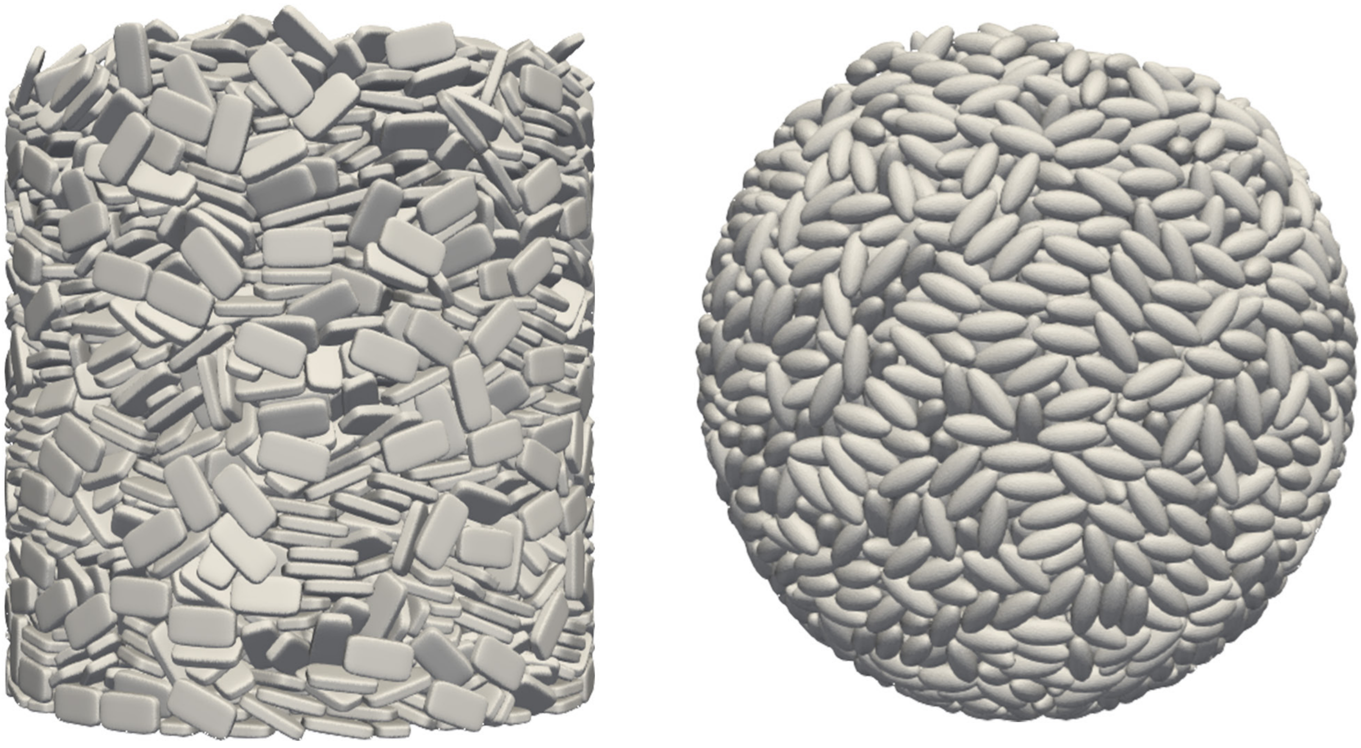
MATERIALS THAT STORE SOLAR POWER FOR WEEKS

Anyone who operates a photovoltaic (PV) system can typically use a battery storage system to increase the self consumption by 10–20%. But solar power could also be used in another way to cover personal energy needs: by converting the electricity into heat using a heat pump and storing it until it is needed for heat and hot water. A research team at the Lucerne University of Applied Sciences and Arts is working on a heat storage system based on phase change materials, specifically designed for this application.



The visualization illustrates two possible storage geometries. The capsules are made of polyethylene plastic and filled with phase change materials. Illustration: HyTES final report

A technical report about the results of a research project in the field of solar thermal energy and heat storage, which is financially supported by the Swiss Federal Office of Energy. The report has been published online in the magazine Schweizer Wirtschaft (issue November 2025).

