EXPERIMENTAL PERFORMANCE ANALYSIS OF A THERMAL ENERGY STORAGE USING PHASE CHANGE MATERIALS FOR FLEXIBLE SECTOR COUPLING IN NORDIC CLIMATES

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Abstract

This study presents the laboratory characterisation of thermal energy storage (TES) using a phase change material (PCM) designed to be integrated with a heat pump, enabling flexible sector coupling (FSC) between renewable electricity generation and building thermal demands. The research focuses on the experimental performance evaluation of a PCM-TES configuration, which achieves a 69 kWh/m^3 storage capacity, designed for residential space heating applications. The PCM used is RT57HC, with a melting temperature between 57-60 °C and a melting enthalpy of 246 kJ/kg. The laboratory analysis here uses an electric heater to emulate a heat pump thermal input while utilising a water tank for heat rejection, enabling systematic assessment of storage behaviour across varied charging and discharging scenarios. Comprehensive testing protocols evaluated critical performance metrics, including thermal power delivery ranging from 5-25 kW, and operational efficiency of 88 %, under diverse flow rate and inlet temperature conditions. Experimental findings provide essential data for subsequent integration with actual heat pump systems at the chosen pilot site: a Live-in-Lab facility, advancing grid flexibility service capabilities, renewable energy utilisation of building energy systems and hence FSC with TES, in Nordic residential heating applications.

Keywords: thermal energy storage (TES), phase change material (PCM), flexible sector coupling (FSC), Heat pump (HP), renewable integration, energy flexibility

1. Introduction

The transformation of global energy systems towards renewable sources has introduced complex operational challenges for electrical grid management and energy security. Nordic nations, including Sweden, face particular difficulties in managing the variability and intermittency associated with wind and solar power generation (Holmberg & Tangerås, 2023). These challenges are compounded by the region's climate characteristics, which create distinct seasonal energy demand patterns that often do not align with the availability of intermittent renewable resources such as solar and wind. Swedish energy policy demonstrates the scale of this transformation challenge. Current governmental strategies project that photovoltaic installations could contribute between 5-10% of national electricity consumption by 2040, equivalent to approximately 7-14 TWh annually (Swedish Energy Agency, 2023). This expansion will create substantial grid management complexities requiring innovative storage and demand response solutions.

Flexible sector coupling (FSC) strategies have gained recognition as effective mechanisms for managing renewable energy variability through cross-sectoral energy flow optimisation, with flexibility enabled by energy storage (IEA ES Task 35, 2023). These approaches enable strategic coordination between electrical, thermal, and transportation energy demands to maximise renewable utilisation while maintaining system stability. Concerning the thermal and electrical sectors, particularly heat pumps when combined with thermal energy storage (TES) can provide robust thermal-to-electrical FSC solutions (IEA ES Task 35, 2023)

Residential heating represents a significant opportunity for flexibility provision, given the substantial energy requirements for space heating and domestic hot water, which accounts for 79% of the total energy used in EU households (Romanchen et al., 2019). Residential thermal applications present attractive targets for implementing sector coupling due to their significant energy consumption and inherent thermal inertia characteristics. Heat pump technologies have experienced widespread adoption across Sweden due to their operational efficiency and compatibility with electrical grid integration. However, direct integration of heat pumps with variable renewable sources creates operational complications when thermal demands do not coincide with optimal generation periods,

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necessitating intermediate energy storage solutions (Nicoletti, Ramundo, & Arcuri, 2024).

Phase change material (PCM) technologies offer enhanced TES capabilities compared to conventional sensible TES systems through their ability to store substantial energy quantities at nearly constant temperatures during phase transitions (Enasel & Dumitrascu, 2024). These materials demonstrate superior energy density characteristics and more predictable thermal output behaviour, making them particularly suitable for residential applications with space constraints. When combined with heat pump systems, PCM-TES can enable strategic electricity consumption during optimal renewable generation periods (i.e., lower cost periods) while maintaining thermal output through stored energy during generation deficits (Huang et al., 2024), this enabling FSC.

The implementation of PCM-TES in Nordic residential heating applications requires a comprehensive understanding of performance characteristics under specific climatic and operational conditions. A controlled laboratory investigation provides an essential foundation for the development and optimisation of PCM storage systems before implementation in a building heating application. Laboratory testing enables systematic performance characterisation across diverse operating conditions while generating critical data for system sizing, control strategy development, and performance modelling.

2. Methodology

The study examines the laboratory validation and performance characterisation of a PCM storage system engineered to support heat pump operation in residential space heating applications. This experimental analysis provides characteristic data of PCM-TES for subsequent integration with actual heat pump systems in operational building environments, advancing the development of reliable TES solutions for enhanced renewable energy utilisation. The experimental methodology of the laboratory analysis is explained here.

