Concrete heating

A unique experiment is currently underway in Seelisberg: a construction physicist from Lucerne had Empa researchers install six cubic meters of special concrete in the garage of his vacation home. The concrete stores heat during the summer and releases it in the winter as and when needed, which enables the house to be heated for weeks – sustainably and ecologically.

TEXT: Martina Peter / PICTURES: Empa

The house of construction physicist Mark Zumoberhaus is not far from Lake Lucerne. The building expert describes his little house as an "experimental hut". He now has a customized prototype in the cellar: the world's first concrete heat storage system.

Bottom left: Empa scientist Josef Kaufmann who developed and built the storage system.

Right: Storage module after casting.

"We have enough energy in Switzerland to keep us warm during winter," says Mark Zumoberhaus, a construction engineer and owner of a detached, wooden-clad house in Seelisberg in the Canton of Uri. He is currently preparing an exciting real-world experiment in his garage together with Empa researcher Josef Kaufmann and his team. After all, Zumoberhaus is convinced that it must be possible to get by without oil or natural gas the whole year round, even in a village 850 meters above sea level. Instead, his (sole) heat source is the sun. The burning question, however, is how to conserve sufficient summer heat for the winter months.

Back in 2007, Zumoberhaus fitted the cladding on his house in Seelisberg with modern but fairly thin heat insulation based on a nine-cubic-meter water tank, which can store heat on a large scale. It is connected to the solar collector unit next to the house and a wood stove, which enables the water in the storage tank to be heated to 85 degrees Celsius in the summer. It ensures that the boiler supplies hot water and that the floor heating works in the winter. The temperature in the living quarters on the third floor is a pleasant 20 degrees, while 16 degrees is sufficient for the bedrooms on the second floor.

Usually, however, the stored energy only lasts until Christmas. And it isn't until February that the output from the solar system is sufficient to heat the boiler and living quarters again. "Until mid-February, I have to fire up the stove every time I enter the house," he says. The temperatures in the upper rooms drop to around 15 degrees. While he could always switch on the off-peak electricity if need be, he would rather do without it. But how?

Attractive solutions for energy problems

"That's my experimental hut," says Zumoberhaus, who advises architects on construction physics for a living. His customers usually want field-tested, reliable solutions. In order to save energy, as most construction physicists in this country agree, the heat insulation on a building's cladding needs to be as thick as possible. However, Zumoberhaus banks on other solutions in his private life: new, as yet untested solutions are more appealing, he explains.

Like many buildings in the region, his house boasts a wooden façade. However, he dispensed with conventional constructive protection from the elements – i.e. a projecting roof and overhangs – in the horizontal Swiss pine formwork. Instead, a good rear ventilation system ensures that any moisture that gets in can dry out again harmlessly. Consequently, the wooden façade is evenly exposed to wind and rain and can actually weather the elements without leaving any marks.

Another experiment was the unventilated tin roof construction with a variable vapor retarder. Thanks to its increased diffusion resistance, this foil, which was novel at the time, prevents too much

Video
Wunderbeton als Wärmespeicher (SRF)
(German language)

http://goo.gl/6kAHZX

Above: Concrete formwork for the small batch production of the storage elements, spring 2015. The concrete storage system comprises 24 separate blocks, which were cast at Empa using a special concrete. Every block weighs around 400 kg and is streaked with copper piping. The blocks are placed in an insulated, watertight metal casing. The local plumber connects it up to the central heating.

moisture from getting into the roof construction in the winter and causing the wood to rot. Thanks to the variable retarder, the moisture stored in the wood is "forced back" into the living quarters via reverse diffusion in the summer: the wooden construction completely dries out again. Zumoberhaus had heard about the foil developed by Hartwig Künzel from the Fraunhofer Institute for Building Physics and the corresponding analysis software WUFI, which promised excellent results. "The idea of finding out whether it would prove successful in practice appealed to me," says Zumoberhaus. So he not only obtained the foil; he also installed diverse sensors and a small weather station to compare the practical results with the theoretical calculations. His results, which corroborated the Fraunhofer Institute's theory, also led to a long-term collaboration with wood construction physics researchers in Germany and Austria.

Concrete heat storage in a modular system

When Zumoberhaus read about Empa's concrete heat storage system in the media in 2012, he was immediately taken by the idea. Researchers from Empa's Concrete/Construction Chemistry lab had reported that concrete building components produced with calcium sulfoaluminate cement (CSA) might make ideal seasonal heat storage systems. If the concrete blocks are heated to 80 degrees via heating coils with the aid of solar panels in the summer, the mineral ettringite contained in the CSA cement emits water vapor. This leaves behind the dehydrated concrete block, which "stores" the heat virtually loss-free. In winter, the process is reversed: water is channeled into the dry concrete, absorbed by the ettringite and heat is released, which can be conducted away via the heating coils.

"Could this be the solution to plug the gap between Christmas and February?" wondered Zumoberhaus. After a discussion with Empa research Kaufmann, he was convinced to attempt the project together. "Other men at my age park a convertible in the garage," chuckles Zumoberhaus. Instead, he decided to place a six-cubic-meter concrete block in his.

Empa scientists Josef Kaufmann and Frank Winnefeld are delighted: "The collaboration is a unique opportunity for us to hone a system that proved itself in the lab for practical use." They received support from the Swiss Federal Office of Energy.

