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Monitoring results of heat pump application with PCM storage

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Abstract

In the “SunStore” project, a new heat storage based on phase change materials (PCM) is being installed, tested and evaluated under real conditions. The PCM is filled in capsules in the buffer storage tank. In particular, the project aims to investigate the advantages of PCM storage in terms of achieving high self-consumption of PV electricity with heat pumps. The pilot system is equipped with an air-to-water heat pump and PCM in capsules, which are filled into the existing heating buffer storage. The system is used to evaluate experiences in real operation over three heating periods. A reference period with a conventional water buffer storage and each one heating period with two generations of PCM capsules have been evaluated. Results show an increase in PV self-consumption and self-sufficiency in heating, which, however, cannot be exactly quantified due to changing boundary conditions in the heating periods, but verified by daily storage temperature evolution. The increase of the seasonal performance factor could not be verified due to limitation in the pilot plant but seems reachable with control improvements. In the meantime, the capsule technology is no longer being pursued, but a PCM-filled storage is being launched on the market as a successor product and further development. The new storage concept addresses the limitations found in the former capsule concept by the monitoring project. The charging and discharging capacity is considerably enhanced by the new concept. Moreover, since no PCM can be in contact with the water due to the separation by a heat exchanger, DHW heating is possible.

Keywords: PCM storage; PV self-consumption; heat pump; monitoring;

1. Introduction

Using the high energy density of the phase change of materials for thermal storage purpose has already gained a lot of interest in research, among many other projects also as international collaboration in IEA Tasks, e.g. [1]. Advantages of phase change materials (PCM) for thermal storage are the heat transfer at nearly constant temperature and the reduced storage volume due to the high energy content in the range of the phase change. PCM are already in application for instance as micro-encapsulated spheres integrated in building materials, and ice storages in cooling applications also use the phase change to name only a few applications.

A lot of scientific work focuses on material and system development, often limited to a few hundred cycles, giving limited assessments on long-term and real-world performance. A current review of a large number of PCM projects clearly concludes that a major research gap lies in the transition to large-scale, validated real-world applications [2]. This is an area where not many studies have been published. The paper addresses this research gab by measurement of macro-encapsulated PCM capsule retrofitted in a water storage for heating buffer application in order to enhance PV self-consumption by extended heat pump operation in a single-family house (SFH).

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1.1 Project outline and objectives

The manufacturer of the investigated macro-encapsulated PCM is a spin-off of the Competence Centre for Thermal Energy Storage (CC TES) at Lucerne University of Applied Sciences and Arts (HSLU), which was founded with the aim of commercialising PCM based thermal storage. In collaboration with HSLU, the manufacturer has developed various salt hydrate-based PCMs designed for typical temperature ranges of heat pumps in buildings. As part of this project, the technology has been tested in a real-world pilot plant. Measurements are evaluated at the university project partner at OST in a publicly funded P&D project.

The project objectives include the following individual objectives related to the manufacturing, quality assurance of the capsules as well as the real-world performance of the PCM with the following key performance indicators (KPIs):

- Production of the PCM capsules required for the pilot plants
- Recording of all relevant mass and energy flows for a complete system balancing, determination of the seasonal performance factor (SPF) and heating self-sufficiency over four heating periods
- Evaluation of the KPIs and comparison of the PCM system solution with the state-of-the-art

The success factors comprise the following objectives:

- Self-consumption is to be increased by 10% compared to the reference measurement.
- Heating self-sufficiency is to be increased by 50% compared to the reference measurement.
- The grid consumption of the entire building is to be reduced by 10% compared to the reference measurement.
- The seasonal performance factor (SPF) of the heat pump is to be increased by 2–4% over the heating period.
- The knowledge regarding the longevity of the capsules shall be expanded.
- Ideal control parameters for the most effective use are to be determined.

To review the success factors, the parameters and corresponding data sources are listed in Table 1. A measurement system for the monitoring of the pilot plant was installed to measure these parameters. Figure 3 depicts the respective measurement concept and system boundaries for the SPF of the generator (SPFgen) and the system SPF (SPFsys), which are to be evaluated for both space heating (SH) and domestic hot water (DHW) operation.

Table 1: Success factors and respective required characteristics.

Success factors	**Needed KPIs**	**Sources**
• Self-consumption • Self-sufficiency SH • Grid purchase	• PV-production • Grid purchase und grid feed-in • Total Electricity consumption • HP Electricity consumption	• Inverter with Smart meter • Electricity meter heat pump, • Electricity circulation pump SH
• Energy efficiency • SPF and SPFgen for - SH and DHW • overall SPFsys for SH	• HP Electricity demand with Differentiation SH/DHW • Heat production SH/ DHW • Heat demand SH	• Two-tariff-electricity counter heat pump w Tariff change by DHW-switching valve • electricity counter heating pump • heat meter 1, 2, 3

2. Methodology

The PCM storage was investigated by monitoring over four heating periods. The first heating period served as reference with water storage, leaving the existing system in the pilot plant unchanged. After the first heating period, the water storage was retrofitted with the PCM capsules. The capsule were exchanged with a new generation after the second heating period.

2.1 Pilot and Demonstration plant description

The pilot plant is a detached house with a guest flat, which is rented out as a holiday home, located on a sunny terrace in Pany in canton Grisons at 1178 metres above sea level.

It was built in 1988 and has the following technical components and heat requirements, some of which were estimated based on information provided by the owner. Figure 1 shows the pilot plant and its location.