2.1 System Design and Configuration

The experimental approach employed a systematic design methodology based on a comprehensive analysis of heating demand characteristics from residential building applications. Three years of thermal load data from the chosen Live-in-Lab (LIL) facility provided the foundation for determining optimal storage specifications and operational parameters. This data-driven approach ensured that the storage system dimensions and thermal capacity aligned with realistic residential heating requirements. The analytical framework incorporated both daily and seasonal demand variations to establish appropriate sizing criteria for the PCM-TES configuration. As an example, Figure 1 shows a daily space heating demand curve in the LIL with the electricity price variation over the same day.

The thermal storage system is a packed-bed configuration utilising the PCM RT57HC (RUBITHERM, 2025) encapsulated within Heat Sel Quad (AXIOTHERM, 2025) capsules. A total of 515 PCM capsules, totalling approximately 146 kg of RT57HC, were packed within a cylindrical stainless steel vessel with a packed-bed volume of 0.48 m^3. The void fraction of the PCM-TES is 0.56, which also denotes the amount of water inside the PCM-TES packed bed by volume. The PCM RT57HC undergoes both a solid-liquid and a solid-solid phase change over the full temperature range of operation: 25-70 °C. These phase change temperature ranges are 55-58 °C and 53-57 °C, with the respective solid-liquid and solid-solid phase change enthalpies 246.35 kJ/kg and 242.3 kJ/kg (Xu & Yu, 2025). Water serves as the heat transfer fluid (HTF), flowing through the packed bed to facilitate thermal energy exchange with the encapsulated PCM.

The PCM-TES was designed to deliver a total TES capacity of at least 21 kWh, with charging and discharging power capabilities of 5-15 kW, depending on the flow rate. As it can also be observed from Figure 1 that the demand looks almost constant over the day, which was a trend for most of the heating season, hence targeting the electricity price peaks, which generally last for 2-5 hours, as seen in Figure 1, was one of the key design parameter which will help in supplementing the heat pump during those periods. This capacity specification was determined through the analysis of peak heating demands at the LIL facility, which experiences maximum thermal loads of approximately 12 kW during extreme cold periods, while the heat pump has a nominal capacity of 18 kW. The 5-15 kW discharging capacity enables effective peak price shaving during high-demand periods and also gives flexibility in choosing different discharging scenarios. Figure 1 shows a daily demand curve in LIL with the electricity price variation over the same day

Figure 1: : A chosen representative day's (21st December 2024) space heating demand curve of the chosen LIL compared with the electricity price variation over the same day

2.2 Laboratory Test Configuration and Instrumentation

The experimental characterisation was conducted in a controlled laboratory environment utilising a representative test configuration that emulates actual building components with equivalent thermal loads and sources. Figure 2 The experimental setup's piping and instrumentation diagram (P&ID) shows an electric heater, water tank, and PCM-TES. An electric heater with 9 kW capacity replaced the heat pump source, providing precise and controllable thermal input for charging operations.

Heat rejection during discharging operations utilises a 1 m³ rectangular water tank made up of HDPE serving as a controlled thermal sink, replacing actual building heating distribution systems. This configuration enables precise monitoring of thermal output through a 4-wire PT 1000 resistance temperature detector (RTD), while maintaining controlled boundary conditions for systematic performance evaluation. The heat sink temperature can be regulated to simulate different building return temperatures and thermal demands, providing flexibility in testing various operational scenarios. Figure 2 This shows the detailed schematic of the experimental setup. Charging the PCM-TES is done from top to bottom i.e , using the inlet at the top and the outlet at the bottom. For the discharging process, this process is reversed using a three-way valve (MV1) with the inlet at the bottom and the outlet at the top.

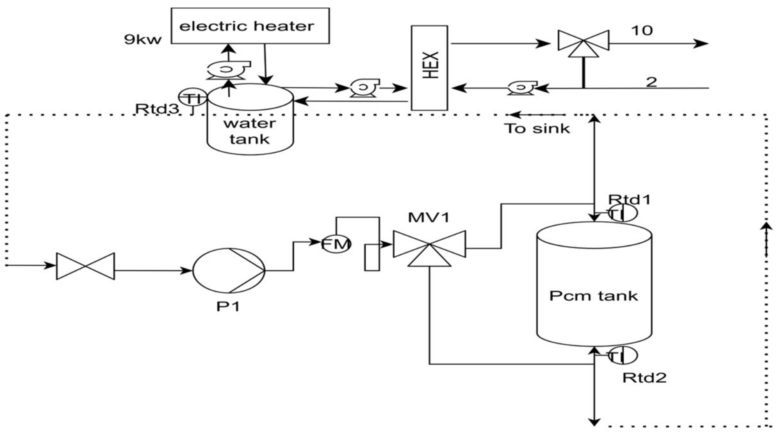

Figure 2: Piping and instrumentation diagram (P&ID) of the laboratory experimental test setup of the PCM-TES, with an electric heater emulating the heat pump supply with a water tank representing both the heat source and sink

