Team Control Number

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Problem Chosen

A

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Summary Sheet

Summary

With the development of science and technology, traditional energy resources like carbon burning will finally run out and can no longer meet the need of mankind. So there comes a growing need for eco-friendly energy resources. Currently available ones include solar, wind and hydrogen energy, one of the most mature of which is solar energy. Our goal is to create models evaluating existing energy storage solutions and in turn helping select the best for every given house. With these models, we analyze cement battery's pros and cons and incorporate it with other solutions.

In the first two models, the house is assumed to be remote and of 1600 square feet, which means that connecting to the grid is too expensive to be taken into consideration. We evaluate each mature energy storage solution and decide the most suitable one for the house. The criteria for energy storage systems include Continuous and Instantaneous Power Rating. That for batteries include the minimum of unit cost, which is expressed as a function of overall capacity, reliability (the possibility of actual power rating higher than needed) and Cost per year. According to the criteria above, the model decides the best energy storage solution for any given house.

By generalizing and combining the two models comes the following one, which takes into account electricity from grids and allows any house location and number of residents. The impact of the former depends on the price of electricity and the distance from the house to the grid, and that of the latter is the required Continuous and Instantaneous Power Rating. With this model, we can determine the energy storage solution for every house.

Eventually, we analyze the current situation and potential of a new type of durable cement battery. It is evaluated in terms of price, energy density and round-trip efficiency. By applying them to the last model, it proves that, in terms of craftsmanship and overall cost, it's not so desirable and worthwhile to employ cement batteries as the main energy storage solution. Since it can be embedded in the house's physical structure, it can be used as a backup electricity resource.

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1 Introduction

1.1 General Introduction

As science and technology develop, the need for energy grows. In the long period, the traditional carbon burning will finally come to an end. One of the most popular and mature eco-friendly energy resources is solar energy. Then the question arises that what energy storage solution should a house apply. This is what we aim at in the essay.

In our models, attributes that describe the house's features are area and distance from grid. In order to evaluate the energy storage systems, we develop functions whose arguments are its Continuous Power Rating and Instantaneous Power Rating. Those for batteries are Capacity, Reliability, and Cost per year.

In recent decades arises a new kind of cement batteries. We analyze its pros and cons, apply it to our models, and compare it with other existing battery types.

As the currently used energy resource is non-renewable, replacing it with new and eco-friendly ones can not be avoided. We need to turn to reliable new eco-friendly energy resources as soon as possible.

1.2 Problem Restatement

The first two models aim at deciding the most suitable energy storage solution for a 1600-square-foot remote house, which means that connecting to the grid is too expensive. Two factors decide the energy storage system: the (Needed) Continuous and Instantaneous Power Rating. And three factors decide the batteries. For a given total capacity, since both too many batteries in the pack and too few make the total price high, there is a lowest unit cost. The second factor is Reliability which means the gap between Needed Power Rating and actual (planned) one. Actually, the Instantaneous Power Rating being exactly the max needed is not always the most economic solution. Since the high power-rating appliances are seldom turned on at the same time, the Actual Instantaneous Power Rating can be reduced to below the needed one, to a point where the problem it brings can be solved by changing the routine. The last factor is Cost per year. Since each battery's Round-Trip Efficiency is constant, for a certain needed capacity, the higher capacity, the higher its price and the longer its lifespan, so there is a minimum Cost per year.

The next model is an expanding of the last two, which allows any location and area of house. It allows and takes into account the connection to the grid and the number of residents, which depends on the area of the house. And we evaluate the model.

The last model is in part an application of cement batteries, a novel kind of battery to the model. We analyze its features, evaluate it and compare it with other relatively mature batteries.

2 Assumptions

1. The level of solar energy is either sunny (light + heat) or cloudy/rainy (light).
2. The electricity use of mobile devices like smart phones, smart watches and computers is tiny enough to neglect.
3. The Round-Trip Efficiency of each battery model doesn't change.
4. The maintainence of batteries means buying a new battery (pack).
5. The price of electricity from a grid is constant.

3 Notations

ER	Energy Remain	N	Needed Electrical Power
V	Solar Energy Collected during the Daytime of a Sunny Day	C	Battery Capacity
L	Age of a Battery	L_0	Lifespan of a Battery
Y	Cost per Year	P	Price per Unit Capacity
PA	Average Power during an hour	PC	Largest Continuous Power of Battery
B	Reliability	A	a function evaluating a battery model
D_n	Needed Energy Density	VL	Volume
T	Round-Trip Efficiency	l	Length of Wire

Table 1. Notations

4 Basic Models

4.1 General

First, we assume that the house is in Lanzhou, China. As the house is 1600 square feet, we suppose that it can accommodate four people, and each of them take a shower or bath every day in summer, which means that water heater works for about one hour a day in summer. Since the water heater requires a continuous power rating, the amount of which varies according to the season, it should be considered as a constant requirement. Since we mainly consider the solar energy storing batteries, we calculate on the basis that number of solar cells can be any value depending on our need.