Figure 1. Location (left), view (centre), and aerial photograph (right) of the pilot plant in Pany

The most important technical data of the pilot plant are listed in the following

- Estimated heat demand of 100 kWh/(m²yr)
- Energy reference area of 200 m²
- Hot water consumption of 180 l/day (16 °C to 55 °C)
- Estimated electricity consumption of 4000 kWh/yr
- Air-to-water heat pump Oertli LSI 140 SHW-SG with output capacity 5.7 – 15.8 kW
- PV system with 17 kW_p, 84 m², 26 modules in west- and 24 modules in east orientation
- Electric battery for solar charging with a capacity of 7.7 kWh
- 800 l heating buffer storage tank and 500 l DHW storage tank
- Buffer tank operating between 40 °C and 52 °C, thermal capacity of 11.2 kWh
- After retrofitting with the PCM Caps, this results in a calculated capacity of 39.1 kWh

2.2 PCM-Capsules

The capsule used is called "BOOSTER CAPSULE 45". It consists of PCM45 and has a melting temperature of 45 °C. The storage energy density of the filled storage unit in the relevant temperature range is 50 kWh/m³. The PCM is based on salt hydrates, which, compared to other PCMs, have a high density and high melting enthalpy (205 J/g for this material), resulting in high storage energy density. The encapsulation has been optimised for packing density, thermal performance and production costs, resulting in the shape shown in Figure 2 and enabling a packing density of 62 %. This should achieve a capacity increase of more than a factor of 2 compared to water.

Figure 2. BOOSTER CAPSULE 45

2.3 Measuring system

Figure 3 shows the system with the measurement points and the system boundaries for calculating the KPIs.

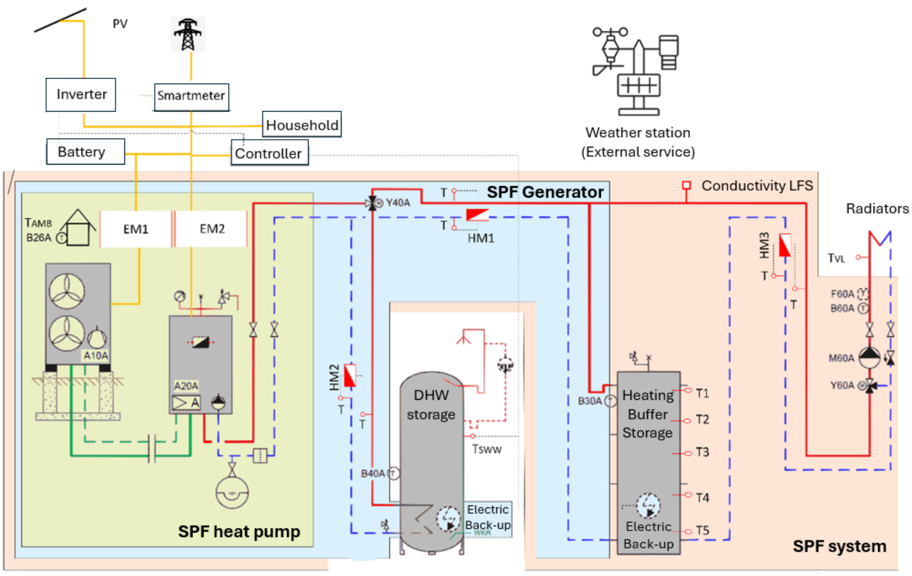

Figure 3. Plant diagram with measurement points and system boundaries for KPIs

The data recorded by the inverter (imported from the Cloud Platform) and data collected using a Raspberry Pi are used for measuring data acquisition. The data are recorded every 5 minutes.

3. Results and Discussion

3.1 Power consumption and key performance indicators

Figure 4 shows the consumption broken down into individual groups over the four heating periods. The blue (3) and light green (6) areas represent the electricity consumption of the heat pump in heating mode.

With the use of PCMCaps, the heat pump runs more in forced heating mode (light green) than without PCMCaps. Overall, however, the proportion of the heat pump in heating mode has remained roughly the same.

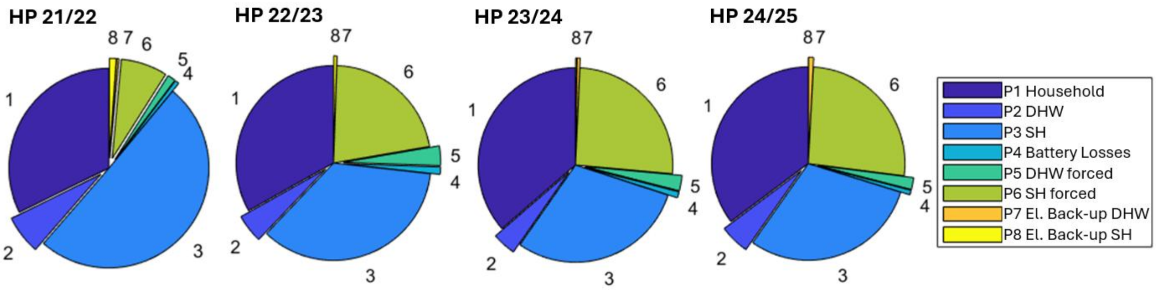

Figure 4. Consumption of different building services with respective systems

The energy consumption depicted in Figure 5 confirms that, in general, there has been a significant reduction in almost all energy consumptions. Only battery losses have increased. However, this increase is due to higher solar radiation, which has led to more frequent battery charging. In addition to the general decline in total energy consumption, it should also be noted that self-consumption in the household and for space heating has increased.

The increase in self-consumption in the household can be explained by the increase in PV production. As there was less snowfall than in the first heating period, PV electricity could be produced throughout almost the entire winter. This could be fed into the battery, which was then used in the evening.