The instrumentation system incorporates 15 strategically positioned 4-wire PT1000 RTD temperature sensors distributed throughout the PCM-TES vessel and its supporting thermal circuits. The temperature sensors inserted into the PCM_TES particularly enable the monitoring of spatial temperature distribution progression during charging and discharging cycles, as can be seen in Figure 3. The electromagnetic mass flow meter (Yokogava AXR) provides continuous measurement of HTF flow rates with accuracy suitable for energy balance calculations. Figure 3 gives a detailed view (both front and top) showing the exact points and insertion depths of the RTDs inside the PCM-TES. The top view shows the angle (approximately 120 degrees) at which the sensors are with respect to each other. The total volume of the tank is 0.606 m^3, including the distribution region and the packed bed volume (0.48 m^3). Additional instrumentation includes circulation pumps (P1) with variable speed control, precision control valves, and a comprehensive data acquisition system operating at 5-second intervals to capture transient thermal behaviour during phase change processes.

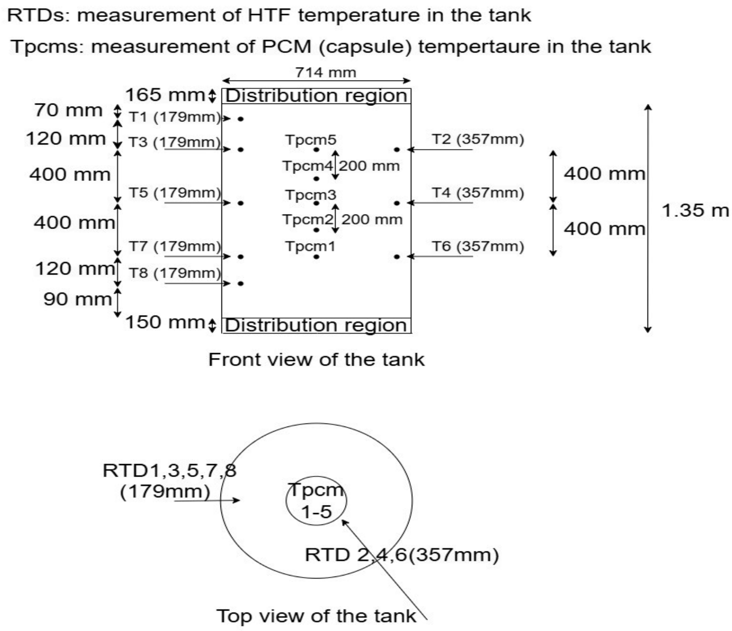

Figure 3: Temperature sensor (RTD) arrangement on the PCM storage

2.3 Experimental Testing Protocol and Performance Evaluation

The experimental investigation employs a comprehensive testing matrix designed to characterise TES performance across operational ranges relevant to the considered residential heating application. Table 1 and Table 2 respectively present the test matrix for charging and discharging that was used for characterising the TES.

Charging tests examine thermal input temperatures ranging from 65 °C to 70°C at the storage inlet, with HTF flow rates varied between 0.15 m³/h and 0.60 m³/h, to investigate the influence of flow velocity on heat transfer effectiveness and charging duration. Each charging cycle was continued until thermal equilibrium was established throughout the storage volume. Discharging evaluation utilises heat sink temperatures between 25-35°C and flow rate variations ranging from 0.15 to 0.60 m³/h. This process continues until discharge is completed, which occurs when the outlet temperature approaches the inlet conditions, meaning when the difference between inlet and outlet temperature is less than or equal to 1°C. Table 1 and Table 2 show the test matrix for charging and discharging that was used for characterising the storage.

Table 1: Charging test matrix

Flow rate (m³/h)	Target charging temperature (°C)
0.15	65
0.25	65,70
0.35	62,65,70
0.5	65
0.6	62,65

Table 2: Discharging Test matrix

Flow rate (m³/h)	Inlet temperature (°C)
0.15	25-30, 30-35

0.25	25-30, 30-35
0.35	25-30, 30-35
0.5	25-30, 30-35
0.6	25-30, 30-35

Energy capacity assessment involved integrating thermal power measurements over complete charging and discharging cycles. Temperature differentials between the inlet and outlet streams, combined with mass flow rates, enable the calculation of instantaneous energy transfer denoted by equation 2. The total stored energy is determined by cumulative integration until thermal equilibrium or complete discharge conditions are reached. Charging power evaluation examines thermal input rates under varying HTF flow conditions and inlet temperature ranges, capturing peak thermal transfer rates during initial heating phases and sustained power levels during phase change periods which is calculated using equation 1. Discharging power assessment evaluates thermal output rates under variable demand conditions, with peak discharge power occurring during initial temperature drops and sustained power during phase change periods. Operational efficiency evaluation compares energy input during charging with energy output during subsequent discharging (under the same initial and final temperature range and HTF flow rates), thus indicating thermal losses to ambient conditions and accounting also for some differences in initial conditions during charging/discharging. Only HTF temperatures were used to measure the energy capacity, not PCM temperatures, because data from only one capsule was used due to water incursion in the sensors of other capsules, making them prone to measurement error.

