EUROPEAN COMMISSION
H2020

Publishable Report

CREATE

Compact REtrofit Advanced Thermal Energy storage

The CREATE project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 680450.

Contents

1. Introduction to the CREATE project

The main aim of CREATE was to develop and demonstrate a heat battery, i.e. an advanced thermal storage system based on Thermo-Chemical Materials (TCMs), that enables economically affordable, compact and loss-free storage of heat in existing buildings.

The buildings sector accounts for the largest share of energy consumption (Europe wide approx. 37 %[1]). As two third of the building stock in 2050 is made up of currently existing buildings, the solution should be realised with the current building stock. The CREATE project aimed to tackle this challenge by developing a compact heat storage module. This **“heat battery”** allows for better use of available renewable energy sources in two ways: (1) Considering that solar and wind energy are abundant, but inconsistently available, proper use requires storage to bridge the gap between supply and demand, i.e. the intermittent nature of renewables (see Figure 1)[2]. (2) Heat storage can also increase the efficiency in the energy grid by converting electricity peaks into stored heat to be used later. In this way heat storage increases the energy grid flexibility (e.g. the seamless exchange of energy in different forms, giving options for tradability and economic benefits). Heat storage is therefore considered an indispensable element to facilitate flexibility in the energy grid. The CREATE concept (Figure 1) addresses these issues.

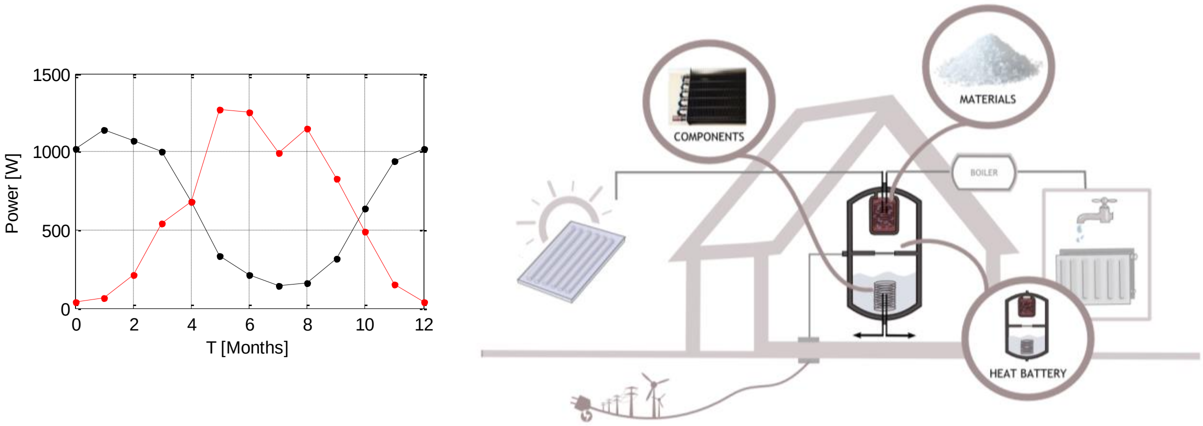

Figure 1. Left: non-synchronized heat supply and demand. Amounts of heat needed (black) and available from solar collectors (red), for a typical year and a well-insulated dwelling in Western Europe.2 Right: Schematic of the CREATE concept. The heart of the system is the heat storage module, i.e. the heat battery. Different sources for heat supply exist, e.g. heat generated by solar collectors on the building or heat-pumps fed by excess electricity from the grid.

The international consortium, existing of research institutes and industries covering the complete value chain for thermochemical storage technology development and demonstration, worked on the development of stable and compact thermochemical materials, on component development and testing, on integrating these components into a system and on testing this system, together with dedicated control software, in the laboratory and finally on demonstrating this system in a real environment. In the following sections, these activities and the results will be highlighted.

---

[1] Technology Roadmap Solar Heating & Cooling, International Energy Agency, 2012. Technology Roadmap Energy Storage, International Energy Agency, 2014. European Technology Platform on Renewable Heating and Cooling (various documents).

[2] “Thermochemical heat storage (TCS) - system design issues”, A.J. de Jong, C. Finck, H. Oversloot, H. van ‘t Spijker, R. Cuypers, Energy Procedia, 2014, 48, 309 – 319.

2. Materials Development

The basis for the compact thermal energy storage (CTES) is a salt hydrate. This class of materials was chosen because of their high potential storage density, given the heat demand temperatures for room heating and hot water preparation and the temperatures available for charging through solar thermal collectors.

