http://dx.doi.org/10.5281/zenodo.1216153

Brief Report on

Estimation of the Total Number of Battery Cells inside a Large Warehouse

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Nomenclature

L	length, m
W	Width, m
H	Height, m
D	Diameter, m
$N_{A\text{-}B}$	Number of A in a B. i.e. $N_{p\text{-}CB}$ means the number of pouch battery in a cardboard box.
a	Length of the gap between cylindrical batteries in the cardboard, m
b	Length of the gap between blocks, m
sd	Safety distance required under the ceiling, m

Subscripts

c	Cylindrical battery
p	Pouch battery
CB	Cardboard box
P	Pallet
S	Shelf
W	Warehouse

Summary: Our simple calculations estimate the number of battery cells inside a warehouse based on the dimensions of Li-on batteries, boxes, racks and other storage details provided in the literature. For a warehouse with dimensions of 80 × 80 × 9 m, there are 3.5 million polymer pouch batteries or 64.5 million cylindrical batteries (type 18650). This number matters for calculations of the risk of self-heating ignition.

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Objective

The objective is to estimate the number of battery cells that can be stored in a warehouse similar to **Fig. 1**. This number can be an important factor in the evaluation of the fire hazard of lithium ion batteries in warehouses.

Fig. 1. Warehouse storage of lithium ion battery [1].

Method

The dimensions used in this estimation was based on the experiment conducted by FM Global in 2016 [1]. **Fig. 2** shows the size of the polymer pouch battery in the experiment.

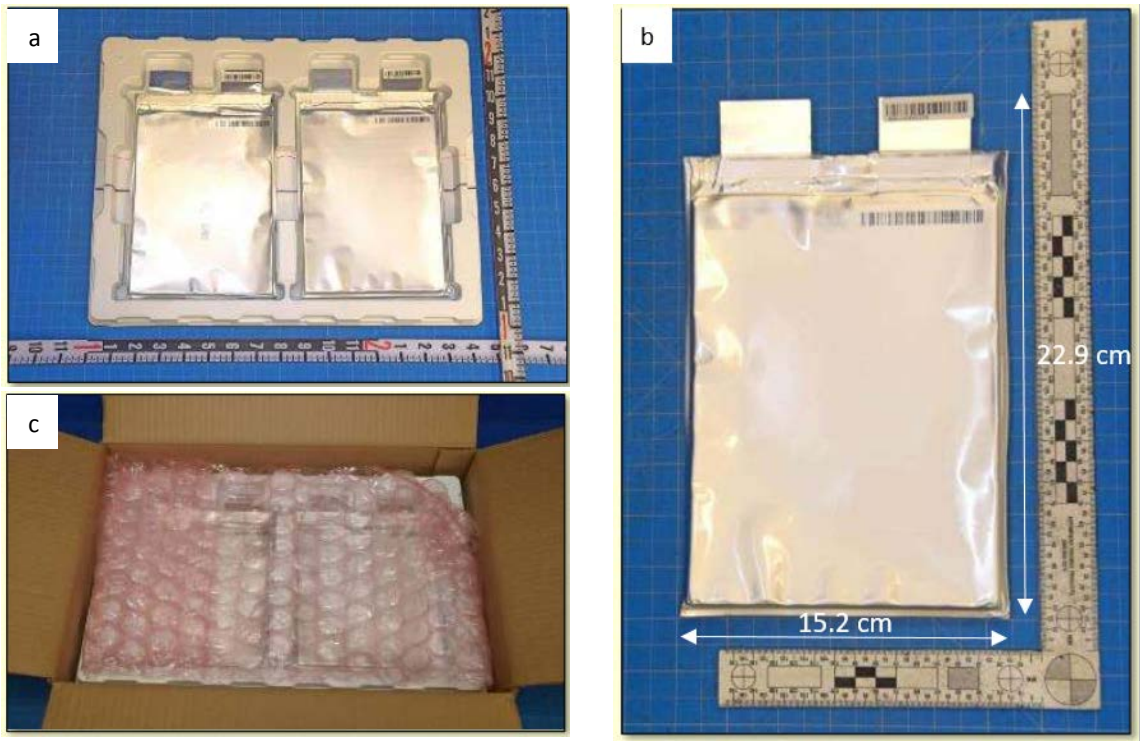

Fig. 2. The polymer pouch battery used in FM experiment: a. pack of the battery, b. size of the battery, c. polyethylene bubble wrap, [2].