Comparison of PCM-TES with a sensible storage is relevant for the analysis, so a sensible storage with the same volume as the PCM-TES (0,606 m^3) and having the same reference temperature (from 25 °C to 65 °C) with just water inside the sensible storage was also calculated using equation 1.

$$P(t) = \dot{m}(t) * c_p * (T_{outlet} - T_{inlet}) \qquad \text{(eq. 1)}$$

Where $P(t)$ = Instantaneous power (W)

$\dot{m}(t)$ = Mass flow rate of HTF (kg/s)

c_p = Specific heat capacity of HTF (J/kg*k)

$$E = \sum_{i=1}^{n} P(i) * dt(i) \qquad \text{(eq. 2)}$$

where P(i) = Instantaneous power at time step i (W)

$dt(i)$ = time interval (5 seconds)

E = Energy capacity (J)

n = total number of time steps

3. Results and Discussion

The experimental investigation provided comprehensive performance data of the PCM-TES system under various operational conditions. This section presents the charging performance followed by the discharging performance, examining energy capacity, instantaneous power, and thermal behaviour.

3.1. PCM-TES Charging

The charging performance of the PCM-TES system was systematically evaluated to understand the energy storage behaviour under varying thermal input conditions. Table 3 summarises the charging performance across inlet temperatures ranging from 62°C to 70°C with flow rates between 0.25 and 0.6 m³/h. The results demonstrate clear temperature dependency, with energy capacity increasing from 39.6 kWh at 62°C to 45.2 kWh at 70°C inlet conditions. This represents approximately 13% higher storage capacity at the elevated temperature 70°C, though this gain primarily reflects increased sensible heat contribution rather than enhanced latent heat utilisation. The charging duration shows relatively consistent values between 6 and 8 hours across most test conditions, indicating less sensitivity to flow rate variations compared to discharge operations. The initial average temperature of the PCM-TES was 25 °C for all the charging tests.

Figure 4 illustrates the cumulative energy accumulation during charging for different temperature-flow rate combinations. All charging curves exhibit rapid initial energy uptake during the first 2 hours corresponding to sensible heating, followed by a more gradual increase between 2-5 hours as the PCM undergoes phase transition. The higher supply temperature cases (65°C and 70°C shown) achieve greater final storage capacities and demonstrate slightly faster charging kinetics during the initial phase. Beyond 5 hours, all curves reach a plateau (i.e., stabilization) as the PCM approaches complete melting and thermal equilibrium with the HTF inlet conditions.

Table 3: Test results for charging

No.	Inlet temperature (°C)	Flow rate (m^3/h)	Energy capacity (KWh)	Charging time (Hour:minute)
1	62	0.5	39.6	6:25
2	62	0.6	39.6	7:15
3	65	0.25	42.5	8:26
4	65	0.35	44.0	7:27
5	65	0.5	43.4	5:58
6	65	0.6	42.9	5:10
7	70	0.25	44.9	7:57
8	70	0.35	45.2	6:09