A large literature search was done for salts suitable for the system concept envisioned within CREATE[i]. Out of hundreds of materials, potassium carbonate (K_2CO_3) was chosen as the salt of choice. At material level (crystal level), the energy density is 361 kWh/m³ and it has an output temperature of about 60°C when hydrated with 10 °C water vapour pressure. Furthermore, it has no health or environmental issues and the cost is about 1 €/kg.

Initially, different K_2CO_3-powders were characterized. In order to arrive at a structurally more stable material, composite granules were produced and characterised.

Figure 2: Granules of potassium carbonate (K_2CO_3) that were produced for the CREATE system.

Small samples of the material were cyclically charged and discharged, and the material proofed to be stable for at least 100 cycles, sufficient for application as seasonal storage material.

Two methods for stabilising the material came out as very promising, and one of these was produced on a larger scale for subsequent module and system testing and demonstration, while the second was produced on a somewhat smaller scale for module testing only.

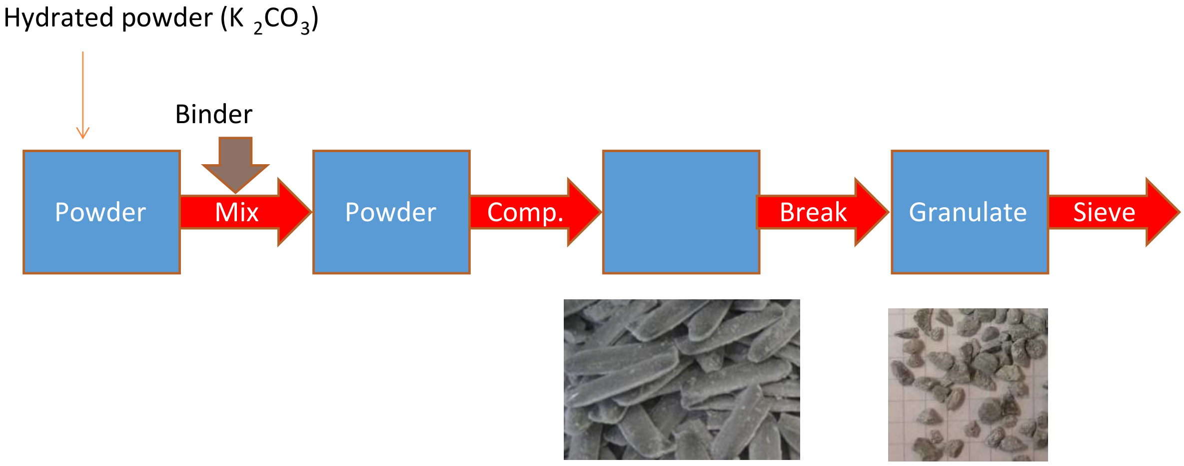

Figure 3: Schematic representation of the TCM production, ready for mass scale.

The chemical industries involved developed and tested a production method for the salt hydrate that can easily be scaled up, and then produced about 1,5 tonnes K_2CO_3. The production steps are shown in Figure 3.

After production, the salt was transported to the laboratory, different granule sizes mixed to give a better filling and then filled into the prototype modules, see Figure 4

