Evaluation of Operation Strategies for Multi-Basin Water–Gravel Seasonal TES in a Thermal Source Network

Summary

Seasonal mismatches in thermal source networks (TSNs) motivate the use of seasonal thermal energy storage (sTES) to reduce auxiliary heating and cooling. This work compares rule-based charging and discharging strategies for multi-basin water–gravel sTES integrated within TSN model developed in MATLAB/Simscape, parameterized using sTES design of the incampus demonstrator (Germany). The analysis compares strategy variants with different levels of basin activation (single vs. multiple basins), source handling (single vs. multi-source), and operating mode (heat-only, cold-only, combined heat–cold), and evaluates performance using seasonal energy balance, heating/cooling demand coverage, auxiliary energy reduction, and cost indicators. A preliminary comparison shows that a coordinated multi-source operating strategy (S3) increases heating and cooling coverage by 8% and 5%, respectively, while reducing auxiliary energy by 9% (heating) and 7.5% (cooling), relative to baseline scenario (S0). Overall, the results clarify how basin selection, source prioritization, and mode switching influence the utilization of multi-basin sTES to TSN operation and provide a basis for selecting robust strategies for further control development.

Keywords: Thermal source network, seasonal TES, multi-basin sTES, multi-source sTES operation

Field of application for the findings: Operational planning of seasonal TES in low-temperature district heating and cooling networks; Charging/discharging control logic for multi-basin and multi-source districts.

Addressed audience: Design engineers, operators and *researchers working on sTES, district heating and cooling, system simulation and digital twins, and practical control concepts for low-temperature networks.*

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1. Introduction

While TSNs enable bidirectional energy exchange (Buffa et al. 2019), seasonal mismatches persist and motivate the integration of sTES (Jodeiri et al. 2022); however, despite extensive research focusing on insulation, geometry, and stratification, most studies still treat sTES as a single stratified volume and rarely examine the operational implications of multi-basin configurations (Xiang et al. 2022; Bott et al. 2022).

Beyond heat-only applications, sTES is increasingly considered in systems providing both heating and cooling services (Bolton et al. 2023). Bidirectional network operation enables interaction with multiple sources, including solar, waste heat, ambient sources, and heat pumps (Buffa et al. 2019). The IEA-DHC Task C report demonstrates the techno-economic feasibility of multi-basin pit configurations and highlights the complexity of parallel charging and discharging processes (IEA DHC 2020). Nevertheless, systematic comparison of charging and discharging strategies that simultaneously address multi-basin coordination, multi-source charging, and combined heat–cold operation within TSNs remains limited.

Our study addresses this gap by benchmarking charging and discharging strategies for a multi-basin water–gravel sTES integrated into TSN, based on three-basin configuration implemented at incampus, Germany.

2. Methodology

2.1 Use case: incampus

Our study is based on sTES being retrofitted from old fire extinguisher water basins at incampus, an industrial park in Ingolstadt, Germany. Incampus comprises a TSN currently supplying five buildings equipped with decentralized heat pumps. It makes incampus a suitable real-world test case for evaluating how coordinated charging and discharging of a multi-basin sTES can improve seasonal balancing, operational flexibility, and network performance. Incampus sTES consists of three hydraulically connected water–gravel basins (denoted A, B, and C), each coupled via a controllable hydraulic interface that enables charging and discharging at variable temperature levels. Depending on the selected operating strategy, basins can be activated individually or simultaneously, and the storage can be used in heat-only, cold-only, or combined heat–cold operation.

A dynamic, physics-based simulation model is developed in MATLAB to represent thermo-hydraulic behavior of incampus TSN (Figure 1). It includes building load profiles, HP substations, uninsulated piping block, energy hub, and hydraulic coupling between TSN and multi-basin sTES. Since the TSN is already in operation, consistency checks against available network measurements are made, while validation of the sTES operation will be completed once the three-basin storage is commissioned and monitoring data become available.

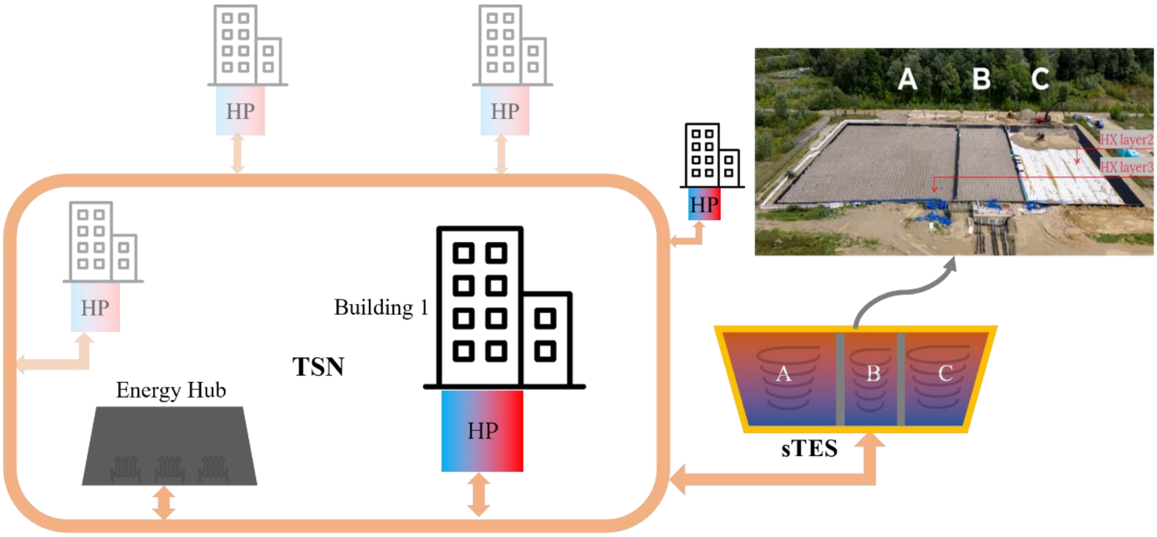

Figure 1. incampus TSN schematic layout with current construction status of sTES (top-right).

