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INNOVATIVE ICE STORE CONCEPTS WITH REDUCED RESOURCE DEMANDS

Summary

This contribution presents the main tasks and results of an ongoing project related to the development of innovative, solar-regenerated ice store concepts with lower ecological impact and lower costs than state-of-the-art concrete container based ice stores. The concept-specific challenges are outlined, and selected experimental and theoretical results for various innovative ice store concepts are presented and discussed.

Keywords: ice store, ice storage, thermal energy store, solar thermal, heat pump, life cycle assessment (LCA), life cycle costing (LCC)

Field of application for the findings: Solar thermal heating and cooling systems with seasonal storage; integration of ice store in building and district energy systems; reduction of resource demands

Addressed audience: Researchers and engineers in solar thermal energy, thermal energy storage, HVAC, and energy system planning for buildings and districts. Decision makers of municipalities.

1. Introduction

Ice stores are gaining increasing importance in the heating and cooling supply of buildings and districts. They can serve both as a long-term heat store in combination with a heat pump and as a cold thermal energy store for the cooling of buildings. Especially ice stores combined with heat pumps integrated in cold solar district heating networks have a great potential for decreasing CO_2 emissions from space heating in the building sector.

The work described in this contribution is part of a research project which aims at the development and implementation of innovative economically and ecologically beneficial underground ice store concepts for commercial use in solar cold district heating networks. The ice store concepts are designed for volumes between 100 m³ and 1 000 m³ and are intended to be trafficable by heavy-duty vehicles.

Currently, ice stores mainly use cost-intensive steel reinforced concrete tanks equipped with two heat exchanger coil loops. Their production is relatively energy-intensive, due to the use of concrete and steel, leading to significant greenhouse gas emissions. In contrast, the newly developed innovative container concepts aim to reduce the environmental impact and resource consumption by at least 50 % and costs by at least 20 %. This would enhance market penetration and reduce the ecological effects of this promising technology.

The main stages of the research project include the elaboration of innovative container concepts, life cycle assessment (LCA) and life cycle costing (LCC) analysis for both existing and new container concepts, the standardization of the concept, preliminary design, documentation and handover as well as the realization of the most promising ice store concept as a pilot in a field environment and pilot testing under various scenarios.

This contribution provides an overview of selected project results, focusing on the development of the various newly investigated ice store concepts.

2. Selection of innovative ice store concepts

Fig. 1 shows a schematic and a photograph of the currently most widespread concept for large-volume underground ice stores. It consists of a concrete container and two polymer heat exchanger coil loops mounted on an aluminum frame. One heat exchanger coil loop is used for discharging, and the other for charging the ice store. Fig. 2 shows a selection of innovative ice store concepts investigated in the research project.

Fig. 1: Concrete tank ice store concept. Left: 3D graphic providing an internal view of the ice store, showing the heat exchanger coils and their mounting (LTTT, 2025). Middle: photograph taken during the construction phase (Krug, 2019). Right: simplified schematic.

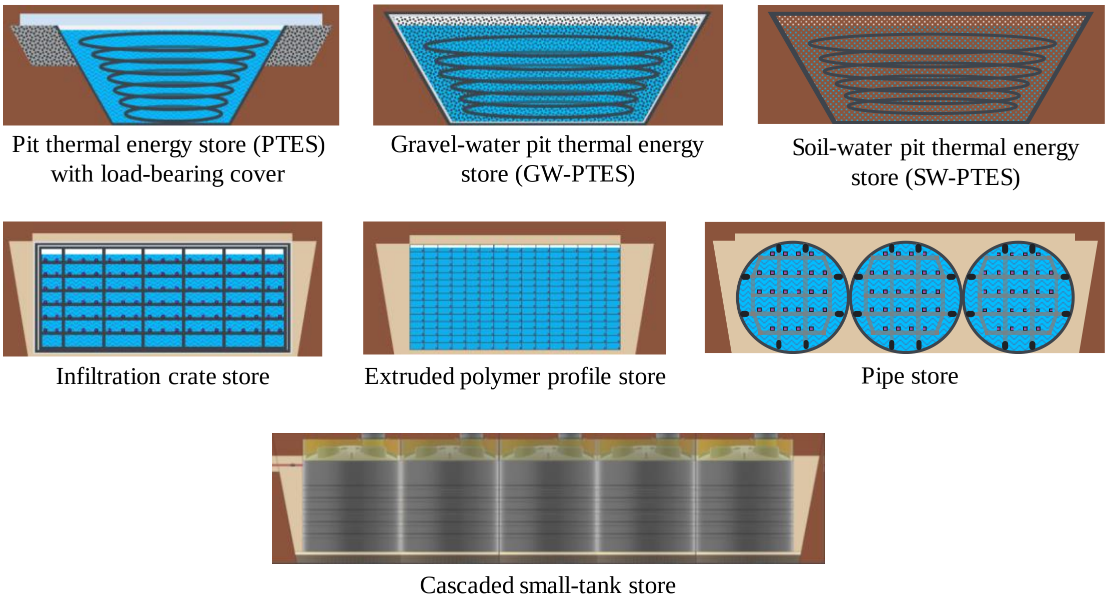

Fig. 2: Selection of innovative ice store concepts investigated within the research project