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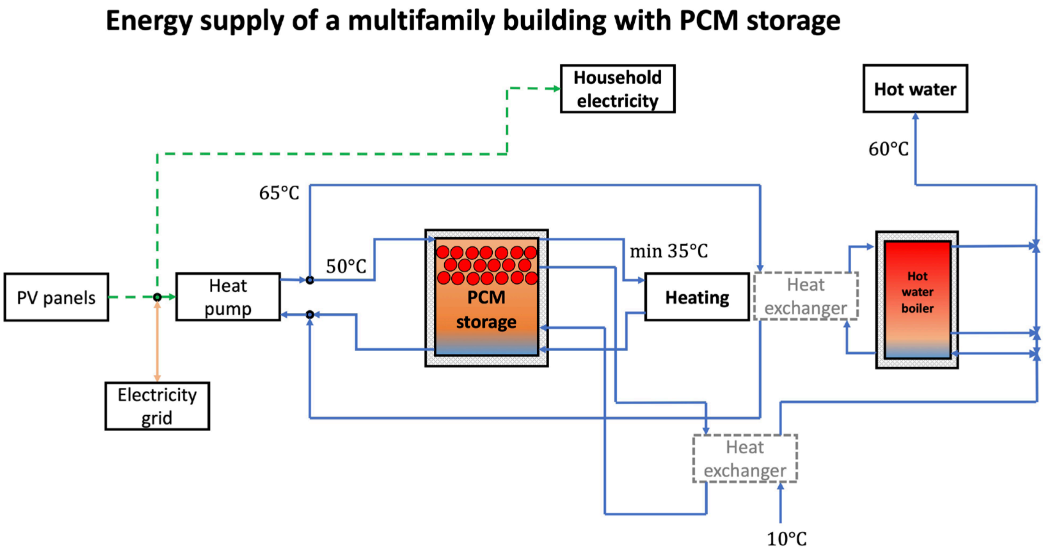


Schematic representation of the energy supply system: A heat pump uses PV electricity to produce heat at a temperature of approx. 50 °C, which is stored in the PCM storage tank and then used for heating purposes. Hot water (60 °C) is not drawn from the PCM storage tank, but comes directly from the heat pump and is stored in a boiler. However, the PCM and hot water storage tanks are coupled: The water is preheated in the PCM storage tank before it enters the hot water storage tank. Illustration: Final report HyTES

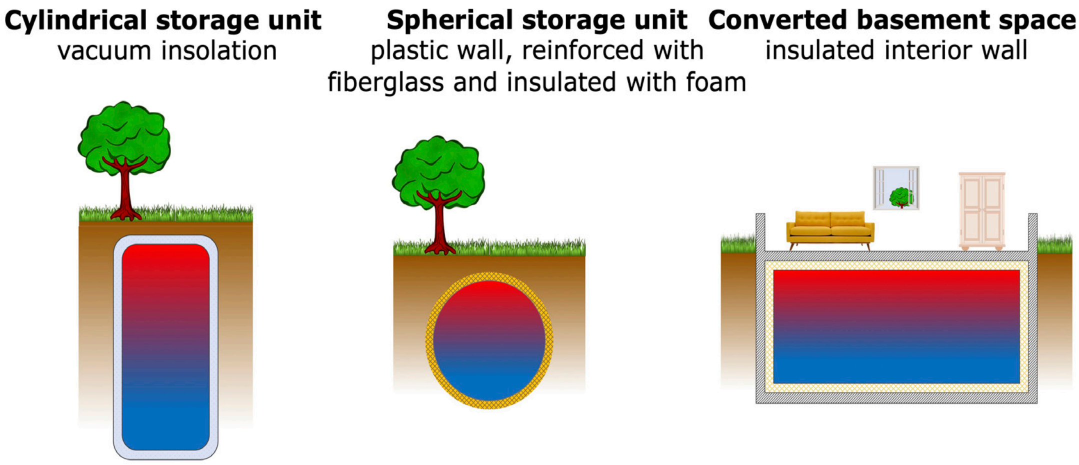
A basement oil tank serves as a powerful energy storage system. The tank is filled once a year and then supplies energy for heat and hot water for months. However, oil heating systems are becoming obsolete due to their high greenhouse gas emissions. They are being replaced by heating systems based on renewable energies, including solar energy. But since the sun is not strong enough year-round to produce enough energy, storage solutions are also needed. These would store excess solar energy during sunny periods to make it available hours or days later when demand arises.