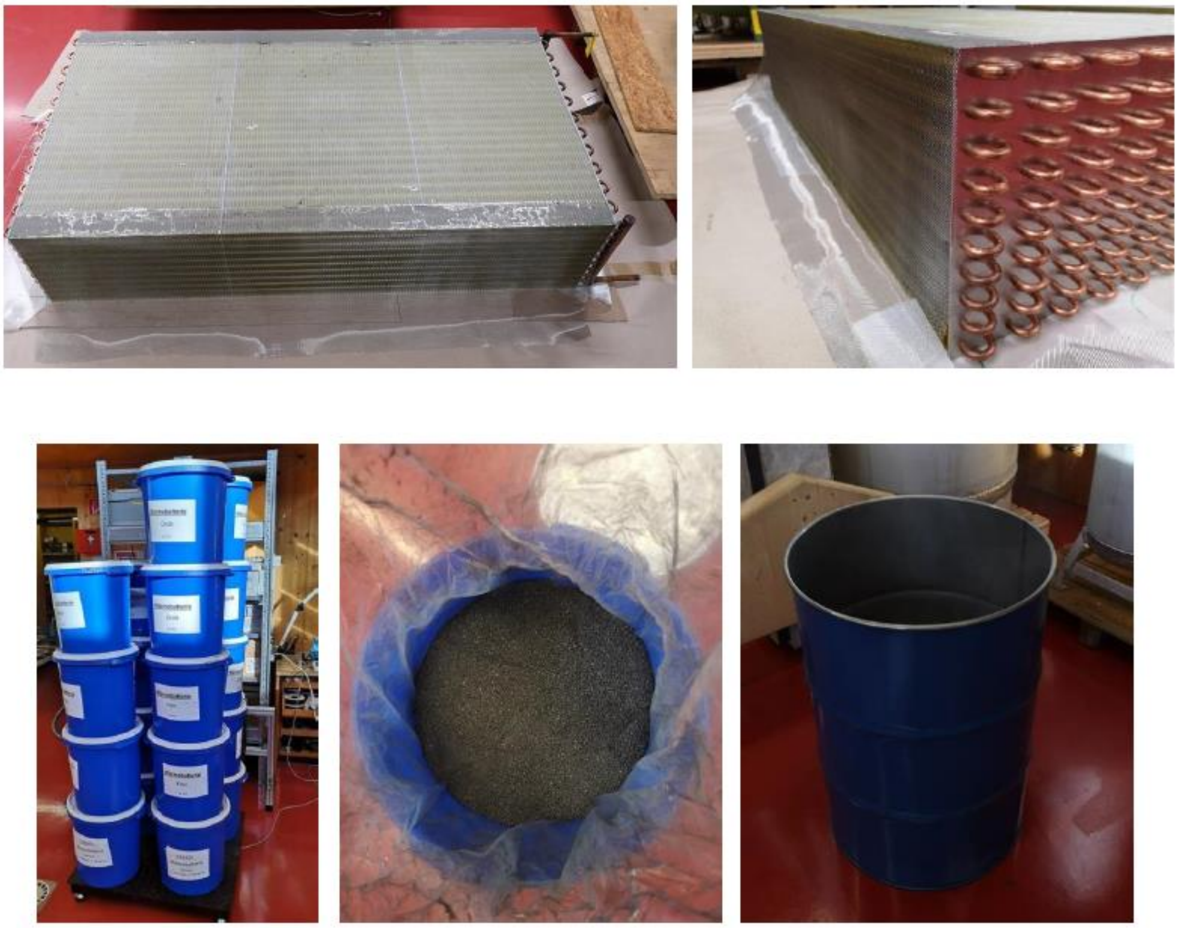

Figure 4: CREATE system module manufacture (Left to right; top to bottom: Heat exchanger top view; side view; 1m^3 TCM material packed in individual containers; TCM material; Drum for mixing different TCM grain sizes.

Regarding the production technology, a study was made into the cost of the different unit productions that are needed and with this, an estimate could be made of the final cost of the salt hydrate when mass produced.

Table 1: Breakdown of the costs for stabilized salt hydrate, when mass produced.

	CREATE Salt Plant [€/kg]
Yearly CAPEX	0.09
Yearly workers OPEX	0.13
Yearly OPEX for materials	1.11
Yearly OPEX for energy	0.02
TOTAL	**1.3**
TOTAL (with profit margin)	**1.6**

3. Storage Components

The CREATE system is composed of a number of standard components and some developed component. The low temperature source, the heat pump, solar collectors, pumps and the large water buffer are standard. CREATE developments are the modules and evaporator/condenser of the heat battery.

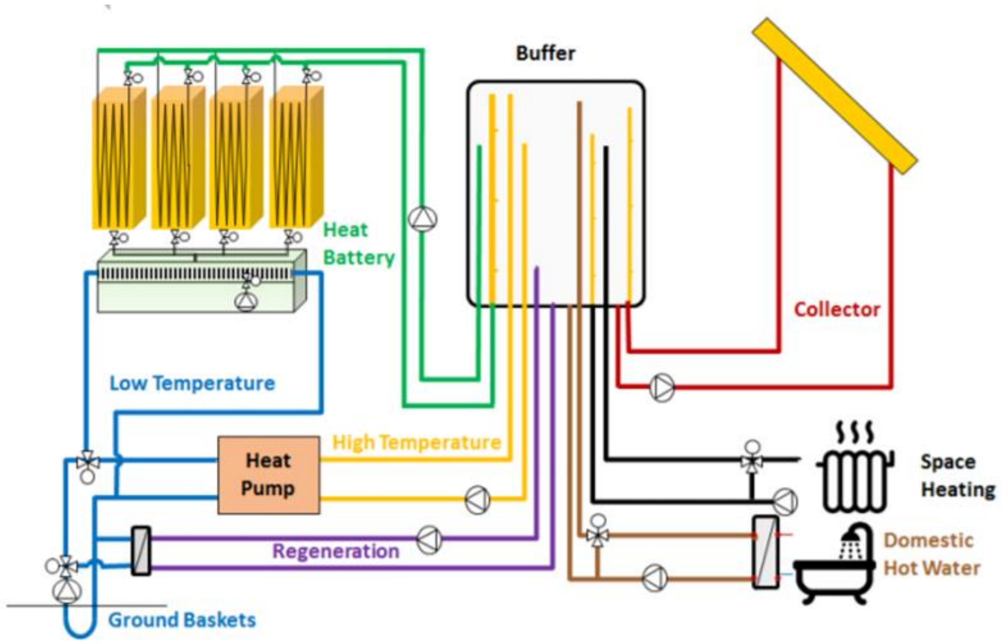

Figure 5: Schematic of the CREATE system.