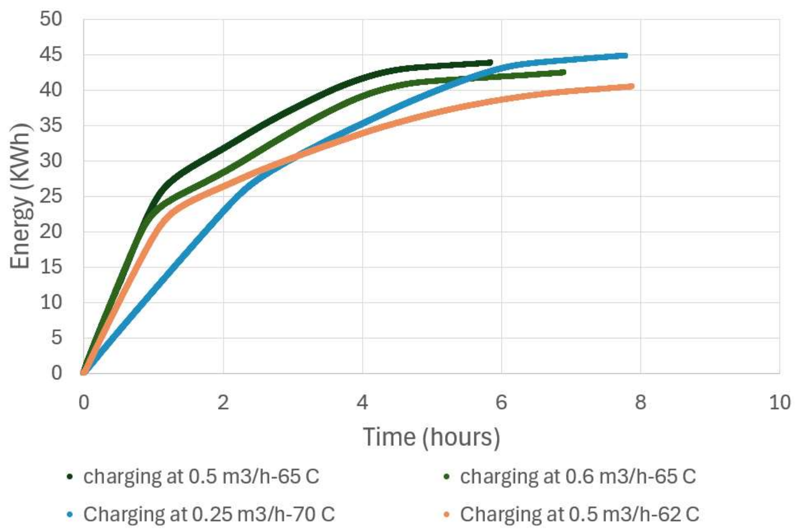

Figure 4: PCM-TES energy capacity for different test conditions

Figure 5 displays the HTF temperatures during charging at 0.35 m³/h with 65 °C inlet temperature. The upper layers (T1 through T4) get heated first, reaching 65 °C within the first hour, while the lower sensors remain near the initial TES temperature of ~25 °C. The thermal front progresses downward through the packed bed over 7.5 hours, with the bottom layers (T7 through T8) showing delayed heating, usually starting after 2-3 hours. The inlet temperature remains rather steady at 65 °C throughout charging, with some fluctuations due to the cold outlet temperature from the TES decreasing the water tank temperature (at a pace more dominant than the electric heater's heating capacity), which, in the case of charging, is being used as the source. The outlet temperature remains low initially before gradually rising as the entire packed bed heats up. This top-to-bottom progression shows downward flow distribution through the TES vessel also the radial temperature distribution can be seen in Figure 5 which in most cases is less than 2 °C.

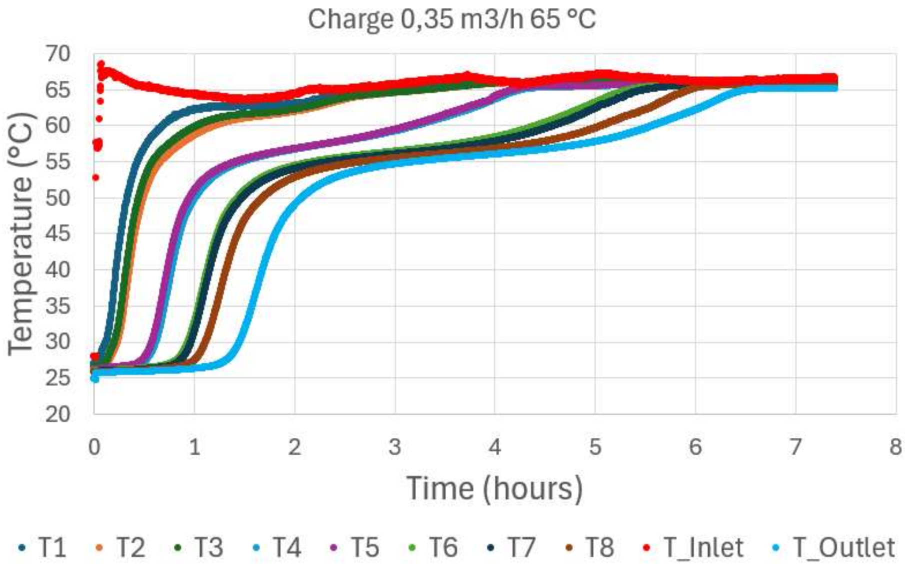

Figure 5: Water (HTF) temperature variations inside the PCM-TES during charging (0.35 m³/h)

Figure 6 shows the PCM temperatures, using Tpcm5 sensor as an example, revealing distinct phase change behaviour. This sensor is placed at 190 mm from the top distribution region and in the same horizontal axis as the RTD2 (T2) and RTD3 (T3) in the PCM-TES. A pronounced phase change, represented by a more gradual temperature range (even if not entirely a plateau) occurs between 45-48 °C, lasting 1-2 hours, representing the solid-solid metastable phase transition. This transition is remarkably clear compared to the solid-liquid phase change between 57-59 °C, which appears only as a subtle change rather than a distinct plateau.

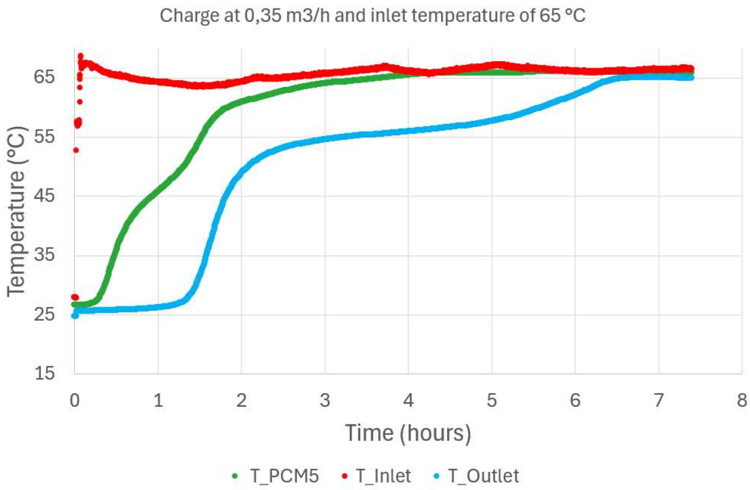

Figure 6: PCM temperature during charging

3.2. PCM-TES Discharging

The PCM-TES discharge performance was also systematically evaluated across varying flow rates and inlet temperature conditions as detailed in Table 4. All discharge tests commenced with an initial storage temperature of 65 °C, representing fully-charged conditions following the charging phase. The recovered energy capacity ranged from 35.5 to 38.7 kWh, depending on the specific operational parameters, demonstrating the influence of heat sink temperature on energy extraction. As anticipated, discharge duration exhibits an inverse relationship with flow rate, with the lowest flow rate of 0.15 m³/h requiring approximately 8 hours for complete discharge, while the highest flow rate of 0.5 m³/h achieves full discharge in approximately 3-4 hours.