Pit thermal energy stores (PTES) and gravel-water pit thermal energy stores (GW-PTES) have already been used as seasonal hot water stores for decades. However, PTES have never been constructed with a cover that allows trafficability by heavy-duty vehicles. GW-PTES provide the required trafficability due to the densified gravel fill. Neither concept was originally designed for use as an ice store. However, the formation of ice with a small volumetric fraction was considered in one low-temperature GW-PTES [Streit, 1996]. In soil-water pit thermal energy stores (SW-PTES), the excavated soil is used as the load-bearing structure instead of gravel. This reduces the resources required for gravel and its transportation, as well as for the removal and disposal of the soil. The gravel or soil serves not only as a load-bearing structure to ensure trafficability, but also as a support structure for the heat exchanger coil loops.

Typically, infiltration crates are installed underground for rainwater infiltration in so-called infiltration trenches. If the rainwater is to be stored, several crates are assembled and enclosed within a waterproof liner. The crates are typically made of polypropylene (PP) and are designed to be trafficable by heavy-duty vehicles. An innovative approach is using the crates as elements for an ice store. In this case the crates could be pre-assembled into modules of a size suitable for road transport and equipped with integrated heat exchanger pipes. Enclosure in a waterproof liner prior to installation is also feasible. On site, the heat exchanger pipes of the individual modules must then be connected to each other or to a supply and return manifold.

Using extruded polymer profiles as an ice store also represents a novel approach in which the container, including the heat exchangers, is manufactured in a single production step. The entire store can be assembled from multiple profiles of a size suitable for road transport. This concept significantly reduces assembly work, as on site, the individual modules only need to be connected to each other.

Underground, horizontally installed polymer pipes with diameters of around 3 m are currently used for the storage of drinking water or firefighting water. Equipped with heat exchangers, these pipes could also serve as ice stores.

Commercially available underground polymer tanks with volumes of up to 20 m³ are currently used as small ice stores, mainly for single-family houses. These comparatively small tanks could be combined in a cascaded configuration to realize ice stores with volumes between 100 m³ and 1,000 m³ ("cascaded small-tank store"). However, the tanks currently available still require structural stabilization to ensure trafficability by heavy-duty vehicles.

3. Investigations and selected results

In this chapter, the main areas of investigation for the different ice store concepts are described, and selected results for the infiltration crate store are presented.

For PTES, the main focus is on investigating different roofing options, including their structural bearings. For GW-PTES and SW-PTES, design and sizing of load-bearing heat exchanger pipes represent one of the primary fields of investigation. In the case of SW-PTES, suitable soil types must additionally be identified to enable ice formation without frost heave. This concept is only trafficable if such soil is available on site. The extruded polymer profile store must be developed entirely as a new concept. Initial investigations focus on the design and cost assessment of the extrusion die, as well as the dimensioning of the load-bearing structure using FEM simulations. For the pipe store, different heat exchanger options and their mounting systems constitute the main areas of investigation, while for the cascaded small-tank store, various approaches to increasing the load-bearing capacity are being evaluated.

Most commercially available infiltration crates are primarily made of polypropylene (PP) and are not certified for use at temperatures ≤ 0 °C, as PP becomes brittle at such temperatures. Therefore, testing the compressive strength of one of the most promising types of infiltration crates was the most important experimental investigation conducted for this ice store concept.

The most promising type of infiltration crates was tested for compressive strength based on EN 17150:2019. Three crates were tested at the local ambient temperature of approx. 10 °C and three at approx. -8 °C. The crates tested at approx. -8 °C exhibited a mean peak load 47.5 % higher and a mean strain at peak load 7.5 % lower than those tested at ambient temperature. The crates tested at approximately -8 °C predominantly failed by brittle fracture, whereas those tested at ambient temperature predominantly exhibited plastic deformation. However, both peak load and failure at -8 °C occurred at loads significantly higher than those required for the designated trafficability. In the author's assessment, the test results presented do not warrant excluding the use of the tested infiltration crates at temperatures between -8 °C and 0 °C. However, the crates were tested only in air and not in an environment typically for the use as an ice store. The mechanical performance in partially frozen water containing heat exchanger pipes, as encountered in an infiltration-crate ice store, still needs to be investigated.

The methodology and results of these and further investigations of the different ice store concepts will be presented and discussed in more detail in the full-length paper.

4. References

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