3.1. Absorber modules

The heart of the storage is the component that enables the charging and discharging of the storage material. The principle is simple: it is a vacuum tight vessel that contains the salt in a heat exchanger. It has three connections with the exterior: the inlet and outlet of the heat exchanger pipes and a vacuum channel connection the absorber module with the evaporator/condenser, enabling the transport of water vapour under low pressure. The low pressure is needed to enable evaporation of water in the evaporator/condenser in winter to discharge the storage.

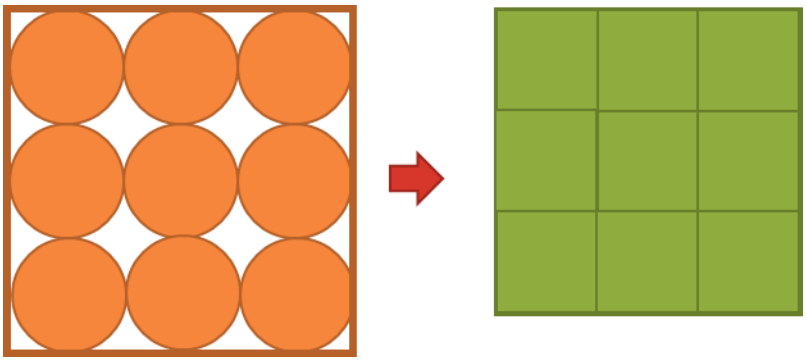

Figure 6: Prismatic storage design reduces space needs by more than 20%

The development challenges for the absorber module is a good vapour transport to all salt hydrate particles in the volume, a good heat transport from salt hydrate to the heat exchanger, minimal material use for the heat exchanger and the containment and a good filling of the available volume in a boiler room. The latter is sought in having a module with prismatic shape, leading to a more than 20% better use of the footprint in the boiler room than with standard, cylindrical containments. This leads to a new challenge: the module has to withstand the vacuum forces. In the chosen design, the heat exchanger is used to provide the strength for this.

The heat exchange between salt and heat exchanger has been developed and tested in three steps: first, with a 1 kg set up, then with a single module at about the real scale and finally with three modules that form the CREATE system.

The 1 kg set up was designed to measure the temperature distribution over time in the volume, with which the numerical simulation could be validated. Furthermore, it gave first insights into the achievable storage density on a component level. Third, a first test could be made on the structural stability of the material on a larger scale, through cycling experiments.

Figure 7: The filled 1 kg heat exchanger.

In a subsequent development step, a larger absorber module was designed, built and tested in the laboratory. This module had a storage volume of about 200 litres. With the module, charging and discharging power, cycling behaviour and temperature distribution were experimentally investigated. The power performance was less than the design power, leading to the decision to enlarge the volume of the modules for the CREATE system to 400 litres. The design of the internal fin and tubes heat exchanger was adapted accordingly.

It is worthwhile mentioning that this module was opened by sawing out one corner, enabling a visual inspection of the salt between the heat exchanger fins after about thirty cycles. A local crumbling of the salt grains was seen, although no decrease of performance over the cycles had been observed. The open absorber then was used for a technology exhibition at the Technical University Graz for a few months, showing the latest step in energy technology developments.

The third step was the absorber module for the CREATE system. This is a prismatic containment of 1.58 by 0.95 by 0.35 meters, that can carry about 400 litres of K_2CO_3. In Figure 8, the heat exchanger for the absorber module is shown on the left and the stainless steel containment on the right. After filling the heat exchanger with the salt hydrate the two are put together (middle) and finally a top plate is welded to the sides to close the module.

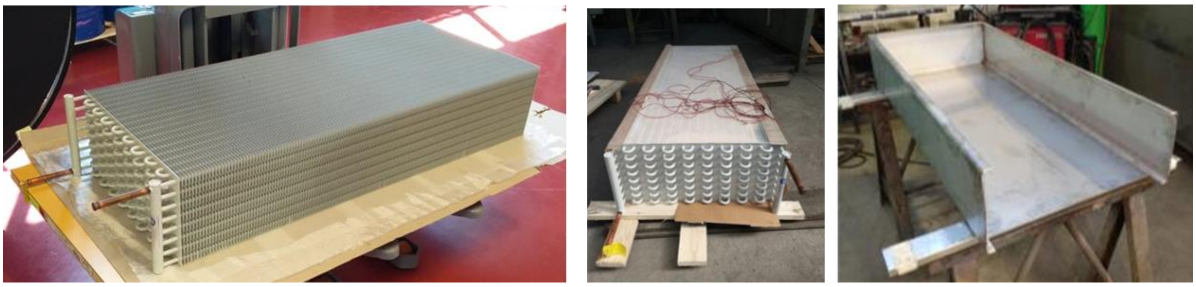

Figure 8: Absorber module heat exchanger (left photo) and containment (right photo) before and after assembly and filling with salt hydrate (middle photo)