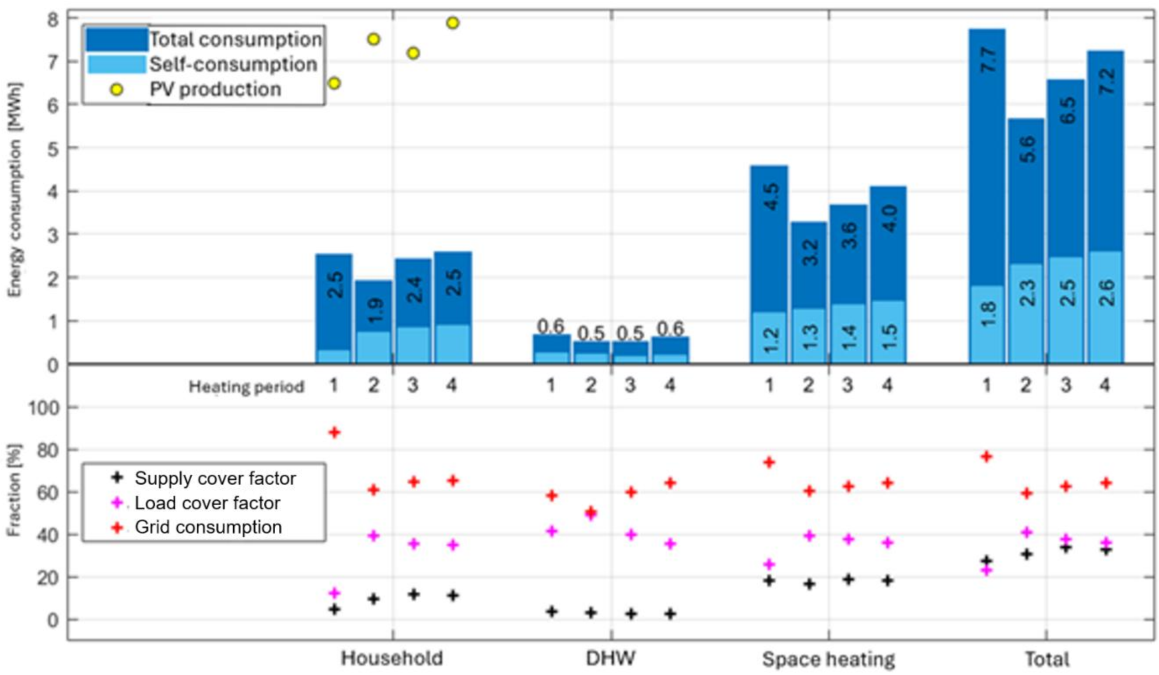

Figure 5. Energy consumption and KPI over the four heating periods

Figure 5 summarises the KPIs for all four heating periods. Compared to the reference period HP1, the heat pump's electricity consumption in heating periods 2-4 is significantly reduced, which is attributable to the lower occupancy rate. Despite lower heating production in HP2 and HP3 compared to HP1, self-consumption for heating actually increased in absolute terms. The load cover factor (ratio of self-consumed PV electricity to the total consumption) in SH was thus increased to slightly above 50 % compared to HP1. The supply cover factor for heating remained roughly the same, as although the self-consumption increased slightly, same as the electricity production. The total supply cover factor (ratio of self-consumed PV electricity to the total PV generation) increased by 10 % in HP2 and by 20 % in HP3 compared to HP1 (from 28 % to 33-34 %). Grid consumption was reduced from almost 80 % to 60-65 % compared to HP1.

The increase in the heating load cover factor which is defined as ratio of PV power (determined according to the prioritization in Table 2) and total electricity consumption of the heat pump in heating mode) in HP2 and HP3 can be attributed on the one hand to the PCM and on the other hand to the higher PV yield, which more often allows the storage tank to be overcharged. However, the influence of the two effects could not be quantified in detail (see Section 3.2), as the HP2 and HP3 differ from HP1.

The storage losses in the heating storage tank amount to 9.5 % in the first heating period and 12-13.5 % in the second and third heating period. However, it should be noted that this heat is not lost but is transferred via the storage tank wall to the boiler room, which is on the same level as the flat and is only separated from it by a simple door.

The seasonal performance factors vary between 2.38 and 2.63, which are also achieved with PCM. This is due to the air-to-water heat pump and the altitude of the site Pany.

3.2 Boundary and operating conditions

To ensure comparability between the individual heating periods, the heating degree days (HDD) were recorded and compared with the long-term average over 10 years (2014–2023, in accordance with the calculation rules of the archived SIA Standard 381/3 [3]). The data originate from MeteoSwiss (average daily temperature) weather station Disentis, which was selected as the location due to the altitude similar to Pany. Figure 6 on the left shows the characteristic values for the system operation over the measurement years. It is striking that significantly less heat was used in heating periods HP2, HP3 and HP4 than in HP1, although the number of HDD does not differ significantly. An explanation for this can be found by comparing the occupancy of the house, which is also include shown in Figure 5 left. Occupancy is not the same every winter due to the owners' prolonged absences and the use of the guest flat as a holiday home. In March and April, the heating was reduced in HP2 and HP3 because the house was hardly occupied, which reduced the heat demand. On the other hand, there were also periods, such as in autumn 23 and 24, when heating continued despite the lack of occupancy. Furthermore, more electricity could be produced in HP2 – HP4 with the solar system, as the PV system was less covered with snow.