In the experiment, the lithium ion batteries tested were $LiFePO_4$/ graphite batteries. The size of the battery was 22.9cm × 15.2cm × 0.8cm. The batteries were separated by polyethylene bubble wraps

and were stacked in a cardboard box shown in **Fig. 3**. Based on the experiment, each boxes can contain $N_{p\text{-}CB}$ =20 battery cells. The size of the cardboard box was 43.1cm × 34.3cm × 16.5cm. Subsequent calculation will use the cardboard box as a basic element.

Fig. 3. The size of cardboard box [2].

The number of cylindrical batteries (18650), as shown in **Fig. 4**, which can be packed in the same cardboard box was also considered. The diameter of the battery is 18mm and the height is 65mm. When packing these batteries in the cardboard box, it was assumed that a 9mm gap was required between each battery to allow for protective material to protect both ends of battery.

Fig. 4. The cylindrical battery (18650) [3].

Using these dimensions, each box can contain:

$$N_{c-CB} = \left[\frac{L_{CB}}{D_c+a}\right] \times \left[\frac{W_{CB}}{D_c+a}\right] \times \left[\frac{H_{CB}}{H_c}\right] = \left[\frac{0.431}{0.018+0.009}\right] \times \left[\frac{0.343}{0.018+0.009}\right] \times \left[\frac{0.165}{0.065}\right] \approx 15 \times 12 \times 2 = 360$$

Where the operator [] means the final value is rounded down to the lower integer. When storing these batteries, the cardboard boxes were placed on pallets. The arrangement of the boxes on the pallet is shown in **Fig. 5**. Each pallet contains 8 stacks and each stack contain 7 boxes, hence the total number of boxes per pallet was 56. The final dimensions of each pallet with the cardboard boxes was 111.7cm × 111.7cm × 115.5cm.

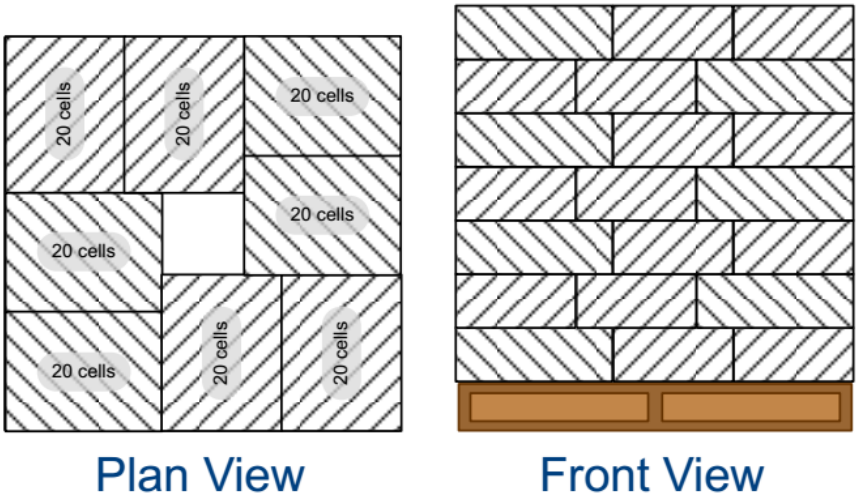

Fig. 5. The structure of pallet in FM experiment [2].

The pallets were placed on shelves as shown in **Fig. 6**. Each shelf can hold 2 pallets. The dimensions of the shelf was assumed to be 3m × 1.5m × 1.5m. The arrangement of the shelves was such that each block layer had 10 shelves arranged side by side and 2 shelves arranged back to back. The number of layer per block was dependent on the building height. For fire safety reasons, the distance between the ceiling and the topmost pallet was kept at, *sd* = 2m. It was also assumed that a gap of 3m was required between each block for easy access to the pallet.