This first prototype absorber module was used in an experimental set up (see Figure 9) to determine the dynamic behaviour during charging, discharging and in stationary mode. The results were used for validation of the numerical simulation and for final design of the control software of the CREATE system. Together with the module, the evaporator/condenser was tested.

Figure 9: The first prototype absorber module (to the right, packed in insulation material), connected to the evaporator/condenser in the middle and to a hot water tank to the left. The sources and sink were provided by the laboratory infrastructure.

3.2. Evaporator/condenser

This component is a heat exchanger in a vacuum containment that is used both for evaporating water at low temperatures for discharging the absorber module in winter and for condensing the water vapour that is produced by the charging in summer. The design challenges are the required power in both modes, with lowest temperature differences over the heat exchanger as possible. In practice, the condensation mode provides high power, while with evaporation the optimal wetting of the heat exchanger surface poses a challenge.
A number of basic heat exchanger geometries were tested: fin and tube, microchannel, falling film and corrugated tube. The corrugated tube proved to be the best option, combining simple design with the best powers. A design was made for three tacked stainless steel dishes, each containing 5 meters of corrugated stainless steel tube, see Figure 10.

Figure 10: Corrugated tube evaporator/condenser. In the middle the stacking of three dishes can be seen. Right: the evaporator/condenser built into the top part of a stainless steel cylinder. The bottom part of this cylinder is the condensed water storage.

4. System Development, Testing and Demonstration

All the developed components were assembled in the CREATE system. The heat battery (see Figure 11) consists of three absorber modules with 400 litres of potassium carbonate each, three vacuum valves, a vacuum tube and the condensed water vessel with evaporator/condenser built in.