2.2 Charging and discharging strategies

The operation of the three-basin sTES is governed by a rule-based controller that decides (i) which basin(s) are activated, (ii) which source/sink is selected, (iii) whether basins are operated sequentially or in parallel, and (iv) whether the sTES is operated in heat-only, cold-only, or combined mode as depicted in Figure 2.

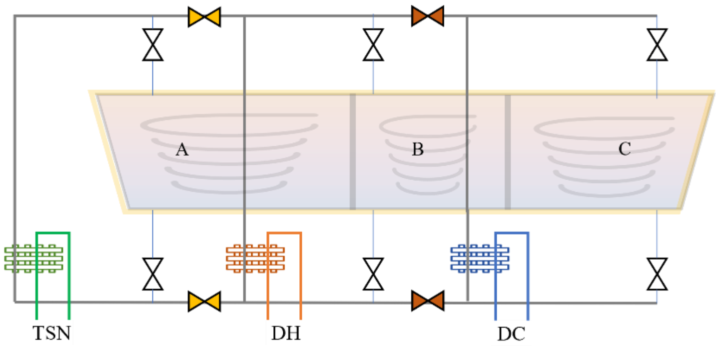

Figure 2. Hydraulic concept for the three-basin (A–C) water–gravel sTES at incampus and its interfaces to the TSN, district heating (DH), and district cooling (DC).

Charging and discharging decisions are triggered by feasibility checks based on temperature matching between the selected source/sink and the target basin, using minimum temperature threshold (ΔT_{min}=2 °C). The benchmarking varies the level of basin coupling (one versus multiple basins activated at a time), activation of multiple available sources, and the hydraulic utilization pattern (e.g., sequential versus parallel activation as shown in Table 1.

Table 1. Rule-based operating strategies for multi-basin sTES at incampus.

ID	Basin activation	Source handling	Basin utilization	Service mode	Detail
S0	Single	Single	-	Heat-only	Single-basin baseline with ΔT feasibility and hysteresis
S1	Single	Single	-	Cold-only	Cold-mode baseline (mirror of S0)
S2	Multiple	Single	Sequential	Heat-only	Parallel charging/discharging to increase power capacity; equal flow split
S3	Single	Multiple	-	Combined	Source prioritization with mode selection
S4	Multiple	Multiple	Parallel	Combined	Source prioritization + basin selection; seasonal or TSN-temperature switching
…	…	…	…	…	…

3. Results and Outlook

Benchmarking under identical boundary conditions indicates that the charging and discharging strategy has a decisive influence on how effectively the multi-basin sTES contributes to TSN operation. The comparison shows that performance depends not only on the number of active basins, but also on how basin selection, source handling, sequential/parallel activation, and heat–cold mode switching are combined. Overall, coordinated strategies can improve seasonal demand coverage and reduce auxiliary energy use; however, the results also indicate that increased control complexity does not automatically yield better overall performance. To provide an initial quantitative assessment, Figure 3 reports preliminary results comparing baseline operation S0 (single-source, single-basin operation) with a coordinated multi-source, single basin scenario S3.

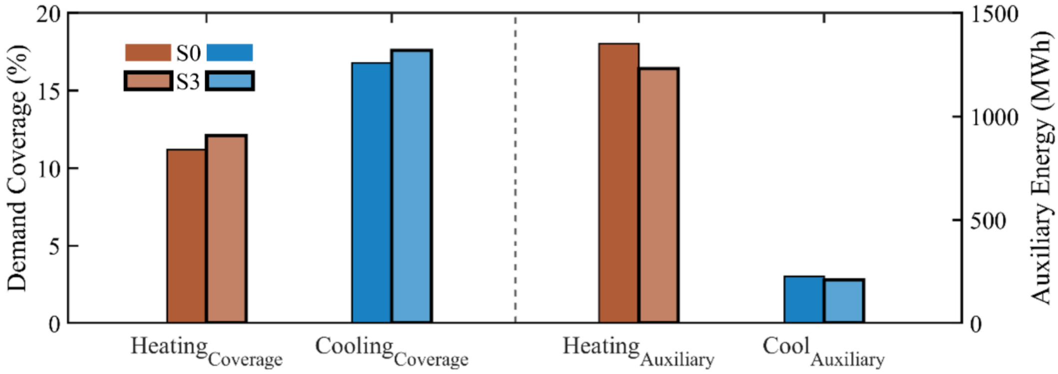

Figure 3. Comparison of baseline operation S0 (single-source, single-basin) and coordinated multi-source strategy S3.

The study confirms that coordinated sTES operation can increase utilization and reduce auxiliary energy need. The full benchmarking across heat-only, cold-only, and combined heat–cold operation is used to identify which rule-based strategies provide the most robust balance.

As an outlook, the identified robust benchmark strategies will be retained as a reduced strategy set for multi-basin sTES operation at incampus. These strategies will also serve as a reference baseline for subsequent work, in which current sTES control (rule-based) is extended toward model predictive control to optimize basin activation and source utilization over a moving horizon.

4. Publication bibliography

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