4.2 Calculation of Power Load

This model aims to help decide the needed capacity for the given house. To evaluate the energy storage system, we need the exact time and power rating (both instantaneous and continuous) of each electrical appliance. In our model, we take into account in all seven electrical appliances, the features of which are supposed and listed in the chart below.

Appliances	**Working hours**	**Power (kW)**
Lights	17:00-22:00	0.2
Refrigerator	00:00-24:00	0.3
Air conditioner	00:00-24:00	0.8(max)→0.4(avg)
Bathroom master and water heater	21:00-22:00	3.5*
Television	19:00-22:00	0.2
Desktop	18:00-23:00	0.2
Cooker	7:30-8:00 11:30-12:30 18:00-19:00	1.5

*Bathroom master is both instantaneous (only in winter) and continuous (one hour every day), it should be considered as continuous.

Table 2. Working hours and power of household appliances

1. Lights

The 0.2kW isn't the total power rating of all the lights, but is calculated by the overall usage of all rooms.

$$W_1 = P_1 \cdot T_1 = 0.2kW \cdot 5h = 1kWh$$

2. Refrigerator

$$W_2 = P_2 \cdot T_2 = 0.3kW \cdot 24h = 7.2kWh$$

3. Air conditioner (AC)

We suppose that there are four ACs, three of which are in room and work all day and the one in the sitting room is off at night. All AC units work about half of the on time.

$$W_3 = P_3 \cdot T_3 = 3 \cdot 0.8kW \cdot 24h \cdot 0.5 + 1 \cdot 0.8kW \cdot 12h = 38.4kWh$$

4. Bathroom master and water heater (BM&WH)

$$W_4 = P_4 \cdot T_4 = 3.5kW \cdot 1h = 3.5kWh$$

5. Television (TV)

Each room has a TV. The one in the sitting room and one in a bedroom work together at a time.

$$W_5 = P_5 \cdot T_5 = 2 \cdot 0.2kW \cdot 3h = 1.2kWh$$

6. Desktop

$$W_6 = P_6 \cdot T_6 = 0.2kW \cdot 5h = 1kWh$$

7. Cooker

$$W_7 = P_7 \cdot T_7 = 1.5kW \cdot 2.5h = 3.75kWh$$

So we can get that

$$\Sigma W = 56.05kWh$$

Consider $(\Sigma W)_{day}$ the power used between 6 a.m. and 6 p.m. every day.

