FlexMyHeat

D4.1c - Comparing electric and thermal batteries for decentralized storage

I. INTRODUCTION

In the context of increasing electrification of heating and cooling systems, decentralized storage solutions are expected to play a key role in supporting the Belgian electricity system. The FlexMyHeat project explores how the integration of heat pumps (HPs) with electric and thermal storage assets can reduce grid stress, lower energy bills, and increase flexibility. This deliverable compares the performance and characteristics of electric batteries and thermal storage in decentralized residential settings, using the modeling and results from deliverables D1.1, D2.1, and D3.1.

While both technologies contribute to self-consumption and peak shaving, their behavior, control complexity, and cost-effectiveness differ significantly. Understanding their relative strengths and weaknesses is crucial to inform investment decisions and control strategies, particularly as we approach 2030.

This deliverable is divided in two parts: first, simulation results are summarized for both technologies across three distinct control scenarios developed within the project:

Business-as-Usual (BAU): Assets are controlled with simple, rule-based logic to maximize local PV self-consumption.

Individual Smart Control: One flexible asset (e.g., a battery or a heat pump/thermal storage system) is optimized with an advanced controller, while other devices operate under the BAU scenario.

Integrated Smart Control: All flexible assets (battery, heat pump, thermal storage) are controlled simultaneously to achieve shared objectives.

Second, this report presents a qualitative comparison of technologies based on characteristics such as lifetime and material considerations. The objective is to provide a clear, evidence-based assessment of their respective contributions to electrical flexibility in a residential context.

II. RESULTS

This section summarizes the performance of electric batteries and thermal storage in terms of electricity cost reduction and peak power mitigation for a household in the 2030 scenario.

Business-as-Usual (BAU) scenario

In the BAU scenario, storage assets are controlled by a rule-based system that charges the storage when there is excess PV generation and discharges it to cover local demand.

Electric Battery: Under BAU logic, adding a battery reduces the household's daily peak power and annual electricity bill compared to the base scenario. It achieves this by storing solar energy during the day and reinjecting it during the evening peak.

Thermal Storage (PCM): When combined with a heat pump, thermal storage under BAU logic shows lower effectiveness in reducing daily peak power compared to electrical batteries, especially during winter. This is because the control logic is dependent on PV generation, which is low in winter, limiting the opportunities to charge the thermal storage in anticipation of heating needs.

The simulations show that under this simple control logic, electric batteries deliver a greater reduction in the annual electricity bill than thermal storage. The project documents attribute this to the higher electrical power output of the modeled batteries (starting at 3 kW) compared to the thermal storage's effective electrical power when charging (around 1.25 kW). Bigger heat storage sizes are then investigated in further deliverables to see the impact (~ 5 kW).

	Mean Daily Peak Reduction	Electricity bill reduction
BESS	7.7%	From 14 to 18 %
Thermal Storage	15.2%	From 4 to 5 %
BESS + Thermal Storage	22,65 %	From 17 to 21 %

Individual Smart Control

Note : for both the Individual and Integrated smart control scenarios, the control algorithms are designed to use imbalance market prices as a direct input for calculating financial gains and optimizing operational decisions.

These scenarios utilize advanced, learning-based controllers to optimize the operation of a specific asset based on market signals (e.g., day-ahead prices) and system state, going beyond simple PV self-consumption.

Electric Battery (Smart Control): Applying a smart controller to the battery (while the heat pump remains on BAU logic) reduces the annual electricity bill by an additional 2-5% compared to the rule-based battery controller. The smart controller optimizes charging times, preferring to charge during hours with the lowest electricity prices rather than just when PV is available, and also reduces peak power by an average of 11.5% compared to the base scenario.

Thermal Storage & Heat Pump (Smart Control): The performance of the smart controller can be analyzed in two stages. First, applying smart control to the heat pump alone yields significant gains over a rule-based controller (RBC). This strategy reduces the annual electricity bill by 10 to 13% (depending on price scheme and flexibility in user comfort temperature), and reduces daily peak power by 10 to 13%. This is achieved through a pre-heating strategy, where the controller learns to run the heat pump during low-price hours before heating is required to meet user comfort.