Photovoltaic systems can also be connected to batteries to store excess energy. And those who produce solar heat with solar collectors can temporarily store it as hot water in a boiler. With somewhat larger boilers, heat can easily be stored and used during periods of inclement weather for about one to two weeks. In the best case, the heating needs of well-insulated buildings can be fully covered with solar heat from the roof. "Such seasonal heat storage systems are powerful, but they are often installed in the middle of buildings and consume valuable living space," says Prof. Jörg Worlitschek, energy storage expert at Lucerne University of Applied Sciences and Arts – Engineering and Architecture (HSLU).

A steel tank full of water and PCM capsules

Against this background, Worlitschek and his colleagues at HSLU are working on a new storage concept – using a heat pump powered by PV electricity to produce hot water, which is then kept in a storage unit. To maximize capacity with minimal volume, the storage unit contains not only water but also capsules filled with phase change materials (PCM). PCMs can absorb large amounts of heat and release it later.

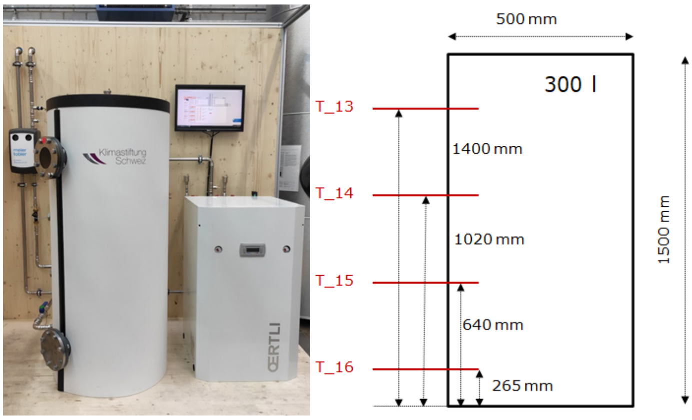
In practice, a PCM storage system is a large underground steel tank filled with water and PCM capsules. Thanks to the capsules, the storage system uses not only sensible heat but



Three storage geometries were investigated in the project. Illustrations: Final report HyTES also latent heat (see box p. 4). This allows it to store more heat per volume within a defined temperature range than a conventional hot water tank. However, its function is otherwise very similar to a standard hot water storage unit.

Simulating the system in a model and in the lab

"We examined how such a storage system could be operated efficiently and what it would cost," says William Delgado-Diaz, who led the research project supported by the SFOE. He and his colleagues created a model of a PV heating system with heat pump, and PCM storage. In the model, the system was installed in an apartment building with eight units and 20 residents (800 m² energy reference area, 264 m² available roof area). According to their calculations, if the building is equipped with a PV system of around 36 kWp and a heat pump with a power of 16 kW, its entire annual heating demand could be met. Based on this calculation, they used simulations to determine the optimal design and cost of the novel storage concept.



Prototype in the Lucerne University of Applied Sciences and Arts laboratory, used to validate calculations for PCM storage systems. The tank (in the middle) contains the PCM storage system with a volume of 300 l and a storage capacity of 13.1 kWh, which is shown schematically on the right (including height specifications for the four temperature sensors). The test setup includes the heat pump (to the right) and a mixing valve for floor heating (to the left). The phase change material used in this storage unit, developed by HSLU spin-off Cowa, has a melt temperature of 48 °C. Illustration: Final report HyTES

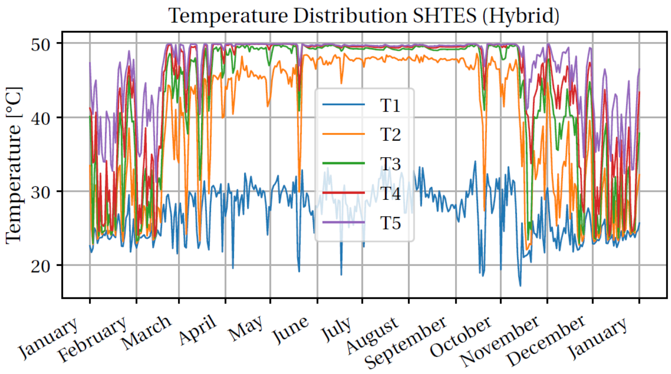
In addition, the researchers built a prototype PCM storage unit in the lab. They tested its functionality and storage potential in combination with a heat pump under different conditions. The phase change material for the prototype was supplied by Cowa Thermal Solutions AG (Root), a 2019 spin-off of HSLU, which launched its first PCM product in 2023.