$$(\Sigma W)_{day} = 23kWh$$

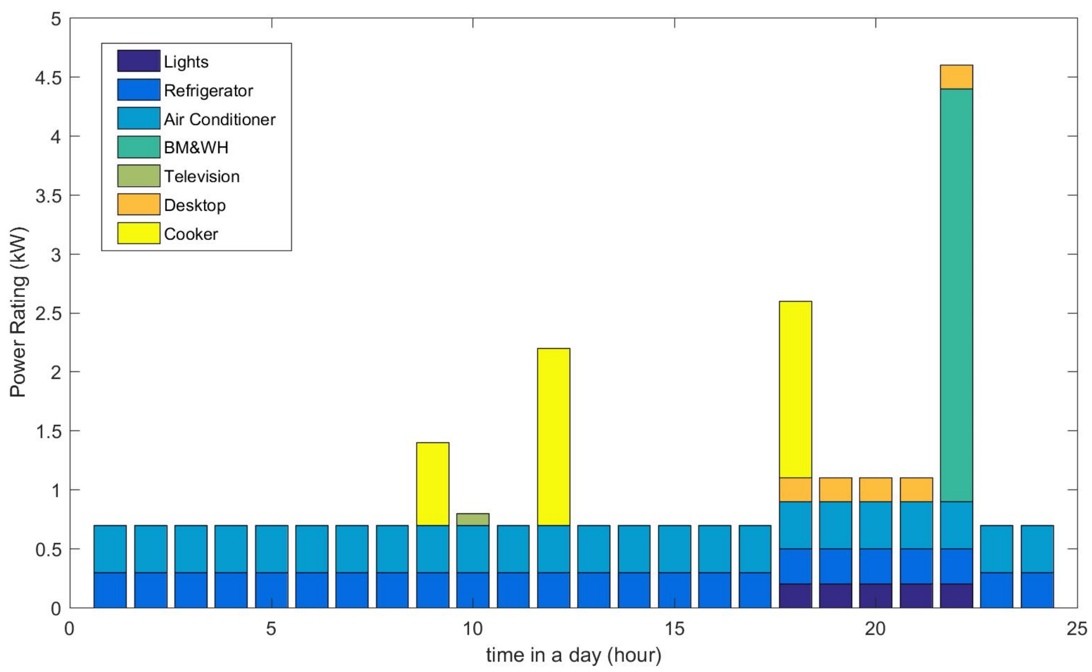

Figure 1. Daily Power Rating of a typical house

4.3 Energy Storage System Decision Model

In this part, we calculate the capacity of the battery to meet the energy needs as well as optimize the costs.

We use weather information to calculate the maximum number of rainy or cloudy days in a row, and therefore decide how much electrical power to be stored.

We conclude from a previous essay[1] that the solar power available on rainy or cloudy days is half of that on sunny days.

We find from a weather database that the time of sunlight radiation accounts for about half of the total hours, so we assume that all the days in a year consists of cycles of 1 sunny day and 1 rainy/cloudy day, repeated several times throughout the year.

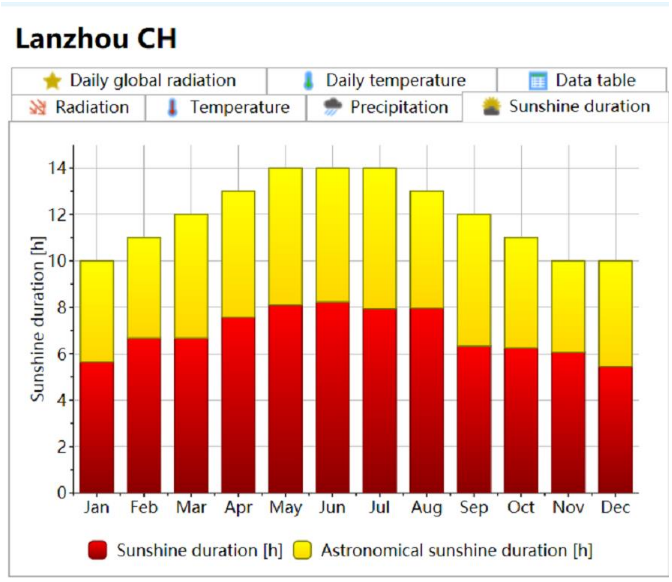

Figure 2. Sunshine duration of Lanzhou

Since the solar energy on sunny days is more than that on rainy days, the maximum solar power stored in the cycle of 2 days occurs at the end of daytime on a sunny day.

According to the difference of the solar energy that is collected between sunny weather and rainy/cloudy weather, as well as day and night, we can use a piecewise function to describe the trend. Also, as the change of continuous power or instantaneous power don't have much impact on the calculation, we can use a piecewise function, every piece of which is a linear function, to describe it.

Here are the schematic diagrams of them:

