# Design considerations for the integration of battery storage systems in UK communities

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## Introduction

Considering the larger use of fluctuating renewable energy sources in the coming years, electrical energy storage systems will increasingly be introduced in the built environment, as a flexible solution to reduce temporary mismatches between supply and demand. The principal aim of this study is to investigate the implications of the integration of battery storage technologies on the architectural design of buildings. The investigation focuses on battery integration in residential buildings, emphasising on their spatial requirements. The footprint (m2), volume (m3), mass (kg), as well as the levelised cost of electricity (LCOE, €/kWh) for nine different battery technologies[1] able to electrically supply a group of five houses in the UK are explored. The study addresses sustainable regional approaches to building energy demand and supply, and low carbon technologies.

## Methodology

The calculation of the nominal capacity of the battery system is based on winter's weekend electricity consumption values, so as to allow for sufficient storage capacity all year round. It is assumed that energy efficiency improvements, electric heating and electrification of transport by including one electric vehicle in each house take place. Electricity consumption data for 2013 were provided by Intertek [1], which were then analysed and extrapolated to 2030. From this analysis a consumption range and thus a range for the batteries' effective capacity for UK households was derived. Details for these calculations are provided in [2]. The houses run on AC,are assumed to be powered by renewable energy sources and are able to operate on island mode. Therefore, 4 days of autonomy[2] for off-grid use [3] were assumed. The batteries' nominal capacity was estimated considering their efficiency, depth of discharge (DoD) and cycle-life [4], as shown in **Figure 1**, as well as the temperature factor, aging factor, design margin, autonomy period, the daily self-discharge factor and the DC/AC inverter's efficiency. To calculate the nominal capacity of the batteries (**Figure 2**), the formula below was used:

$$C_{nom4} = \frac{4 * (C_{eff_{we}} + C_{eff_{wd}}) * k_t * k_a * DM * k_{sd}}{\eta_{batt} * DOD * \eta_{inv}}$$

where $C_{nom4}$ is the nominal capacity of the battery for four autonomy days

$C_{eff_{we}}$ is the effective capacity of the battery for a day in the weekend

$C_{eff_{wd}}$ is the effective capacity of the battery for a weekday

$k_t$ is the temperature factor

$k_a$ is the aging factor

$DM$ is the design margin

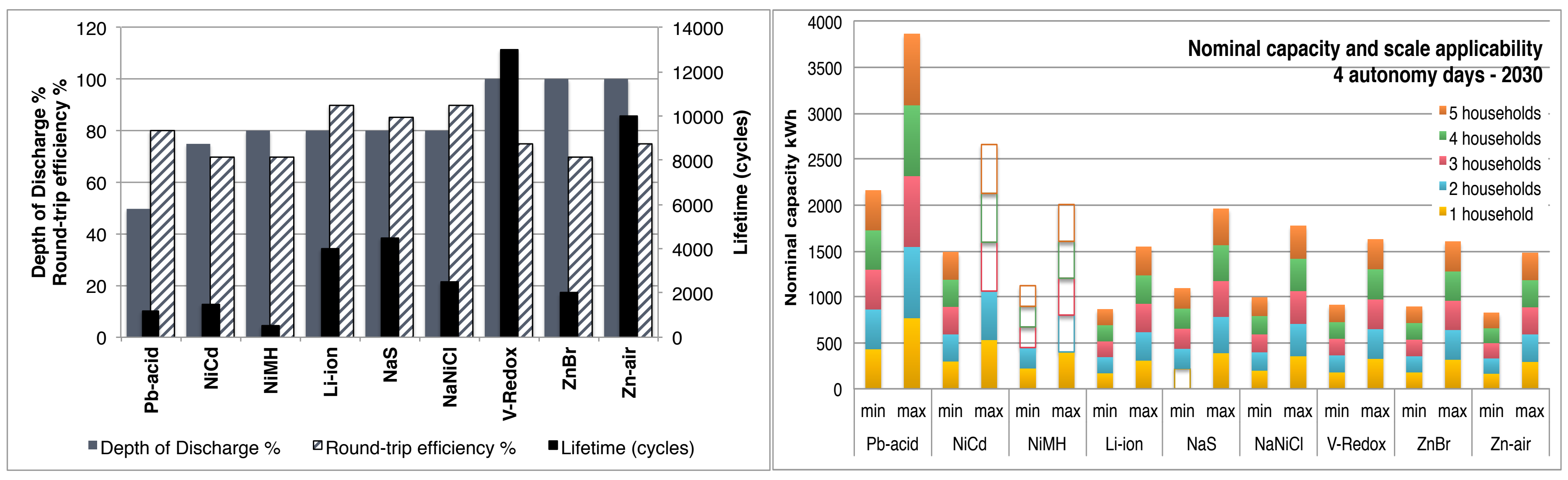
$x$ is the autonomy period in days

$k_{sd}$ is the daily self-discharge factor

$\eta_{batt}$ is the round-trip efficiency of the battery

$DOD$ is the depth of discharge

$\eta_{inv}$ is the inverter's efficiency



*Figures 1 and 2: 1.Efficiency, DOD and cycle-life of battery technologies, 2. Nominal capacity of battery technologies (void boxes indicate that technology is not applicable due to energy rating constrictions)*