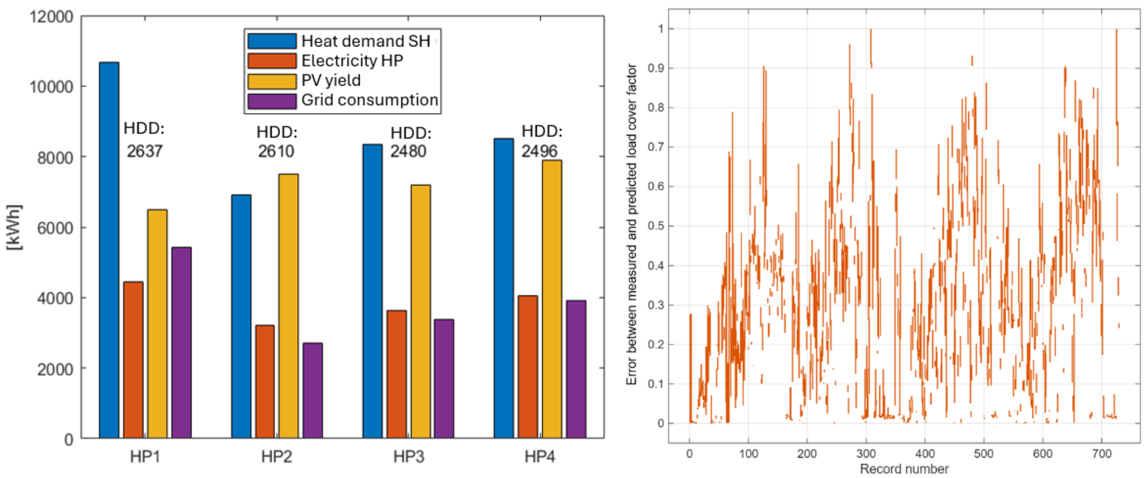

Figure 6. Characteristic values for heating demand, heat pump electricity demand, PV yield and HDD for the four heating periods (left) and RMSE error bars of the regression analyses

In order to deduce correlations of the KPIs depicted in Figure 5 and the boundary and operating conditions during the heating period, regression analyses have been performend in Matlab-Simulink applying a set of about 30 different methods. However, resulting errors in terms of the random mean squared error (RMSE) remained high as depicted in Figure 6 right even for the best fits and were not considered feasible for a comparison of the baseline consumption of the reference heating period using the boundary and operating conditions of the following HP2-HP4. Thus, the differences in the various measurement periods make it difficult to directly attribute the changes in KPIs relating to an entire heating period to the different boundary and operating conditions. These circumstances were taken into account by also using individual days with similar conditions to compare the effect of the PCM storage tank, as shown in Figure 7.

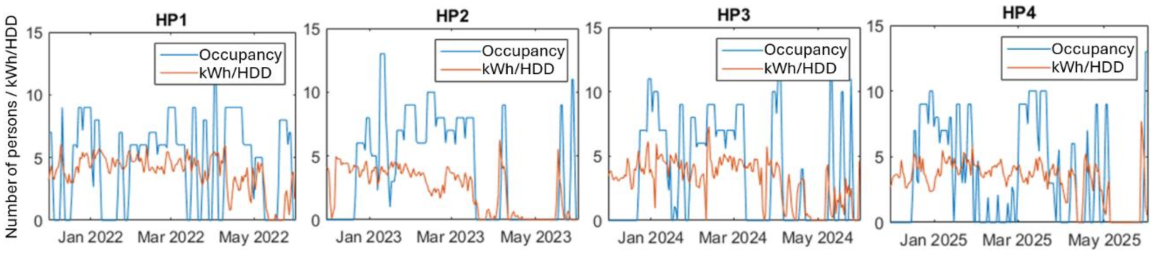

Figure 7: Comparison of heating demand per HDD with occupancy

3.3 Cyclic behaviour

During the second heating period, it was noticed that the running times of the heat pump did not increase as expected but actually decreased. More switching cycles of the heat pump were also recorded in the second heating period. This indicates that the PCM storage led to increased cycling.

At first glance, this seems counterintuitive, as the storage capacity has been increased twofold. However, this can be explained by the operation. During the cold months, the PCM storage is also operated with sliding setpoints, usually below the melting temperature. This means that the potential of the PCM's melting enthalpy cannot be exploited. Since the PCM is in solid form during the sliding operation, the possible discharge capacity of the storage tank decreases because heat transport in solid PCM is poorer than in water. Since the water content in the storage tank is reduced, the relative storage capacity during sliding operation is also reduced. The consumer does not notice this, since the mass flow and/or discharge temperature of the heat transfer medium into the building is simply increased. For the heat pump, however, this means more frequent switching in order to restore the temperature.

It was evaluated by analysis of daily measurement data that the storage temperature drops more quickly in the second heating period than in the first heating period. The volume flow remains more or less the same. This confirms the assumption that the lack of capacity is compensated by a higher temperature reduction.

3.4 System performance

In the beginning of the project, it was assumed, that the PCM could increase the SPF of the heat pump, since more energy can be stored and thereby produced during daytime, while the nighttime operation with the lower source temperature can be avoided. However, during the monitoring of the three heating periods with the PCM storage, this could not be verified also due to limitation for the control of the already installed heat pump. On the contrary, the operation with PCM storage showed higher fraction of cyclic operation, i.e., the heat pump exhibited more compressor starts, even though the storage capacity has almost doubled, which could be explained by the sliding temperature setpoint and limited sensible capacity of the PCM, see section 3.3. Investigations by idealised simulations have also shown that an advantage of the daytime production compared to 24 h production of the heat pump can be mitigated by a higher temperature level and storage losses for the daytime operation for the system layout in Pany pilot plant. Thus, the potential of an SPF increase is strongly depending on the operating conditions.

3.5 Change of strategy for the PCM storage to the Compact Cell

In the beginning of 2024, the manufacturer of the PCM storage decided to discontinue the marketing of PCM capsules with immediate effect. The technical and economic reasons for this decision were quality issues due to hairline cracks in the capsules which could lead to PCM leakage into the water tank, and related cost increase for quality control, an insufficient economic scaling potential due to reliance on storage types with revision openings. Moreover, the development state of an alternative storage type denoted as Compact Cell was already advanced.