Second, adding a smartly controlled thermal storage system to the equation provides a substantial additional layer of flexibility and savings. The addition of thermal storage further reduces the annual electricity bill by another 19.1%, bringing the total cost reduction to nearly 30% compared to the original rule-based controller. It also provides an additional peak power reduction of 12-14%, for a total peak reduction of over 24%. This is accomplished by charging the thermal storage when electricity prices are low and then discharging this stored heat to meet demand during high-price evening periods, allowing the heat pump to remain off.

Integrated Smart Control

The simultaneous, integrated control of all flexible assets—the electric battery, heat pump, and thermal storage—unlocks the highest potential for household savings and grid support. Simulations show that this coordinated approach can reduce the average annual electricity bill by as much as 35.1% compared to a scenario where the heat pump strictly follows the temperature setpoint. Furthermore, this integrated strategy significantly mitigates grid impact, resulting in a peak power reduction of up to 26% compared to the business-as-usual control of heat pumps.

An analysis of the monthly performance reveals that **the source of these financial gains varies with the seasons.** During warmer months such as April, May, September, and October when heating demand is low, the cost reduction is primarily driven by the smart control of the electric battery, which optimizes charging and discharging against market prices. Conversely, during the colder months, the smart control of the heat pump and thermal storage becomes the dominant factor in reducing costs, as these assets work together to shift heating demand away from high-price periods.

The performance **difference between prioritizing either the electric battery or thermal storage is not significant**, revealing only a slight trade-off between achieving the lowest possible energy cost and the maximum peak power reduction.

		Bill reduction	Peak reduction
	Heat Pump (BAU)		
Business As Usual	Adding thermal storage to heat pump	4-5%	8%
	Adding electrical battery to heat pump	14-18%	15%
	Adding both thermal storage and electrical battery to heat pump	17-21%	23%
Smart Control	Adding smart control to heat pump	7-13%	9-13%
	Adding smart control to heat pump and adding smart control thermal storage	27-29%	23-25%
	Adding smart control to heat pump and adding smart control electrical battery	10-12%	4-5%
	Adding smart control to heat pump and adding smart control thermal storage and smart control electrical battery	33-35%	25-26%

III. QUALITATIVE AND QUANTITATIVE TECHNOLOGY COMPARISON

While the FlexMyHeat simulations reveal the crucial *operational* value of storage, a complete strategic picture requires a deeper look at the fundamental characteristics of each technology. This section provides a quantitative and qualitative comparison of electric batteries and PCM thermal storage across key technical and economic metrics.

	Electrical batteries	**PCM Heat Storage**
Storage cost	The installed cost has dropped significantly in recent years, with current prices ranging from **€400-€800/kWh (incl. VAT)** when the battery is purchased as part of a combined package with new solar panels. The cost per kWh is typically higher when retrofitting a battery to an existing PV system, as fixed installation costs are not shared across the two components. The final cost can vary considerably based on the manufacturer, the installer's margin, and the inclusion of a more expensive hybrid inverter required for the system.	The installed cost is highly dependent on the specific PCM technology and its operating temperature, currently ranging from **€300-€500 per 'service kWh'**. A 'service kWh' is defined as the usable thermal energy that can be extracted from the heat battery at a temperature sufficient for its application (e.g., above 60°C for domestic hot water). To create a comparison with electrical storage, an equivalent cost in €/kWhe must be calculated, which factors in the heat pump's Coefficient of Performance (typically 2 to 4). Looking forward, the technology's learning curve is extremely promising and is expected to reduce installed costs by a factor of two to three.
Energy density	This is a primary advantage of lithium-ion technology, which covers a large market share for domestic electrical batteries . Typical values range from 150-300 Wh/kg (gravimetric) and 400-800 Wh/L (volumetric)[1],[2],[3]. This high density allows for a large amount of energy to be stored in a **compact and lightweight** unit, making installation feasible in most homes without requiring significant space.	PCM-based thermal storage offers 4 times as much energy density as traditional water heaters, close to 55Wh/l (@60°C), thanks to the contribution of latent heat (energy from a phase change). While this thermal density is not directly comparable to that of an electrical battery due to the different forms of energy, a meaningful "electrical equivalent" density can be derived by factoring in the annual Coefficient of Performance (COP) of the heat pump used to charge it.
Lifetime	The lifespan of an electrical battery is limited by its age (calendar life) and its usage (cycle life).	The cycle life of PCM heat storage is high, potentially reaching up to 10,000 cycles, though this longevity depends

