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Parametric Analysis of TES Temperature Effects on COP and Payback in PV–Heat Pump Systems for Residential DHW

Summary

Energy efficiency is a key pathway toward a sustainable society. In buildings, an especially relevant system combines on-site photovoltaics (PV), heat pumps (HP) for HVAC and domestic hot water (DHW) demand, and thermal energy storage (TES). However, existing studies often overlook a critical factor: the reduction in heat pump coefficient of performance (COP) caused by TES temperature differentials. This study investigates this effect using a DesignBuilder/EnergyPlus model of a PV+HP+TES system serving the DHW demand of a residential building in Spain. A parametric analysis of TES volume and temperature was performed, along with a sensitivity analysis of TES amortization under different PV excess injection compensation prices. Results show that optimal TES temperature depends on storage volume and significantly affects savings. Additionally, amortization sensitivity to injection price behaved as non-linear, meaning that small price reductions may enable economic viability of PV+HP+TES systems under future renewable energy scenarios.

Keywords: Thermal Energy Storage, Heat Pumps, On-site PV, Parametric Analysis.

Field of application for the findings: Thermal Energy Storage

Addressed audience: Researchers and practitioners.

1. Introduction

Global warming is one of the most significant challenges of this century. Among the available mitigation strategies, energy efficiency plays a central role. Buildings account for approximately 40% of annual energy demand in Europe, making them a key target for efficiency improvements. A system of growing interest combines on-site photovoltaic (PV) generation, heat pumps (HP) for HVAC and domestic hot water (DHW), and thermal energy storage (TES) (Li et al., 2022).

However, many studies overlook a critical factor: the reduction in heat pump coefficient of performance (COP) caused by unavoidable temperature differentials during thermal exchange with TES. Larger temperature differences decrease COP but increase storage capacity, creating a trade-off that requires detailed analysis (Osterman and Stritih, 2021). Furthermore, some studies neglect to account for the injection of excess PV electricity into the grid, a direct competitor with energy storage. This creates a gap in the integrated assessment and optimal design of PV+HP+TES systems, where long and dynamic simulations are required.

In this study, to evaluate the effects of TES size, temperature and grid injection compensation price, a DesignBuilder/EnergyPlus model was developed for a 12-dwelling residential building in Pamplona, Spain. The system includes rooftop PV panels, a heat pump supplying domestic hot water (DHW), and a storage tank acting as TES. A parametric analysis was conducted on TES temperature, TES volume, and PV excess injection price, using Spanish electricity prices from 2023. This model will be described in the methodology, followed by a discussion of the economic savings results.

2. Methodology

The case study is a 12-dwelling residential building in Pamplona. DHW demand was estimated at 907.2 L/day according to the spanish regulation "CTE-DBHE-Anejo F", with an hourly profile adapted from Sborz et al. (Sborz et al., 2022) , featuring afternoon and evening peaks. The system was modelled in DesignBuilder using a plant loop with a heat pump and a DHW loop with a storage tank acting as TES. The heat pump charges the TES in series, and the TES discharges to meet the DHW demand.

The model uses a heat pump based on the LIFT 81-P÷1204-P model from Trane, with a maximum supply temperature of 80 °C. To reproduce its performance, the heat pump parameters in EnergyPlus were calibrated so that simulated electrical consumption matched manufacturer performance curves across outdoor and load temperatures. This calibration captures the COP reduction at higher load temperatures, which is key to the TES temperature parametric analysis. The TES base temperature was set to 60°C and charged up to a variable maximum temperature, defined as a parameter in the analysis. The economic savings for each parametric case are calculated as the reduction in cost of buying electricity minus the compensation price that is not earned, using the smallest volume and temperature (0.2 m3 at 70°C) as a base of 0 €·year^{-1}. The total TES price for the amortization study was obtained (“Generador de precios de la construcción. CYPE Ingenieros” n.d.).

The control strategy prioritizes charging the TES during hours with the lowest electricity price, ensuring it is fully charged each day. When excess PV generation is available, the electricity price is set to 0 €/kWh, thus prioritizing TES charging during these periods. Additionally, a minimum temperature control is implemented, forcing charging whenever TES temperature falls below 60 °C to maintain adequate operating conditions.

3. Results

3.1. Economic savings, effects of temperature and size

The results focus on the annual economic savings of TES implementation as a function of storage volume and maximum storage temperature. Tab. 1 presents savings (€·year^{-1}) for each simulated combination, color-coded by performance and highlighting the top 10%.