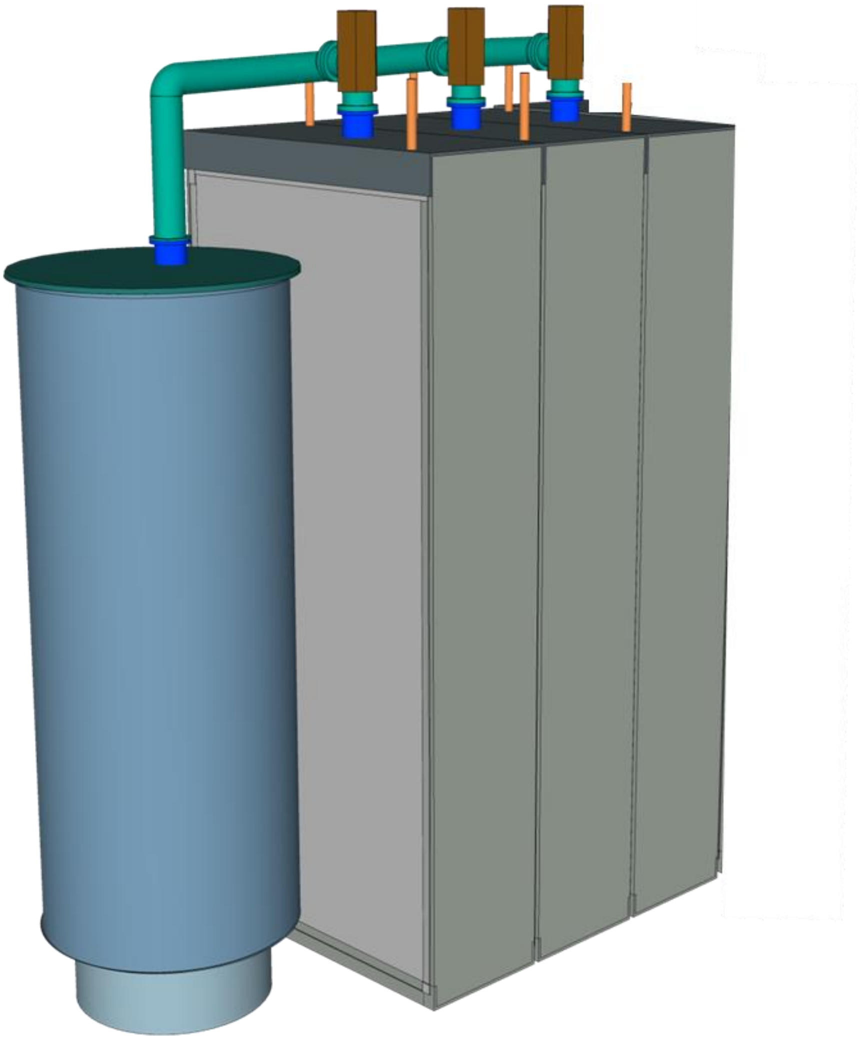

Figure 11: Schematic of the main components of the CREATE heat battery. On the left, the condensed water vessel with the evaporator/condenser built in. On the right, the three absorber modules containing 400 liters salt hydrate each. The green pipe on top is the vapour channel, connecting the evaporator/condenser with the three vacuum valves on top of the modules.

Next to the heat battery, the system consists of a buffer storage, a heat pump as back-up heater, an expansion vessel and a control unit. All components were built into a sea container. In this way, the system could be tested first connected to the laboratory infrastructure and then be shipped to Warsaw, Poland to be connected to the demonstration house.
Connected to the laboratory, the system was tested in a series of hardware-in-the-loop (HIL) experiments. In these, a system simulation program running on a computer determines the heat flows to and from the storage system. The simulation program emulates a house as heat demand

and a weather program plus solar collectors as heat source. With the HIL test, the performance of the individual modules in the heat battery and the control strategy was assessed and improved.

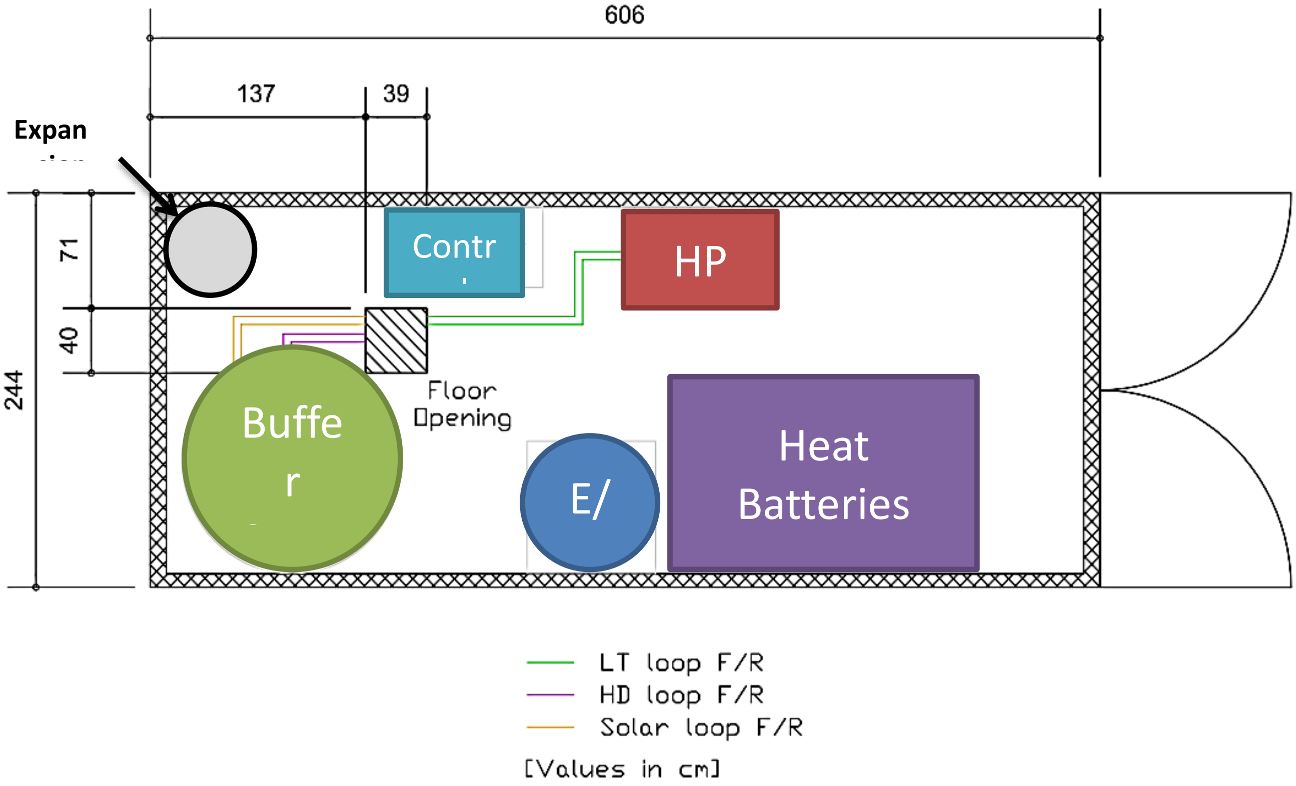

Figure 12: Layout of the components of the CREATE system in the container.