The Compact Cells are highly compact heat storage units entirely filled with phase change material [4]. Thanks to the developed technology, the storage units are more compact than comparable water storage units and are also easy to install. The concept is based on a heat exchanger surrounded by PCM, packed in a housing with excellent thermal insulation, which enables high space saving potentials.

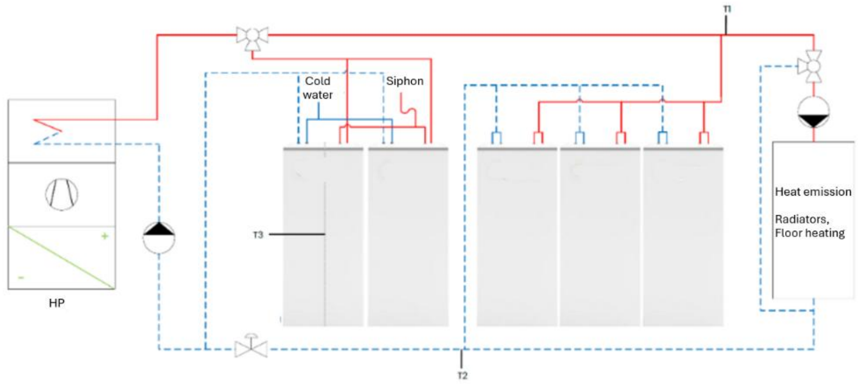

Figure 8. Hydraulic scheme of Compact Cell 45 with Compact Cell 58 as DHW storage (WPSM 1.6) [4]

Figure 8 shows the system integration based on the Swiss heat pump system model ("Wärmepumpen-systemmodul" WPSM), standard configuration 1.6 [4]. Due to its two heat exchanger water circuits, the product can be loaded via a heat pump and used as a hot water storage tank, with the second circuit serving as a hygiene circuit for drinking water. When used as a buffer storage tank, both circuits are connected in parallel to minimise pressure losses and maximise transfer performance. The system can also be operated as a combi storage tank or as a classic buffer storage tank with DHW storage tank; the latter solution is described in more detail below.

3.6 Integration of the Compact Cell in the pilot plant in Pany

In order to achieve the desired capacity increase for the pilot project, 2-3 buffer cells and 1-2 hot water cells would be desirable. The required floor space for this would be 0.6 m² to 1 m², which would save a significant amount of space in the boiler room and open up the possibility for alternative uses. The cells would be connected in parallel according to Tichelmann. Figure 9 on the left shows the integration of the compact cell compared to the original storage integration and illustrates the space saving potentials of the new storage concept. In particular in situations where space limitations are critical for the installation of a heat pump and respective storages, PCM storage solutions enable very compact thermal storage for a stable operation of the heat pump, in particular in retrofit situations, where space is normally restricted.

Figure 9. Comparison of installation space (left) and Compact Cell installation in Pany (right)

3.7 Thermal analyses of latent storage types

Figure 10 shows two days with storage charging and discharging in HP1 with water storage on the top and in HP3 with PCM capsules in the bottom, respectively.

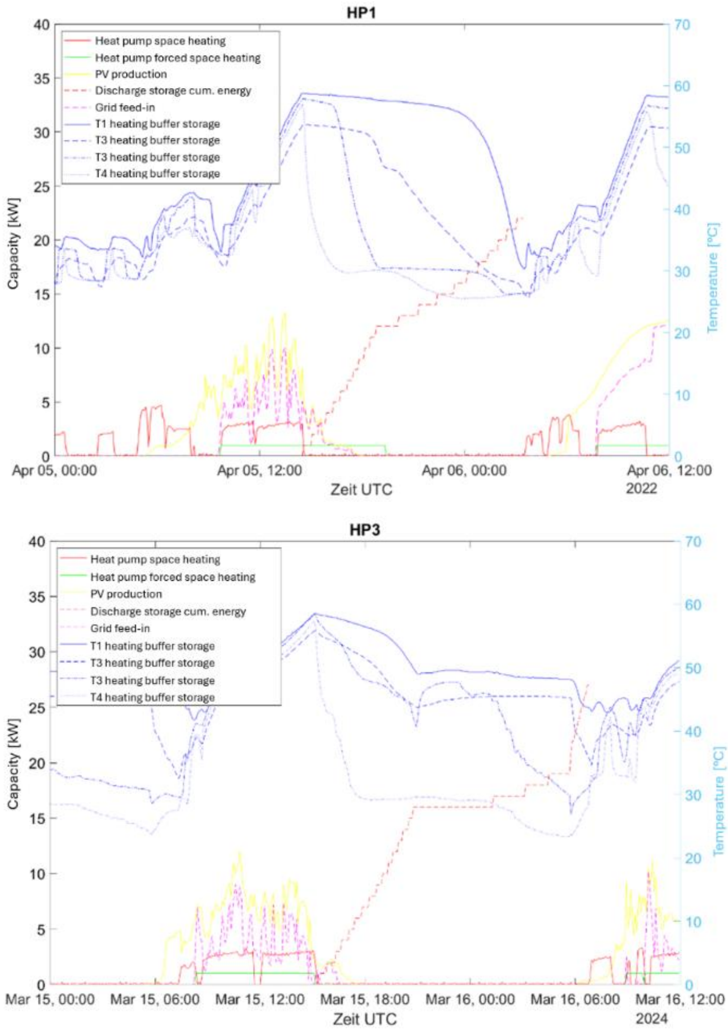

Figure 10. Storage discharge in HP1 without PCM (top) and in HP3 with PCM (bottom)

The average discharge power in both cases is approximately 1.7 to 1.8 kW. In the case of the sensible storage, the top temperature remains almost constant for a long time and then drops rapidly. In the latent storage, the temperature of the top sensor drops more quickly. The second-top sensor in latent storage can maintain the temperature for a long time and then drops sharply shortly before the end. Presumably, the water flowing in from the bottom of the storage tank cannot warm-up quickly enough in the PCM storage tank because the thermal resistance of the capsules is too high. This results in a larger temperature difference between the PCM and the surrounding water. This means that the thermal resistance of the PCM capsules (heat conduction within the capsules and through the capsule wall) becomes the limiting factor for the storage capacity.