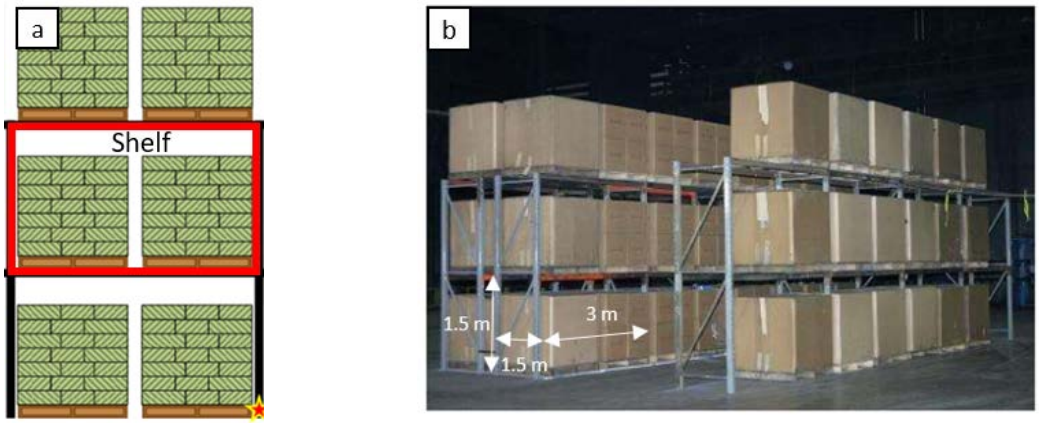

Fig. 6. The shelf: a. the structure, b. the size [2].

Since 30% of the warehouses in the US has an area of more than 10,000m^2 [4]. A conservative assumption of 6,400m^2 was used in the calculation below.

Assuming that:

- A warehouse with the dimensions of 80m × 80m × 9m; and
- The shelves were arranged in the form shown in **Fig. 7**

It was calculated that the number of shelves in the warehouse were:

$$N_{S-W} = \left[\frac{L_W}{W_S \times 2 + b}\right] \times \left[\frac{W_W}{L_S \times 10 + b}\right] \times 20 \times \left[\frac{H_W - sd}{H_c}\right]$$

$$= \left[\frac{80}{1.5\times2+3}\right] \times \left[\frac{80}{3\times10+3}\right] \times 20 \times \left[\frac{9-2}{1.5}\right] \approx 10 \times 2 \times 20 \times 4 = 1{,}600$$

Since each shelf can hold 2 pallets and each pallet can hold 56 cardboard boxes, the total number of cardboard boxes in the warehouse is:

$$N_{CB\text{-}W} = N_{P\text{-}W} \times N_{CB\text{-}P} = 1600 \times 2 \times 56 = 179{,}200.$$

Hence, the number of battery that can be stored are:

$N_{p\text{-}W} = N_{CB\text{-}W} \times N_{p\text{-}CB} = 179{,}200 \times 20 \approx 3{,}500{,}000$ pouch batteries; or

$N_{c\text{-}W} = N_{CB\text{-}W} \times N_{c\text{-}CB} = 179{,}200 \times 360 \approx 64{,}500{,}000$ cylindrical batteries.

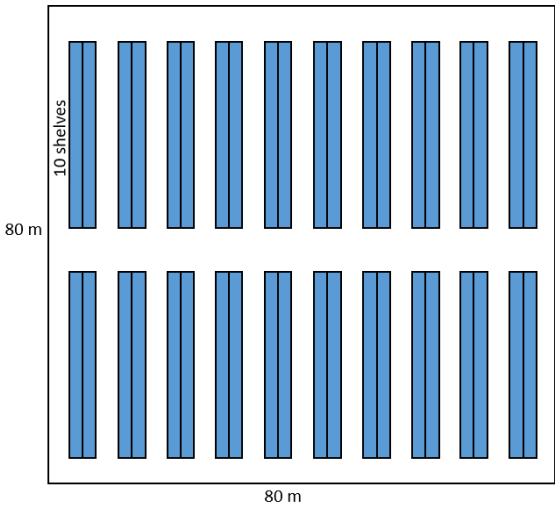

Fig. 7. The arrangement of shelves in a warehouse (top view).

Conclusion

From this calculation, it can be estimated that a warehouse with dimensions of 80 m×80 m×9 m can store around 3.5 million of pouch batteries or 64.5 million of cylindrical batteries (18650).

Acknowledgements

The authors thank Xuanze He and Benjamin Y. Khoo for proofreading. We acknowledge China Scholarship Council (CSC) for their financial support.

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