HOW A PCM STORAGE SYSTEM WORKS

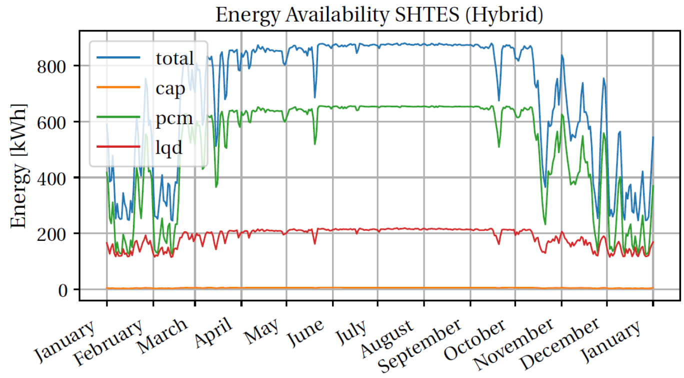
To understand how a PCM storage system functions, take the example of a renovated apartment building with a heating system that requires water with a temperature of 35 °C. On sunny days, PV electricity from the building's roof is used by the heat pump to heat water to about 50 °C, which is then directed into the PCM storage unit. On cold days, the hot water required for heating can be drawn directly from the storage unit. By mixing it with water that is returned to the heating circuit, the desired supply temperature of 35 °C is achieved.

As heat is drawn off, the storage unit cools down, and it is here that the great benefit of the PCM capsules becomes apparent: once 40 °C is reached, the encapsulated phase change material "freezes," releasing latent heat. During the transition from liquid to solid, large amounts of heat are stored that can be used for heating. Once all the PCM capsules have "frozen," additional sensible heat can still be withdrawn from the storage unit until the water temperature reaches 35 °C. When the sun shines again, the newly available PV electricity is used via the heat pump to generate heat, which recharges the PCM storage unit. In practice, the PCM system is alternately charged and discharged, depending on the demand for heat and the amount of sunshine.

The phase change material is chosen so that its melting temperature lies slightly above the heating system's supply temperature. In a 20-year-old building with floor heating, for example, the melting point of the PCM used typically lies in the range of 40 to 42 °C, whereas in a new building with floor heating it lies between 30 and 35 °C. Since hot water for bathrooms and kitchens requires higher temperatures, it is generally not drawn from the PCM storage unit, but is instead provided separately by the heat pump and stored in a conventional hot water boiler.



Temperature distribution in the PCM storage tank (basement room with insulated interior wall) over one year (calculated in 10-minute intervals and in daily averages). T1 stands for the temperature at the bottom of the storage tank, T5 for the temperature at the top. During the summer months, the temperature at the top of the storage tank is practically 50 °C throughout, and even at the bottom, temperatures of up to 40 °C are reached (the temperature peaks are not visible in the graph due to the averaging of daily values shown by the blue curve). In winter, however, when a lot of heat is extracted from the storage facility, lower temperatures prevail. The temperature at the top of the storage facility then drops to 35 °C and below. Graph: Final report HyTES



The graph shows how much thermal energy a PCM storage unit (basement room with insulated interior wall) stores (blue), calculated in 10-minute intervals and in daily averages. This energy consists of the sensible heat of the water (red) and the latent heat of the phase change material (green). The phase change material stores significantly more energy than the water. The PCM storage unit stores 1.7 times more energy than a water storage unit of the same size that does not contain phase change material. The orange line represents a plastic capsule containing the PCM material. Illustration: Final report HyTES

An optimum at 85% self-sufficiency

Ideally, a heat storage system would fully cover a building's heating needs with its own PV electricity and at the lowest possible cost. However, a storage unit that achieves 100% self-sufficiency would need to be very large and would not be economically viable. The HSLU researchers therefore sought a PCM storage unit size with the best cost-benefit ratio for the modeled apartment building. Their findings show that an 8 m³ PCM storage unit would achieve 85% self-sufficiency. Heating costs would be around 35 Swiss cents/kWh, significantly higher than that of a gas heating system (at current gas prices), but still within a "reasonable" range, according to the project's final report.