The parameters that have been used in order to estimate the footprint, the volume the mass and the LCOE of the battery technologies are illustrated in **Figure 3.**

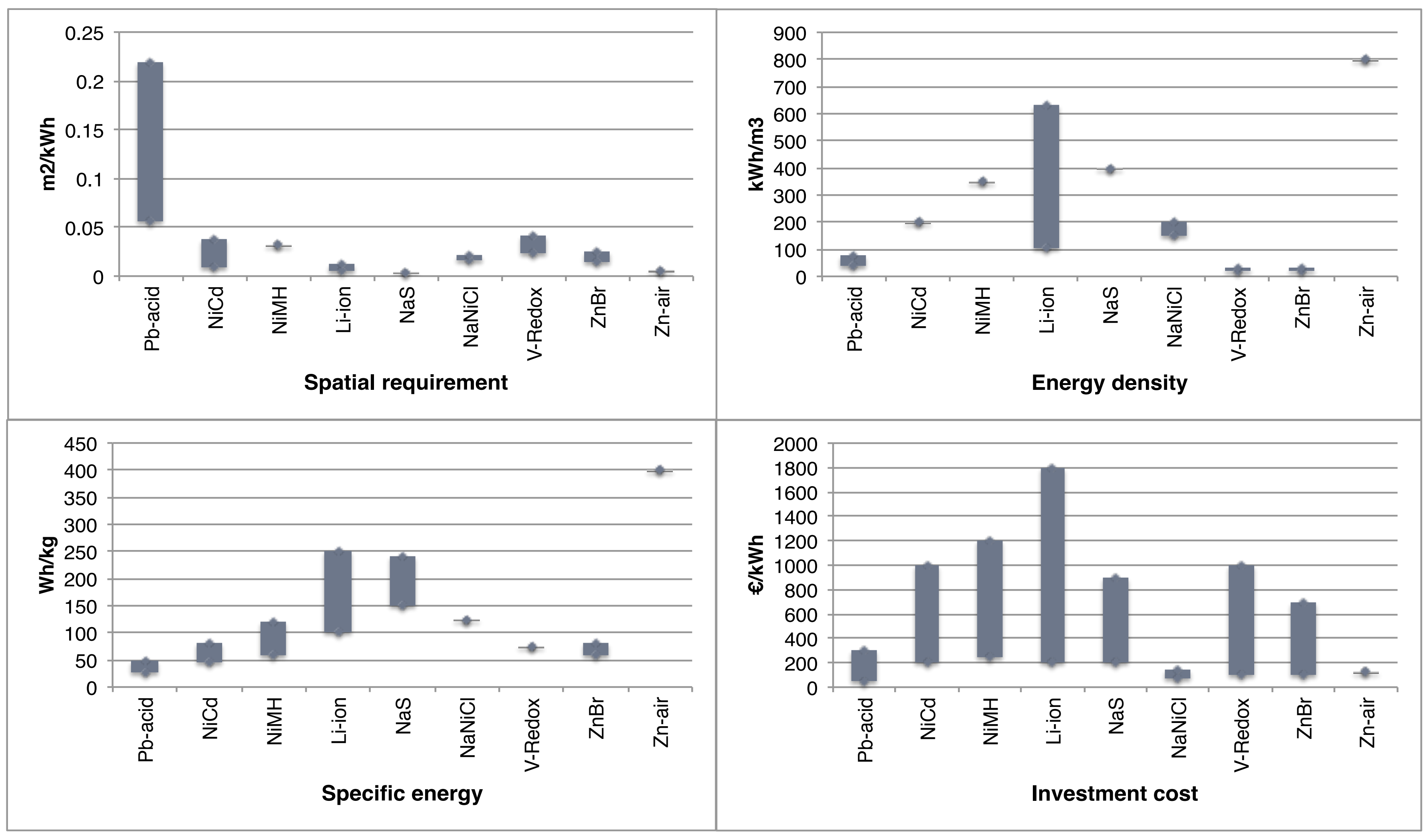


*Figure 3: Parameters that informed the estimation of the footprint, the volume, the mass and the LCOE of battery technologies [4]*

The LCOE of the battery, $C_{LCOE}$ (€/kWh of electricity generated over lifetime of technology), is calculated using the formula below:

$$C_{LCOE} = \frac{C_{batt}}{C_{nom} * \eta_{batt} * N_{cycles} * DOD}$$

where $C_{batt}$ (€/kWh) is the battery investment cost

$N_{cycles}$ is the battery's cycle life and

As this work deals with ranges for the input data, i.e. electricity consumption and parameters in **Figure 3**, the outputs of the calculations presented in the next section are also depicted in ranges, considering a low range and a high range for the design aspects.