In the spring, against a breath-taking backdrop with a bright blue sky and framed by the Central Swiss mountains towering up to 3'000 meters into the air, a heavy truck finally rolled up. The Empa team unloaded 24 concrete blocks, which had been cast at Empa, and installed them against the rear wall of the garage. The concrete storage system's first drying tests went well, even if it was not heated up to the intended 80°C. Zumoberhaus is adamant about the advantages of the energy storage system: apart from CO_2 emissions during production and transport, it is ecologically sound. And cost-effective: one ton of CSA concrete costs less than 400 Swiss francs.

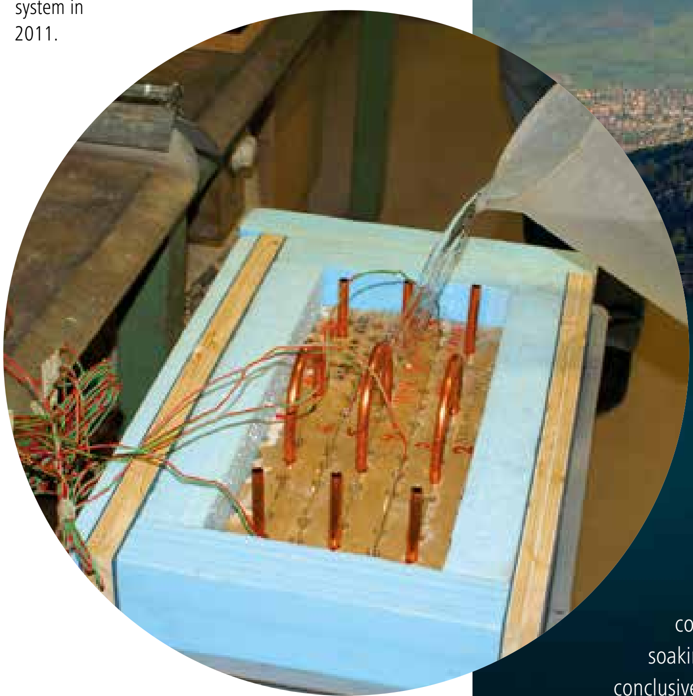
Is the concrete storage system already a solution that is suitable for daily use by other home owners in its present form? "No," stresses Zumoberhaus. But then that is not his intention. "For me, it's simply another experiment that I got involved in." If it doesn't work, he can easily dismantle the heat storage system again after the three-year test phase thanks to its modular structure. "But it's bound to yield results that will be useful for research on energy storage systems and help find the solution to our energy problems," Zumoberhaus is convinced. And thus it comes as no surprise that the two Empa researchers, Kaufmann and Winnefeld, are already pondering simple, more practical solutions. //

The crystals that store heat

“The heat storage system actually arose out of pure curiosity,” says Josef Kaufmann, one of the two inventors. While searching for materials, he stumbled across the interesting properties of the mineral ettringite, which binds a lot of heat when dehydrated. This, he pondered, should be a perfect material for seasonal heat storage. Meanwhile, his colleague Frank Winnefeld was involved in a CTI project aimed at developing a cement that sets particularly rapidly. The candidates included a Chinese CSA (calcium sulfoaluminate) cement, which is still quite unusual in Europe. This cement forms very high proportions of ettringite during the binding process (hydratation), making it an almost perfect concrete mixture for a heat storage system.

Ettringite, a mineral with the chemical formula $3\ CaO \cdot Al_2O_3 \cdot 3\ CaSO_4 \cdot 32\ H_2O$, binds 32 molecules of water in its crystal structure. At temperatures above 80 degrees Celsius, however, the crystal rereleases the majority of the water to create so-called meta-ettringite – the “dry” form of the mineral. The majority of the material keeps its shape and can be stored indefinitely in the absence of moisture. When water is added, meta-ettringite is converted back into ettringite, thereby releasing around 600 kilojoules of heat per kilogram.

Lab prototype of the concrete heat storage system in 2011.



From the lab bench to the garage

As a first step, Winnefeld used phase diagrams to develop a special concrete made of CSA cement, Portland cement and gypsum, which contains a maximum concentration of ettringite. The two researchers then cast small sample cylinders, dried them, moistened them again and analyzed the amount of heat emitted in a calorimeter.

Following some promising results, the first lab prototype was developed in 2011: a small concrete block measuring 18 x 40 x 50 cm in size. It already had drill holes to speed up the soaking process and integrated copper pipes to heat the block from within. The experiments were conclusive: if you pour water at room temperature over the block, it heats up to 80 degrees Celsius within an hour. The method passed the practical test and is now patent-pending. In January 2012, Empa-News, Swiss journals, internet portals and daily newspapers all reported on the project.

“We were over the moon when Mark Zumoberhaus got in touch with us and requested a heat storage prototype for his house in Seelisberg,” says Kaufmann. “This gave us the unique opportunity to demonstrate this kind of storage system on a 1:1 scale.” Kaufmann and his team designed the modular structure of the prototype: 24 individual concrete elements, equipped with drill holes and water channels to wet the concrete, and slots for forklift trucks to enable the storage system to be installed and removed. Every block contains copper pipes embedded in concrete, which are interconnected and transport solar-heated water in the summer to dry the concrete. In the winter, cold water flows through the pipes and carries the hydratation energy generated by the ettringite into the house.

Some things still remain to be seen: the repeated conversion of ettringite into meta-ettringite and back again may cause cracks in the concrete blocks. Do they improve the storage performance or will they have the opposite effect? Do the quantities of heat released in practice match the values from the lab? Where can the construction still be optimized? In May and June 2015, solar heat was already channeled into the concrete storage system. By next March, we will know more.