The influence of the heat sink temperature on discharge performance is evident when comparing test conditions. Lower inlet temperatures (25-30°C) resulted in higher energy recovery (37.3-38.7 kWh) compared to elevated inlet temperatures (30-35 °C) for the same initial temperature of 65 °C, which yielded 34.3-36.4 kWh under comparable flow rates.

Table 4: Test results for discharging

No.	Inlet temperature (°C)	Flow rate (m³/h)	Energy capacity (kWh)	Discharging time (Hour: minute)
1	25-30	0.15	38.1	7:59
2	25-30	0.25	38.7	5:40
3	25-30	0.35	37.3	4:36
4	25-30	0.5	37.4	4:01
5	30-35	0.25	35.2	5:49
6	30-35	0.35	36.4	4:51
7	30-35	0.5	34.3	3:13
8	30-35	0.6	35.5	3:22

Figure 7 illustrates the heat transfer fluid temperature evolution during discharge at a 0.25 m³/h flow rate with an inlet temperature of 30-35 °C, corresponding to test condition 5 from Table 4. The temperature sensors distributed vertically throughout the storage tank indicate that thermal stratification is maintained throughout the discharge process, with lower zones depleting first while the upper zones retained higher temperatures for extended periods. The outlet temperature remains at 57 °C or higher for about 3 hours.

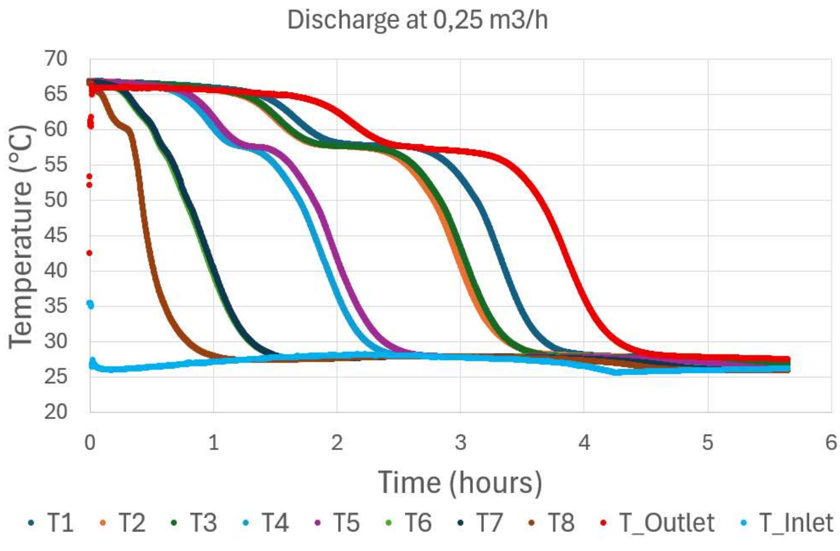

Figure 7: Water (HTF) temperature variations inside the PCM-TES during discharging (0.25 m³/h)

Figure 8 presents the instantaneous thermal power and cumulative energy discharge for the 0.25 m³/h flow rate case. Upon initiating discharge, it very quickly reaches a peak power of approximately 12 kW, exhibiting a stepped decline with a sustained plateau around 8-9 kW between 2-3.5 hours during the primary (i.e., liquid-solid) phase transition. Power drops sharply to 2 kW as phase change completes, before reaching zero at full discharge. The cumulative energy curve reaches approximately 38.7 kWh, as also summarised in Table 4. Across the test matrix (Table 4), peak discharge power ranged from 5 kW at 0.15 m³/h to 25 kW at 0.6 m³/h, demonstrating the system's flexibility to balance power delivery against different discharge durations. The discharge characteristics demonstrate that the system can be optimised for either maximum power delivery (high flow rates with 3-4 hour discharge) or extended thermal output duration (low flow rates with even up to 8-hour discharge), enabling adaptive operation to match specific building heating requirements and renewable energy availability patterns.