It can also be seen that no heat was extracted from the storage tank between 9 p.m. and 2 a.m. As a result, the temperature at the second storage tank sensor, which had dropped shortly before, recovered. This is another indication that the required extraction capacity leads to a large temperature difference between the capsules and the surrounding water. Figure 11 shows the storage tank load at the end of May. After the heat pump has switched off, the storage tank remains idle as there is no heat demand in the building. The temperatures of the sensors drop, especially the second highest sensor. The temperature loss of the highest sensor is larger than in HP1 without PCM, which is even discharged, see Figure 11, indicating that this is not heat loss through the storage tank wall, especially since it is the same storage tank with the same insulation.

Rather, it indicates that the PCM had not yet completely melted when the heat pump was switched-off. After the heat pump is switched-off, the heat flows from the water into the PCM and continues to melt it. This means that the storage tank could continue to absorb heat. In this situation, however, further overcharging would not make sense, as the heat is no longer needed.

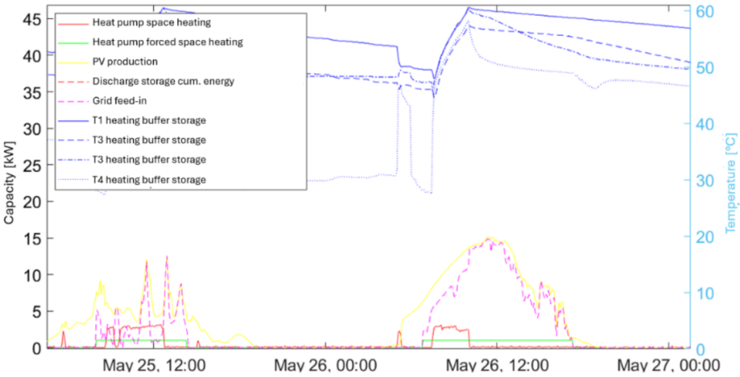

Figure 11: Storage loading in HP3 on May 26, 2024

The following conclusions can be derived from the above investigations:

- The bottleneck is the heat extraction capacity. Laboratory tests have demonstrated a power density of 8–12 kW/m³ (or 0.2 kW/kWh) at a temperature difference of 5 K between the phase change and discharge temperatures. The performance and cost optimisation of the capsule shape has led to this relatively low power density, which, however, was sufficient for buffer storage applications in the manufacturer's opinion at the time. The new storage concept Compact Cell, see Section 3.5, can deliver at least 1 kW/kWh at a temperature difference of 5 K, and more than 3 kW/kWh when used for domestic hot water. This means that the heat pump does not switch back on because there is too little energy in the storage tank, but because this energy takes too long to transfer from the PCM capsules to the water, resulting in insufficient temperature.
- The same bottleneck can also be seen during charging. The water measured by the sensor reaches the target temperature and the heat pump switches off. However, the heat has not yet flown completely into the PCM capsules, i.e. if heat continues to be fed into the storage tank at low power, it can continue to be loaded without exceeding the maximum temperature. However, this is limited by the minimum power of the heat pump (minimum speed) minus the power simultaneously drawn by the heating circuit. The heat pump data sheet does not contain any detailed performance data, but according to estimates, the minimum thermal heat pump output A5/B60 is approx. 3 kW with an electrical input of approx. 1.7 kW.
- With an optimised control strategy, the heat pump's loading capacity is continuously reduced before the final charging temperature is reached. The heat pump delivers minimum output as long as sunlight is available so that heat is not drawn from the storage tank by the heating circuit. This gives the heat in the storage tank time to flow from the water into the PCM, thereby increasing capacity.
  The control strategy should also include a switch-off point for self-generated electricity optimisation. Otherwise, during the transition period, the storage unit will be charged unnecessarily often, even though the heat is not needed, see Figure 11.

The limited heat transfer between the capsules and the water is due to the heat resistance of the capsule material, which is high-density polyethylene with a heat conductivity of 0.4 W/(mK) and the solid PCM, which forms at the capsule wall during discharging with a heat conductivity of 0.5 W/(mK). Even though the capsule geometry has been optimised regarding packing density, heat transfer and costs [5], the heat transfer remains limited. The results of the project showed that the thermal performance was not good enough for the buffer storage application with this specific heat pump.

The limitations of the heat transfer are addressed with the new Compact Cell. An optimised control strategy cannot be tested in the pilot project in Pany because the heat pump control can only be parameterised to a limited extent.

Figure 12 shows the amount of heat extracted from the storage tank on selected days during three heating periods HP1 – HP3. As reference for the new storage type model, the first values of the current heating period HP5 are also depicted. The amount of heat was determined between the time the heat pump was switched off and the time it was switched on again the next morning. The temperature difference refers to the top storage tank sensor at the time of switch-off and switch-on. The maximum temperature of the storage tank sensor is between 53 °C and 60 °C. Figure 12 on the left shows the absolute amount of heat, while the Figure 12 on the right shows the volume specific heat in [kWh/m^3]. The theoretical potential for the water storage tank was determined using the temperature difference between the 5 sensors at the start and stop times of the discharge measurement.