## Results and discussion

The results of the investigation regarding the footprint, the volume, the mass and the LCOE for the nine battery technologies are presented in **Figure 4**.

*Figure 4: Footprint, volume, mass and LCOE for the nine battery technologies (lower values are more favourable)*

It is apparent from **Figure 4** that although some technologies have similar nominal capacity values (**Figure 2**), not only can they have different footprint, but also different volume, mass and LCOE. **Pb-acid** requires the biggest nominal capacity and is by far the most unfavourable technology in terms of footprint, volume and mass. It has relatively low LCOE, which makes is an economic option. **NiCd** is just behind Pb-acid as regards the nominal capacity and the mass. It has a big footprint especially when the maximum spatial requirement is assumed and medium volume. It has high LCOE, making it an expensive storage option, but might not be applicable for groups of 3 or more houses. **NiMH** has medium capacity requirement and has little applicability, being able to serve up to 1 or 2 houses depending on their daily electricity consumption. It also has a quite big footprint especially in the case where the minimum spatial requirement has been considered. It has medium volume and mass and the highest LCOE, making it the most expensive option over its lifetime. **Li-ion** ranks second in terms of nominal capacity requirement. It is among the top three technologies regarding footprint and ranks second in terms of volume and mass when the maximum energy density and specific energy values are assumed. Li-ion, like NaS and ZnBr, has medium to low LCOE assuming a great reduction in investment cost by 2030 due to R&D. **NaS** has medium nominal capacity requirement and might not be applicable for one house. It ranks either first or second as regards the footprint and is among the top three technologies as regards volume and mass. **NaNiCl** has medium nominal capacity requirement and is a medium option regarding footprint. It ranks third or fourth in terms of mass. It has medium volume range like NiCd and NiMH and it has very low LCOE. **V-Redox** has medium to low capacity requirement and it is an unfavourable technology regarding its footprint and volume. It has medium mass values and the lowest LCOE assuming low investment cost in 2030. **ZnBr** has medium to low capacity requirement and it is a medium option regarding footprint, ranking fourth if the minimum value for spatial requirement is assumed. It has medium mass values and just like V-Redox, it is unfavourable in terms of volume. **Zn-air** requires the least nominal capacity. It is one of the top three technologies regarding footprint and the top technology in terms of volume and mass, exhibiting the highest energy density and specific energy among all battery technologies. It also has one of the lowest LCOE values.

## Conclusions

This study presented design aspects regarding battery storage integration in buildings in 2030. In terms of **footprint**, Li-ion, NaS and Zn-air are the top three technologies exhibiting the smallest footprint and Pb-acid the last one having the biggest footprint. As for **volume** considerations, in the case where the minimum energy density values are considered (high range), Zn-air, NaS and NiMH are the top three technologies exhibiting the smallest volume. In the case where the maximum values are considered (low range), the top three are Zn-air, Li-ion and NaS. In both cases Pb-acid, V-Redox and ZnBr are the least favourable technologies requiring the biggest volume. Regarding **mass**, in the case where the minimum specific energy values are considered (high range), Zn-air, NaS and NaNiCl are the top three technologies exhibiting the smallest mass. In the case where the maximum values are considered (low range), the top three are Zn-air, Li-ion and NaS. In both cases Pb-acid and NiCd are the least favourable technologies having the biggest mass. In terms of **LCOE**, Zn-air, NaNiCl and V-Redox are the top three options, while NiMH and NiCd and Pb-acid rank last.

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[1] The battery technologies explored in this study are the following: Lead-acid (Pb-acid), Nickel Cadmium (NiCd), Nickel-Metal-Hydride (NiMH), Lithium-ion (Li-ion), Sodium Sulphur (NaS), Sodium Nickel Chloride (NaNiCl), Vanadium Redox (V-Redox), Zinc Bromine (ZnBr) and Zinc-Air (Zn-air).

[2] The days of autonomy are the days on which an off-grid house would solely rely on the electricity stored in the battery to power itself. These would be the days with minimal or no renewable energy available, e.g. minimal or no sunlight.

[1] Intertek 2012. Household electricity survey: A study of domestic electrical product usage.
[2] Chatzivasileiadi, A. 2015. How can batteries 'fuel' the built environment? ArchiDOCT 3 (1), pp. 31-45.
[3] Little M. Solar photovoltaic system design info sheet - feasibility study. Solar Workshop for Engineers Without Borders and Royal Academy of Engineering; London: Renewable Energy Innovation; 2013. p. 2
[4]Chatzivasileiadi, A., Ampatzi, E. and Knight, I. 2013. Electrical energy storage technologies and their applications in buildings. Renewable and Sustainable Energy Reviews 25, pp. 814-830.

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