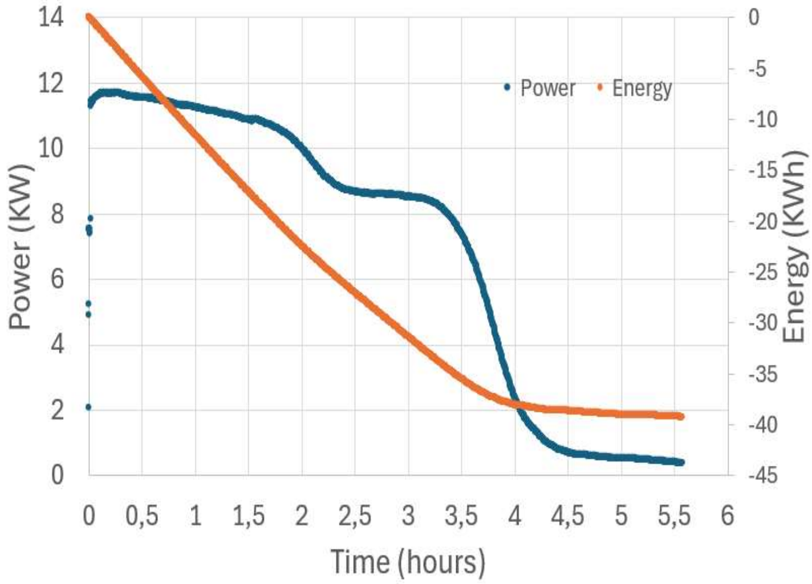

Figure 8: Power and energy capacity vs time (0.25 m³/h)

The discharge experiments revealed notable behaviour characteristics of the RT57HC phase change material under varying flow rate conditions. Figure 9 illustrates PCM temperature profiles during discharge operations starting from 65°C with heat sink temperatures between 25-30°C across three different flow rates (0.15, 0.25, and 0.5 m³/h). The primary liquid-solid phase change is clearly visible at approximately 56-57°C for all three flow rates, consistent with the specified phase transition range for this phase. The duration of phase change plateaus demonstrates clear flow rate dependency, with lower flow rates exhibiting significantly extended plateau periods. The 0.15 m³/h discharge condition maintained the phase change plateau for approximately 6 hours before complete thermal depletion, while the 0.5 m³/h case completed discharge within 2 hours.

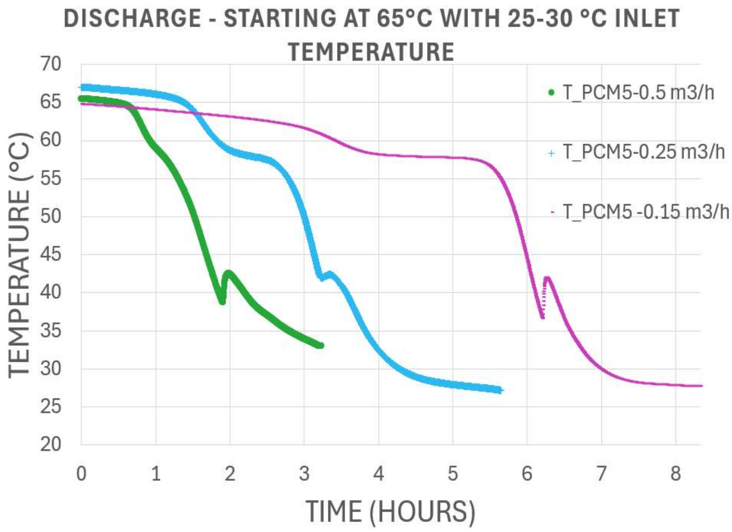

Figure 9: PCM temperature variation under different flow rates

Interestingly, a potentially metastable phase change plateau emerged at approximately 42 °C during all discharge tests, indicating a shifted temperature for the expected solid-solid phase transition phenomenon for RT57HC. Supercooling was also evident in this secondary phase change. In-contrast, this secondary phase change should have occurred, in stable conditions as found through comprehensive material characterisations done (Xu & Yu, 2025) within the expected temperature range of 50-53 °C, which is characteristic of this material. The stable phase change did not display any supercooling either (Xu & Yu, 2025). The metastable phase change phenomenon was verified through a test where the system was allowed to cool under ambient conditions for 2 days, successfully reverting the stable phase change behaviour to the expected stable temperature range of 50-53 °C, as demonstrated in Figure 10.

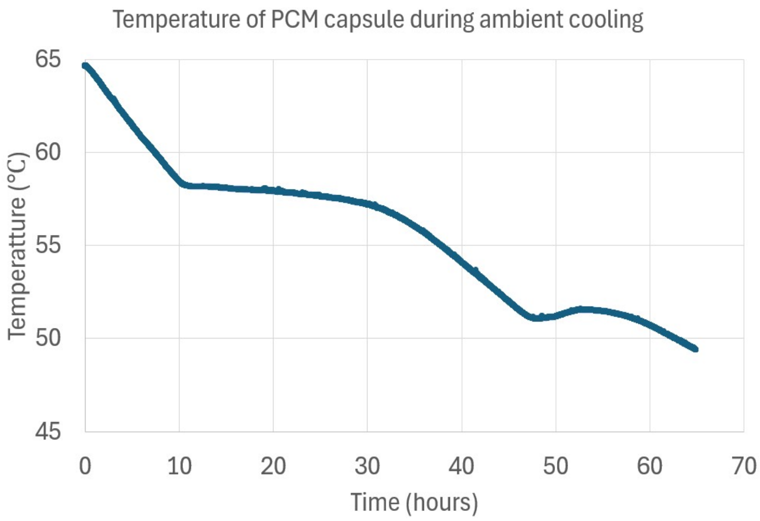

Figure 10: PCM temperature in the PCM-TES through natural cooling under ambient conditions