The mass was determined according to the storage geometry, with the intersection point of two mass elements lying in the middle between the sensors.

$$Q_{th} = \sum_{i=1}^{5} (T_{i,stop} - T_{i,start}) * m_i * c_{p,Wasser}$$

The measured energy from the sensible storage tank (HP1) is between 75 % and 85 % of this theoretical potential. The average value from the five measured values (80 %) was defined as a correction factor as a basis for comparison for the PCM storage tank and newly defined as 100 %. For the PCM storage containing the capsules (HP2 and HP3), a storage capacity was determined as a basis for comparison from the temperature differences with the heat capacity of water, and the actual measured storage capacity was compared with the theoretical storage capacity multiplied by the correction factor. This results in a capacity for the PCM storage that is between 10 % and 80 % higher than that of the water storage. Although only a few days were evaluated, it is clear that the PCM storage generally achieved lower temperature differences than the water storage, meaning that the increase in capacity of the PCM compared to water could not be fully exploited with the capsules. Although the phase change and thus a large part of the storage potential lies within a small temperature range, it is necessary to achieve a larger temperature difference, as this drives the discharge power from the PCM (overcoming the thermal resistance). In HP5, though, the discharge capacity of the Compact Cell reach the best values of the PCM capsule, but with half of the storage volume, so the volume specific discharge energy is up to 70 % higher than in the case of the PCM capsules and the water storage, demonstrating the much higher energy density as well as heat transfer and therefore space savings possible.

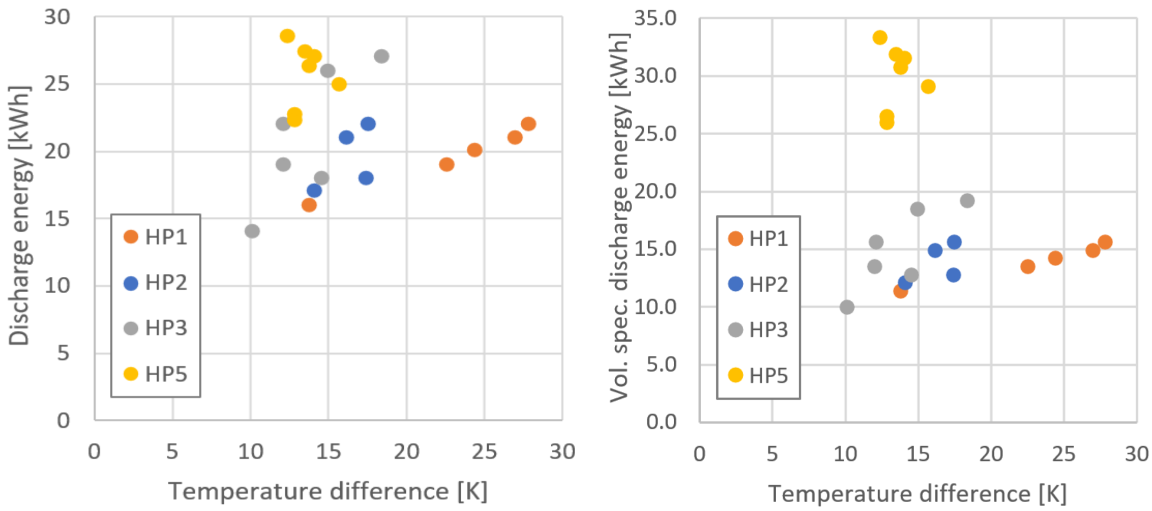

Figure 12: Amount of heat extracted from the storage tank for different temperature differences as absolute energy (left) and volume specific energy (right)

The higher volumetric capacity of the Compact cell compared to a common water buffer storage is also illustrated by the comparison in Table 2. The footprint of the compact cell implies space savings of about 50 %, based on the cubature (base area as square) it is reduced to only half of the respective water storage, based on the effective volume (base area as circle) the volume is reduced to 60%.

Table 2: Comparison of space requirements for water and PCM storage

Space requirement	Unit	Compact Cell	Water storage with 10 cm insulation
Number	-	3	1
Length	m	0.6	0.95
Width	m	0.34	0.95
Height	m	1.4	1.99
Volume cubature	m^3	0.85	1.79
Footprint	m^2	0.612	0.9025
Effective Volume	m^3	0.85	1.41

Figure 13 shows a comparison of the discharge capacities during a discharge cycle of the water storage on the top, the PCM capsules in the middle and the compact cell at the bottom. The water storage has a stable temperature for most of the discharging, followed by a sharp decrease in the end of the discharge cycle, when the hot water volume decreases. The PCM capsules have a higher discharge energy, but the temperature decreases more rapidly, i.e., heat transfer for the capsule and discharge capacity is lower due to the limited heat transfer from the capsules to the water. The discharge profile of the Compact Cell at the bottom shows the solidification plateau clearly, showcasing the improved heat transfer of the new technology. The storages tested here are a 300 l water tank with and without capsules and a standard single Compact Cell that was installed in Pany.