Three main trends are observed. First, volumes below 2m^3 result in net economic losses, as minor storage capacity fails to offset the COP reduction associated with higher operating temperatures.

Second, maximum savings occur at lower temperatures for larger volumes, but these optimal points do not correspond to a constant storage capacity. For example, 9m^3 at 70°C (105 kWh) and 4 m^3 at 74°C (65 kWh) yield similar savings, indicating that optimal performance depends on the specific volume–temperature combination rather than total capacity alone.

Tab. 1. Economic savings (€·year^{-1}) results from the parametric analysis

	Max. storage Temperature (ºC)					
Vol. (m3)	70	72	74	76	78	80
0.2	0	-10	-19	-35	-54	-72
0.4	-5	-14	-21	-47	-70	-84
0.5	-2	-17	-35	-51	-73	-94
0.6	-10	-28	-40	-60	-85	-102
0.8	-20	-35	-56	-69	-98	-116
1	-40	-43	-66	-82	-103	-67
2	-55	18	3	89	85	74
3	126	144	96	167	209	190
4	106	138	**226**	**224**	201	167
5	106	**217**	**237**	198	169	186
6	171	**245**	206	183	159	190
7	**234**	**221**	201	174	180	166
8	**244**	198	189	174	179	161
9	**227**	190	184	171	168	134
10	194	172	178	158	162	152

Third, undersizing is penalized more severely than oversizing. Undersized TES configurations deplete before the end of the day and require morning recharging during high-price hours. In Tab. 1, this appears as a sharp decrease in savings when moving from optimal combinations to smaller volumes or lower temperatures. Note that this effect is specific to the herein-used series configurations, where the heat pump cannot bypass the TES.

3.2. Simple amortization study: effect of electricity injection compensation price

A simplified amortization analysis was performed by dividing TES cost by first-year economic savings for the best case at all volumes. Fig. 1 shows amortization time as a function of TES volume and temperature under different injection compensation price scenarios: from 100% (Spain 2023 baseline) down to 0%.

The simple amortization study showcases that using regular 2023 compensation prices, they payback period of the TES is higher than its lifetime (around 20 years for a typical TES). In scenarios of reduced compensation prices, volumes of 3-5m^3 present amortization times equal or lower to the TES lifetime.

Also, results show a non-linear relationship between compensation price and amortization time. The initial reduction in compensation has the greatest impact, while further reductions produce smaller changes, indicating an asymptotic trend. A reduction of 25% causes volumes of 3m^3 to have amortization periods of lower than the 20 years of estimated lifetime of a TES. This highlights the sensitivity of TES economic viability to compensation schemes and its potential under future scenarios with increased PV penetration in the grid.

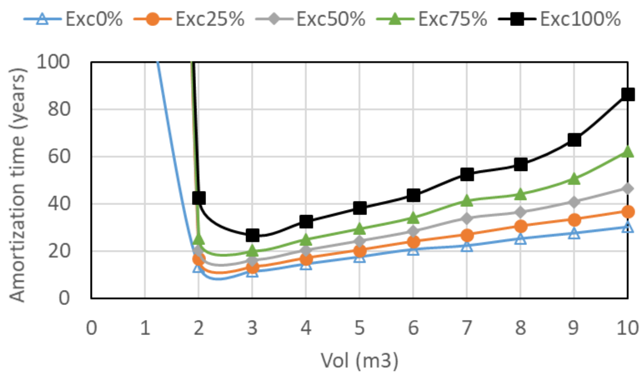

Fig. 1: Amortization time for different TES volumes

4. Conclusions

This study researched the dynamic behavior of PV+HP+TES systems, using a DesignBuilder/EnergyPlus model of a residential building in Pamplona, Spain. The focus was the seldom studied influence of TES temperature across different storage sizes in a parametric study of a DHW system.

Results show that maximum economic savings depend on specific combinations of TES volume and temperature rather than on a constant storage capacity. In the considered series configurations, slight undersizing can sharply reduce savings, as the TES depletes before the end of the day and recharges during high-price morning hours instead of PV production periods.

The study also examined how PV injection compensation affects TES amortization. The relationship is significant and non-linear: small changes in compensation can strongly influence payback time, while further reductions have less effect. These findings highlight the need for case-by-case analyses under different grids, pricing schemes, and future renewable scenarios to evaluate the economic performance of TES systems.

5. References

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