After the HIL tests, the system was decommissioned from the laboratory and prepared for transport. In July 2019, the system was transported from Austria to Poland (Figure 13)

Figure 13: The container with the CREATE system in from of the laboratory (left) and start of shipment from Austria to Poland (right)

In Warsaw, the CREATE system was connected to the demonstration house. The house is in use as an orphanage, reason why it is somewhat bigger than a single family house. Figure 14 gives the main data on this house.
Prior to the demonstration period. the house was prepared with the equipment needed for a good connection to the CREATE container. In the garden, a vertical soil heat exchanger was

installed to serve as heat source for the evaporator/condenser and the heat pump. On the roof, solar collectors were installed to serve as heat source for the heating and for the charging. The boiler room and the heating control were adapted for connection to the demonstration system. Finally, the radiators in the house were equipped with fans to increase their power and to lower the necessary supply temperature, enabling heating with the CREATE system.

Built year:	**2009**
Basement:	none
Overground storeys:	2 + attic
Useful space:	277,6 m^2
Building volume:	1258,5 m^3
External sidewalls:	plaster, aerated concrete 24 cm, mineral wool 12 cm, plaster
Roof:	gypsum-carton board, wooden structure, mineral wool 20 cm, wooden board, ventilation space, chipboard, galvanized steel sheet
Boiler room area:	7,1 m^2
Main heating source:	Bifunctional gas boiler 31 kW
Artificial heating source:	none
Heating system:	Conventional radiators; heating pipes placed in the floor
Mechanical ventilation:	none

Figure 14: The CREATE demonstration house in Warsaw, Poland. Visible are the 10 solar collectors that serve as heat source and the blue container with the CREATE storage system to the left. The table gives the main characteristics of the demo house.

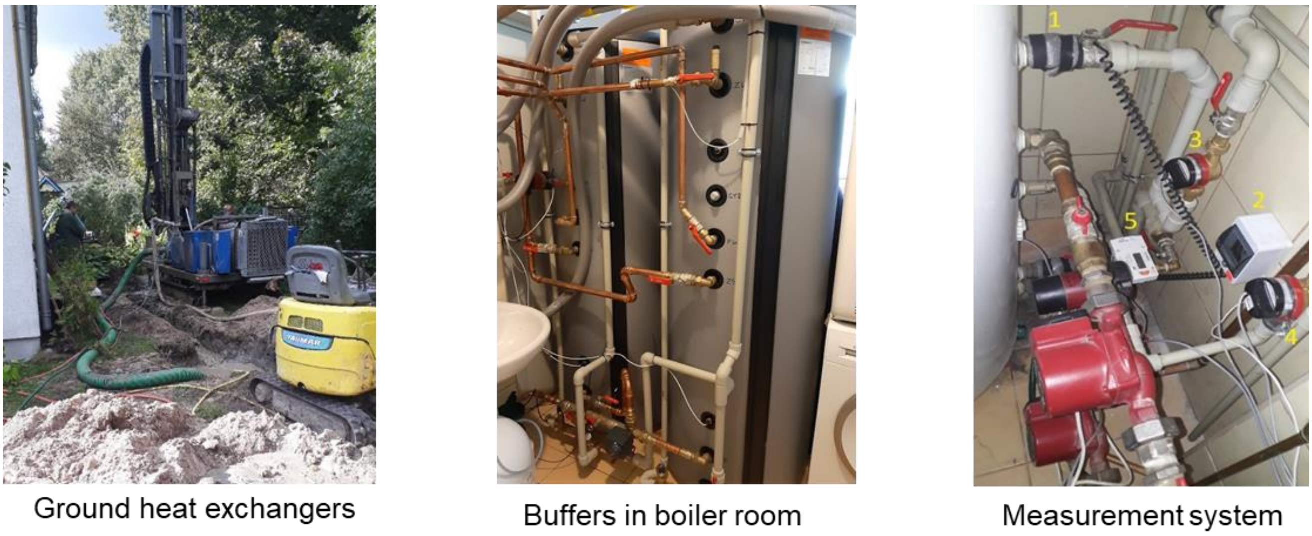
Ground heat exchangers
Buffers in boiler room
Measurement system

Figure 15: Installation of the vertical soil heat exchanger (left), the buffers (middle) and part of the measurement system (right) in the boiler room of the demonstration house.

After installation and commissioning tests, a demonstration test program was run. For about 6 months, the system was run in automatic mode and performed satisfactorily. There were no malfunctions. After the demonstration period, the system was decommissioned and the house went back to the standard heating system.