3.3. Overall Discussion

The PCM-TES system's demonstrated capacity of 38 kWh during discharge adequately addresses the Live-in-Lab's peak heating demand of 12 kW. The flow rate-dependent discharge duration (3-8 hours) provides operational flexibility to match daily heating profiles: extended discharge at low flow rates (0.15-0.25 m³/h) aligns with prolonged evening heating periods, while rapid discharge (0.5-0.6 m³/h) addresses short peak demand events. Hence, different operating strategies for using the heat pump can be developed, and the supply from PCM-TES can serve as a supplement or even replacement for the heat pump in some scenarios.

The PCM-TES enables effective, flexible sector coupling between electrical and thermal sectors for renewable energy integration. During periods of excess renewable generation, especially from intermittent sources such as solar and wind, the heat pump can be used to charge the PCM-TES, converting surplus electrical energy to stored thermal energy and reducing potential renewable curtailment. During low generation periods with high electricity prices, stored thermal energy discharges to meet heating demands without heat pump operation, reducing electrical load during grid stress. A sensible energy storage with similar volume and temperature conditions will account for 46.2 kWh/m^3 compared to the 69.3 kWh/m^3 achieved by PCM-TES.

4. Conclusions & Future work

The systematic experimental analysis of this PCM-TES system demonstrates robust TES performance characteristics suitable for FSC applications in residential heating. Laboratory testing revealed that the system maintains sharp thermocline behaviour with stratification throughout extended charging periods, with minimal radial temperature variations of less than 2 °C. This confirms effective flow distribution through the packed bed configuration without significant dead zones.

A TES capacity of 66-74 kWh/m^3 during charging and 62 kWh/m^3 during discharging were achieved respectively, across diverse HTF supply temperature levels within the test matrix, demonstrating reliable energy storage performance independent of specific operational parameters. The PCM-based system provides approximately 48 % higher energy storage capacity compared to an equivalent volume of sensible hot water storage. This significant advantage confirms the value of phase change material technology for space-constrained residential applications where volumetric energy density is critical.

Within the systematic experimental test matrix employed, the inlet temperature analysis identified 65 °C as the optimal charging temperature for this PCM-TES configuration, as increasing the temperature to 70 °C only results in slight increase in energy capacity whereas needing much more time for charging whereas decreasing the temperature to 62 °C may help in decreasing the charging time but being closer to the phase change temperature range makes it not an optimal choice. Flow rate emerged as the primary determinant of time in charging scenarios, with high flow rates of 0.5-0.6 m³/h enabling complete charging to 40 kWh within 4 hours, while reduced flow rates of 0.25 m³/h extended charging duration to approximately 7 hours at identical inlet temperatures. This flow rate dependency offers valuable operational flexibility, enabling the adaptation of charging strategies to match renewable energy availability patterns and variations in electricity prices. This is a key result with value for the next phase of the project, where the PCM-TES will be operated together with the heat pump in the real LIL. Discharging performance evaluation revealed an energy capacity of 62.7 kWh/m^3, corresponding to 88 % of the charging capacity, due to differences in the initial temperature of the PCM-TES respectively at charging and discharging coupled with some thermal losses. The thermal losses are expected however to be not too significant, with the system insulated thoroughly. However, per the results, it was also decided that e.g. the PCM-TES insulation will be doubled, to further minimize thermal losses, particularly during winter months.

The experimental characterisation confirms the technical viability of the PCM-TES system for integration with the heat pump-based system at the LIL facility, supporting FSC strategies that align with both the electrical and heating energy consumption. The consistent energy storage capacity, efficient thermal recovery, and predictable operational behaviour position this technology as a promising solution for enhancing grid flexibility and renewable energy utilisation in Nordic climate applications. Future implementation phases will focus on: integrating the real-world system implementation of this PCM-TES with an actual heat pump in the LIL where both PCM and HTF temperatures will be used to calculate the energy capacity hence increasing the accuracy of the results; deploying advanced predictive control algorithms; and monitoring long-term performance under operational building conditions to cost-effectively contribute to the energy system flexibility and renewable integration objectives.

5. Acknowledgements

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