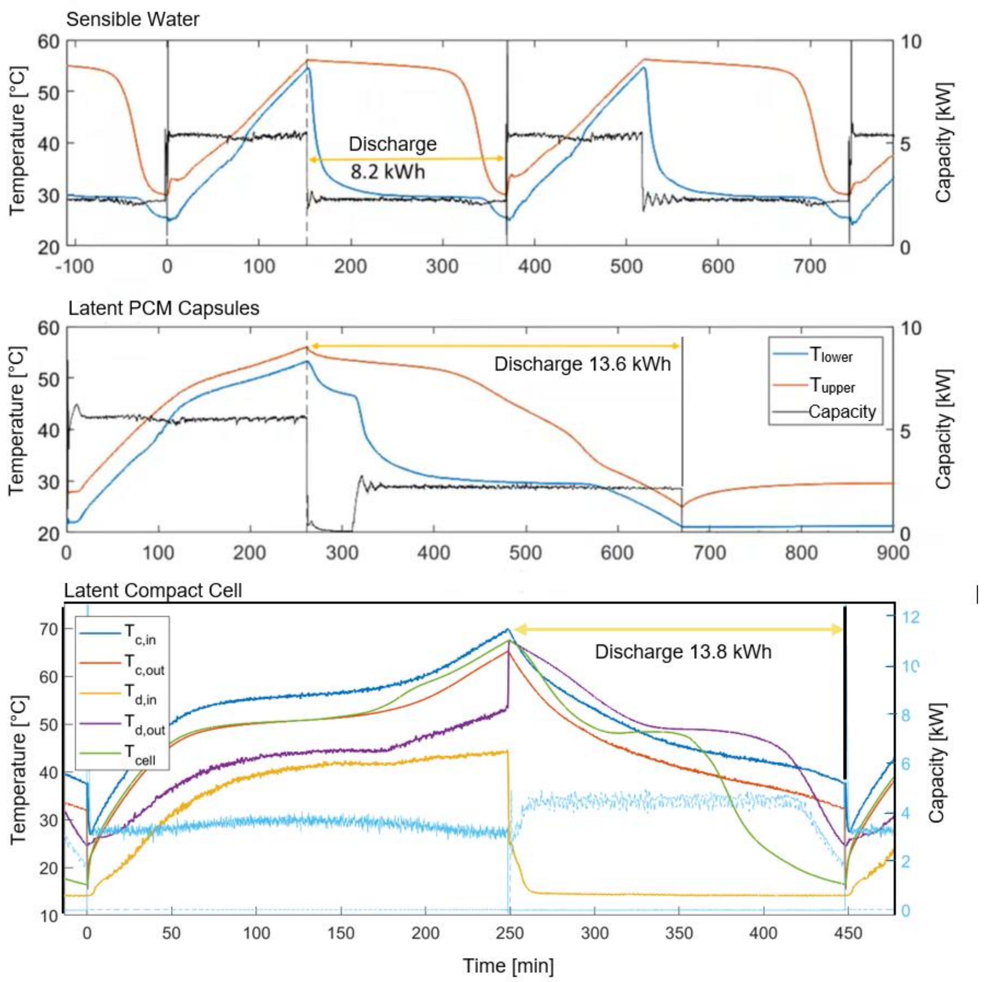

Figure 13, Comparison of discharge capacity among the different storage types

3.6.1 Outlook on future research

The change in strategy let to an installation of the compact cell in the pilot plant. Figure 9 on the right shows photos of the integration of the new storage concept in the pilot plant Pany, with the above mentioned 2-3 buffer cells and 1-2 hot water cells. Thereby, the compact cell concept can be monitored in the same environment, which enables a comparison with the PCM capsule concept and evaluate how limitation of the old concept regarding the limited charging and discharging operation can be overcome by the new concept with enhanced heat transfer between the heat exchanger and the PCM. Moreover, experiences with the DHW operation can be gathered and compiled. First results of this fifth heating period HP5 measurements have already been integrated in the Figure 12 which confirm the higher volume specific energy and thereby the space saving potentials.

4. Conclusions

The investigations carried out in Pany as part of the project have shown that the use of phase change materials (PCM) as buffer storage for heat pumps technically works and leads to a significant increase in storage capacity. The project has been one of the longest monitored operation periods for PCM storage as heating buffer storage. During the heating periods with PCM capsules, the load cover factor in space heating also denoted as autarky increased by up to 50%, from an initial 21% to values between 35–40%. The self-consumption rate grew by 10–20% compared to the reference period, from 28% to 33–34%. The effective storage capacity of the buffer increased by up to 80% compared to the pure water storage tank. These findings were collected over three heating periods with PCM capsules, but were not adjusted for climatic influences or changes in user occupancy, which could not be tracked with sufficient exactness by regression of measured values. Therefore, the improvement in the aforementioned KPIs cannot be attributed exclusively to the increased storage capacity, but heating periods incorporating PCM storage exhibit improvement of the KPIs.

At the same time, however, it became apparent that the original capsule concept was limited by restricted heat transfer from the water to the PCM: the charging and discharging capacity fell short of expectations, which is mainly caused by the limited thermal conductivity of the capsule wall and the solid PCM. Furthermore, an improvement in the Seasonal Performance Factor (SPF) could not be demonstrated in the field test (measured values ranged between 2.38 and 2.63, which lies in the same range as the reference HP1), as the available storage capacity could not be optimally utilized in real operation.

At the end of 2023, the manufacturer implemented a change in strategy, removing the capsule product from its product portfolio and shifting development to the so-called Compact Cell – a compact storage unit filled entirely with PCM. Compared to water, the theoretical volumetric storage capacity can be increase up to a factor of 3 per litre of storage volume. The enhanced storage and charge/discharge capacity enables the integration both for heating buffer and DHW storage operation. This is especially beneficial in retrofit projects where space is often a limiting factor. The strict separation of the system (a heat exchanger is surrounded by PCM) results in a much less error-prone system that can also be designed in a cubic shape. The thereby possible DHW operation as fresh water system notably extends the application range.

The Compact Cell was launched in 2025. At the same time, integration into the pilot plant in Pany has been undertaken, where the existing system is being replaced by five Compact Cells. This provides a representative showcase project that demonstrates not only technical feasibility but also practicality.

First measurement data of the pilot plant of the current heating period HP5 confirm the enhanced thermal behaviour resulting in similar storage feature of a water storage, but on a footprint which is decreased by a factor of 2 related to the storage cubature. By optimising the PCM to a melting temperature of 48 °C the Compact Cell combines high storage density of 75 kWh/m³ with heat pump compatibility in the practical temperature range, which optimises the charging efficiency for PCM storage.

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