The researchers also showed that a heating system with PV, heat pump, and PCM storage unit is far more climate-friendly than an oil based one. Literature values put emissions from an oil heating system at 319 gCO_2eq/kWh, mostly from burning oil. With a PCM-based system designed for 85% self-sufficiency, emissions would be between 11 and 83 gCO_2eq/kWh. A major share of this comes would come from the "gray" emissions from the electricity required to power the heat pump.

Limited storage costs

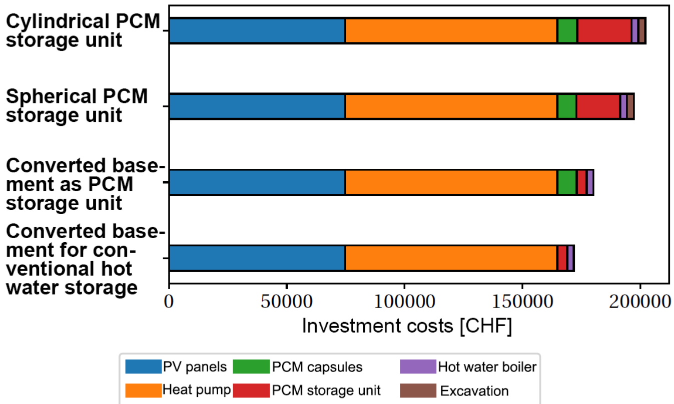
The HSLU researchers estimate investment costs for a PCM storage unit for an apartment building, including excavation, at 8,000–31,000 Swiss francs (8,482-32,871 euros, depending on the type and a reasonable storage size). The total system cost would amount to 179,000–207,000 Swiss francs. PCM storage thus would account for only a small proportion of the overall costs. "The main cost drivers are the PV system and the heat pump," says Delgado-Diaz. However, it should be noted that suitable phase change materials are still

SENSIBLE AND LATENT HEAT

Heat that can be extracted from water when it is cooled from 10 to 0 °C, for example, is referred to as "sensible" (or "perceptible") heat. If heat continues to be extracted from this water, it freezes. During the phase transition from 0 °C water to 0 °C ice, 'latent' heat is released. If the 0 °C ice is cooled further, to – 10 °C for example, sensible heat is released again. Ice storage systems are based on latent heat released during the phase transition from water to ice.

Water undergoes a transition from liquid to solid at 0°C. Other substances have different melting points. Phase change materials with melting points in the range of 30 to 40°C are of interest for PCM storage. This makes it possible to store large amounts of latent heat in a temperature range that can be used for heating purposes.

In 2023, Cowa Thermal Solutions introduced its first hot water storage tank based on phase change material with a melting point of 48 °C (pictured, three storage tanks connected in a cascade). The phase change material is based on sodium acetate trihydrate, a salt with a faint vinegar smell. In the PCM storage tank tested at HSLU, the phase change material is placed in a converted basement room or in an underground water tank. Photo: Cowa



When it comes to the investment costs of an energy system with PV, heat pump, and PCM storage, the latter has the least financial impact. The total cost includes the cost of the underground storage tank (red), the cost of the PCM capsules (green), and the cost of excavation (brown). Added to this is the cost of the hot water boiler (purple). Graphic: Final report HyTES

in development, and final system costs can only be roughly estimated.

Currently, it is therefore not worthwhile to equip an apartment building with a PV system and heat pump with an additional PCM storage unit. But this could change in the future, as Worlitschek from HSLU explains: "In today's energy environment, the investment in PCM storage may not pay off. In a future energy system with dynamic electricity prices, systems that make high use of their own solar power will benefit financially much more than today. The flexibility gained through PCM storage will be more valuable than it is now. The less grid electricity one needs, the less they are exposed to price fluctuations. In the long run, such heat storage systems would therefore also pay off financially."

↗ The **final report** on the project "HyTES – Optimization of hybrid seasonal heat storage systems using phase change materials" is available here: at: https://www.aramis.admin.ch/Texte/?ProjectID=48006.

↗ For **information** about the project, contact Stephan A. Mathez (stephan.mathez@bfe.admin.ch), external head of the SFOE's research program on solar thermal energy and heat storage.

↗ Further **technical articles** on research, pilot, demonstration, and flagship projects in the field of solar thermal energy and heat storage can be found at www.bfe.admin.ch/ec-solar.

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