phase change as shown by Figure 2b. Before and after phase change, a difference of 2°C is observed. We can also see that the region between the 2 lowest radiators is the last to fully melt after 7 hours heating. Heat losses of 70W have been measured during storage at the phase change temperature. This means that 25 days are necessary to fully discharge the thermal tank, what illustrates the advantage of negligible heat loss for long-term PCM storage.

References

[1] European Environment Agency, "Decarbonising heating and cooling - a climate imperative," 23 February 2023. [Online]. Available: https://www.eea.europa.eu/publications/decarbonisation-heating-and-cooling.

[2] Y. Li, G. Rosengarten, C. Stanley and A. Mojiri, "Electrification of residential heating, cooling and hot water: Load smoothing," *Journal of Energy Storage,* vol. 56, 2022.

[3] B. Ashley, M. Khzouz, T. Statheros and E. Gkanas, "PCMs for Residential Buildings: Review," *Buildings,* vol. 7, no. 3, 2017.

[4] J. Robadey and R. Richard, "A new heat and cold storage system to enhance the thermal autonomy of residential buildings," *J. Phys.: Conf. Ser.,* vol. 2600, 2023.