	Calendar life is typically 10-15 years, after which chemical degradation reduces performance. Cycle life ranges from 500 to 3,000 cycles, depending how the battery is used (depth of discharge, temperature, charging speed).	on maintaining optimal operating conditions to prevent issues like subcooling or phase segregation. The system's calendar life is typically around 10-15 years, but it is often designed to allow for easy replacement of the PCM material within the heat exchanger. This feature, combined with the fact that the used PCM can be recycled and that the design allows repairability, ensures the long-term sustainability and serviceability of the storage unit.
Materials criticity / impact	**High** The supply chain relies on **critical raw materials**, including lithium, cobalt, nickel, and graphite. The mining of these materials is energy- and water-intensive, and is often concentrated in a few geopolitical regions, raising concerns about environmental impact, ethical aspects, and supply security. There is a strong industry push towards recycling and developing chemistries with more abundant materials (like LFP or sodium-ion) to mitigate these issues.	**Low** The materials used are generally **abundant, inexpensive, and non-toxic**. They include organic paraffins (derived from petroleum), salt hydrates (using common salts), and bio-based fatty acids (derived from vegetable oils). These materials have a significantly lower environmental impact, are not subject to the same supply chain risks, and are generally easier to recycle or dispose of safely at the end of life.
Electricity stored	A battery stores electricity directly in an electrochemical form. It is charged using electricity and discharges electricity back to the home or the grid. This provides **direct and highly reactive electrical flexibility**, capable of responding in milliseconds to provide a wide range of power services.	A PCM system does not store electricity directly. Instead, its only way to "store" electricity is to consume it by **turning on the heat pump**. The heat pump uses this electrical input to generate thermal energy (heat), which is then stored in the Phase-Change Material. This stored heat can be released later to meet heating needs, eliminating the need to run the heat pump and consume electricity at that moment. This process provides powerful, **indirect electrical flexibility** by shifting the electricity *demand* of the heating system, though it cannot provide electricity back to the home loads or grid.

IV. Conclusion

The transition to a decarbonized residential sector in Belgium does not rely on a single "winner" in the energy storage debate, but on the intelligent integration of complementary technologies. The FlexMyHeat project's findings show that while electric batteries provide essential, fast-acting electrical flexibility, their full value is realized when paired with PCM thermal storage, which offers a durable, low-cost method for shifting the enormous energy demand of heating systems.

However, this synergy is only accessible through advanced digital control; simple rule-based systems fail to unlock the vast potential of thermal storage, especially in winter. The simulations prove that an integrated, multi-asset control system yields the greatest benefits, reducing household bills by over 35% and peak grid demand by over 26%.

It is important to note that these results were achieved without factoring in the flexibility from domestic hot water (DHW) production. Integrating this thermal demand could unlock further significant gains, particularly by using thermal storage to shift DHW production during summer months when there is no space heating demand.

Therefore, the strategic priority for Belgium must be to foster an ecosystem that supports this integration through dynamic tariffs and interoperable control platforms. By doing so, homes can be transformed from passive consumers into active, flexible assets that ensure a resilient, affordable, and secure energy future.

V. REFERENCES

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