4.1. Measurement results

Throughout the project, the performance of the storage technology was tested and measured on different levels. The measurement results are summarised inTable 2.

Table 2: Overview of the experimental results with the three different volumes CREATE heat storage modules.

	1kg – WP5 (40/10)	WP6 (35/10)	WP7 – System (35/10)	WP7 – System HIL	
Energy	0,53	116	514	**523**	MJ
	0,15	32,2	143	**145**	kWh
Heating power	5	1657	1666	**1929**	W
Spec. heating power	4,7	6,6	4	**5**	W/dm³
Energy density (based on free volume of the HX)	550	461	409	**415**	MJ/m³
	153	128	113	**115**	kWh/m³
Energy density (based on full system)			197	**200**	MJ/m³
			55,4	**56**	kWh/m³

There are four levels of the heat storage that have been tested. First, the 1 kg set up that was used to determine the material performance and give feedback to the material development. Then, the first prototype of 200 litres (denoted WP6 in the table, as the work was done in Work Package 6). The final absorber modules, developed in WP7, were tested both in constant temperature mode (35 °C heat delivery and 10 °C evaporator temperature) and in Hardware-in-the-loop, HIL) configuration, in which the circumstances were much mor dynamic.

For every measurement, the energy stored is listed, together with the heating power, the specific heating power, the energy density based on the volume of the heat exchanger in the absorber module and the energy density based on the volume of the full system. The latter is included for a better comparison with alternative storage technologies, like hot water buffers.

Regarding the heating power, the HIL experiment showed a bit less than 2 kW, while the target was 2.5 kW. The limitation was caused by the evaporator. There was not sufficient time to improve the evaporator and in practice a lower than design power was no problem, as the buffer tank already served as power support.

Regarding energy density based in heat exchanger free volume, we see a decreasing value going from the smallest module to the bigger ones. With larger volumes, the effectiveness of the heat exchanger per volume of heat exchanger decreases and it is not obvious how this can be improved by the heat exchanger design. Nevertheless, the energy density of 115 kWh/m3 for the largest module in the HIL experiment is very good.

5. conclusions and outlook

The target of CREATE was to develop and demonstrate a heat battery, i.e. an advanced thermal storage system based on Thermo-Chemical Materials (TCMs), that enables economically affordable, compact and loss-free storage of heat in existing buildings.

The consortium developed a stable and compact salt hydrate (potassium carbonate) as compact thermal energy storage medium. It developed and tested a storage module that has a unique, prismatic shape in order to use the available volume as efficient as possible, with an internal heat exchanger to charge and discharge the salt and a central evaporator/condenser unit and condensed water storage vessel. The control algorithm was developed and tested. A demonstration system consisting of three compact storage units, evaporator/condenser, condensed water vessel, a buffer and auxiliary components was designed, built and tested in the laboratory, before it was shipped to a demonstration house in Warsaw, Poland, and demonstrated for a period of 6 months.
The project worked to have this system with the target to accomplish three breakthrough elements: economic affordability, compactness and no heat loss during storage.
Regarding **economic affordability**, the project finished while still not satisfying the element of economic affordability. Partly this is caused by the choice, demanded by an intervention by the EC, for a salt hydrate that has a lower storage density than the originally targeted salt hydrate, sodium sulphide. With the system configuration developed, and with the assumption of having a series production of 10.000 system per annum, the cost of the system is estimated at 30 k€, with a corresponding time for returning the investment of about 20 to 30 years. With a number of improvements identified, further cost reductions are possible and already have been taken up by a number of follow-up activities.
Regarding **compactness**, we have achieved 115 kWh/m^3 on storage module level and 347 kWh/m^3 on materials level (grain level). This is 63 % of the level that was targeted, taking into account that not the sodium sulphide, but the potassium carbonate had to be chosen, with its lower theoretical maximum storage density.
Regarding **no heat loss during storage**, the target was fully reached; the potassium carbonate completely held its storage potential between charging and discharging, as tested with both the first module and the three modules of the demonstration system.

With the development steps made, the CREATE consortium has made an important steps towards the future market introduction of compact thermal storage technologies.
In nationally funded follow-up projects both in The Netherland and in Austria, the technology will be brought further in technology readiness level.
In the Dutch follow-up, a large part of the CREATE consortium partners are working on a pilot for the potassium carbonate system, together with additional, new value chain partners.
And in Austria, the module design will be further developed with a different material and with Austrian value chain partners, and demonstrated in two different setting: as seasonal storage in a single family house and as short term storage for power to heat in a hotel/restaurant.

CREATE

Compact REtrofit Advanced Thermal Energy storage

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 680450

---

[i] https://doi.org/10.1016/j.apenergy.2017.04.080