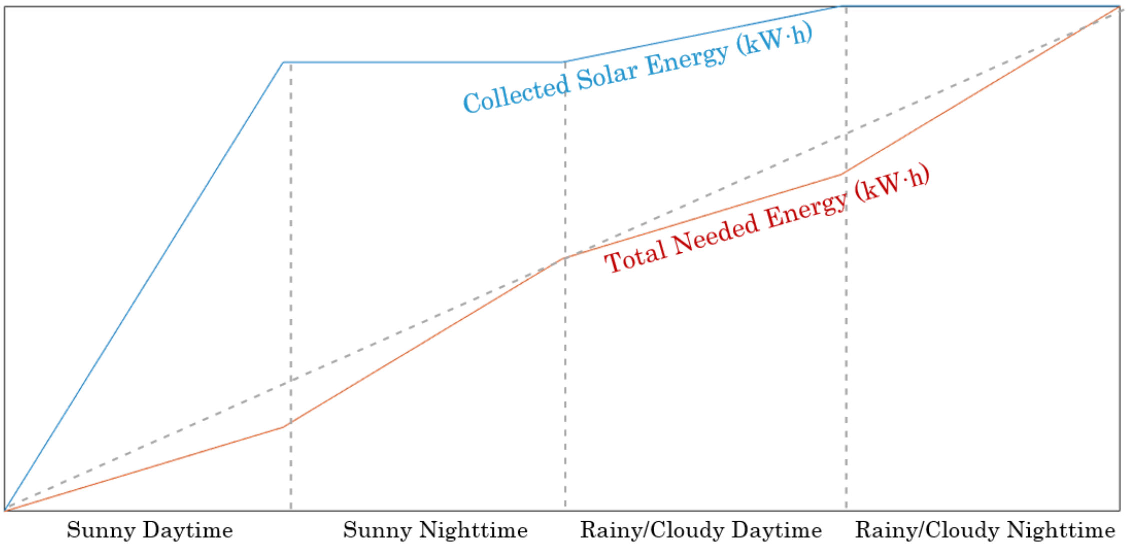

Figure 3. Collected and needed energy in different periods of time

The blue line roughly shows the change of collected solar energy during different periods of time. The red one roughly shows the increase of total needed energy. To make sure that the availability of the collection and restoration of energy is maximized, the values of the two function should be same at the end of each cycle.

In order to work out ER (the energy remain), we can have collected solar energy minus total needed energy. Then we get the new image:

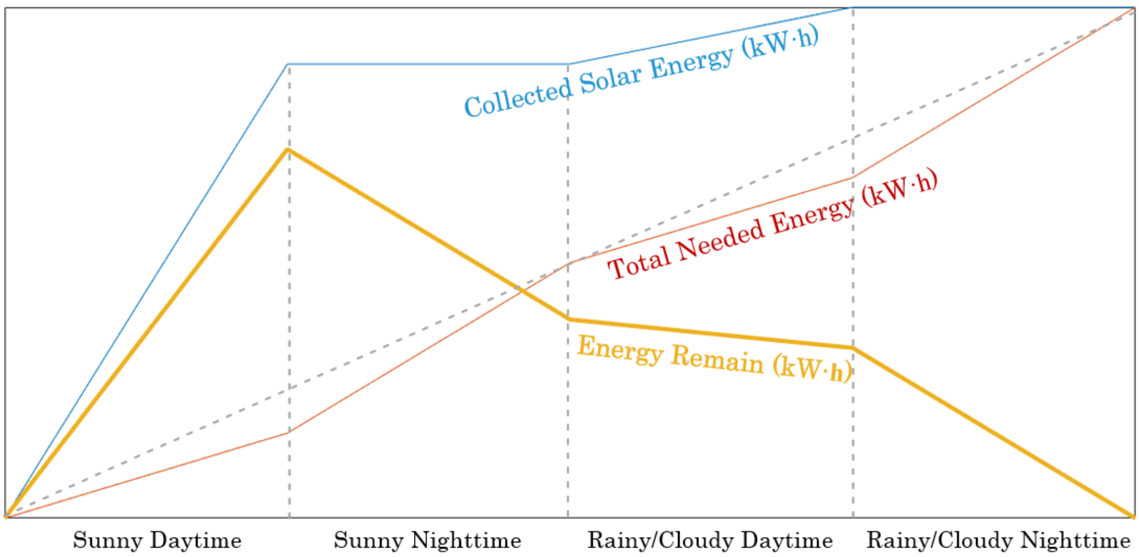

Figure 4. ER in different periods of time

From the yellow line we can see that the maximum of the energy needed to restore appears at the end of the daytime of a sunny day. So,

$$N = V - (\Sigma W)_{day}$$

And,

$$\text{the total energy collected} = \text{the total energy used}$$

$$V + \frac{V}{2} = 56.05 \times 2 = 112.1$$

$$V = 74.7$$

$$N = 74.7 - 23 = 51.7kWh$$

But because of the loss of electrical capacity over time, the total capacity of the batteries should be above N. Assume that it is C.

We also conclude the equation F about L0 is:

$$F(L_0) = a \times e^{-b \cdot L_0} + c$$

$$F(0) = C$$

So $c = C - a$

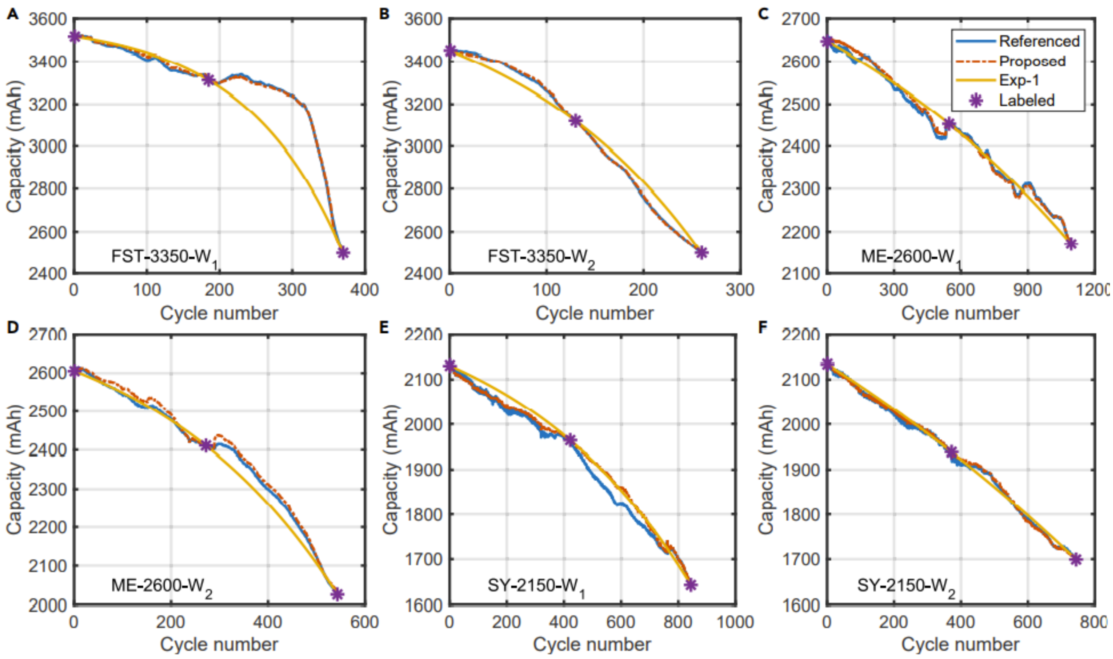

Figure 5. How the capacity falls as the battery ages

Let F(L_0) = N.

$$L = \frac{ln(\frac{N - a + C}{a})}{-b}$$

Then the cost per year should be:

$$Y = \frac{P}{L}$$

where

$$L = \frac{ln(\frac{N - a + C}{a})}{-b} = \frac{ln(\frac{a}{N - a + C})}{b}$$

$$P = f(C)$$

With data of P and C, we fit the curve of f: $P = C \cdot 8(yuan/A \cdot h)$

Calculate the value of C at the minimum point of Y, then at that point the cost is optimized.

4.4 Battery Decision Model

We plan to design the power-restoring batteries with three choices: Lithium-Ion batteries, Lead-Acid batteries, Flow batteries and Sodium Sulfur batteries. A spare battery will be used to deal with emergencies such as a sudden breakdown of the batteries. These types of batteries will be evaluated in terms of costs, reliability, and battery lifespan. Since there is too much energy lost during the transportation between different battery models, we suppose that all batteries in a battery pack are of the same model.

The exact features of the four choices are listed in the table below:

	Lithium-Ion Batteries	**Lead-Acid Batteries**	**Flow Batteries**	**Sodium Sulfur Batteries**
C(A·h)	100	100	100	100
S(USD/A·h)	2	5	40	100
L(cycle)	750	350	1000	4500
PC(W/A·h)	2	25	100	100

Table 3. Features of four types of batteries[2]

The cost is calculated by this equation:

$$Y = \frac{C \cdot P}{L}$$

The reliability is calculated by:

$$B = \frac{hours\ of\ (PA < 90\% \cdot PC)}{total\ working\ hours}$$

Therefore, the evaluations of the four batteries are listed in the table:

	Lithium-Ion Batteries	**Lead-Acid Batteries**	**Flow Batteries**	**Sodium Sulfur Batteries**
Y	1.333	7.	20	11.111
B	N/A	0.917	1	1
L	750	350	1000	4500

Table 4. Evaluation of the four types of batteries

Lithium-Ion batteries are low in largest continuous power of battery, so that it is hard to meet the usual electrical power needs of over 500W. (The minimum Power Rating on any day is above 500W.)

Lead-Acid batteries are lower in price, while they still meet the power needs.

Flow batteries and Sodium Sulfur batteries are rather high in price, both in terms of initial cost and cost per year, but they have a much longer lifespan.

5 Generalized Model

5.1 Adjustments & Generalizations

To generalize this model, the evaluations of the type of battery should be decided by personal preference parameters for each of the aspects: costs, reliability, and battery lifespan.

5.1.1 Battery Lifespan (L)

According to the capacity of batteries at different ages[2], we draw a scatter plot:

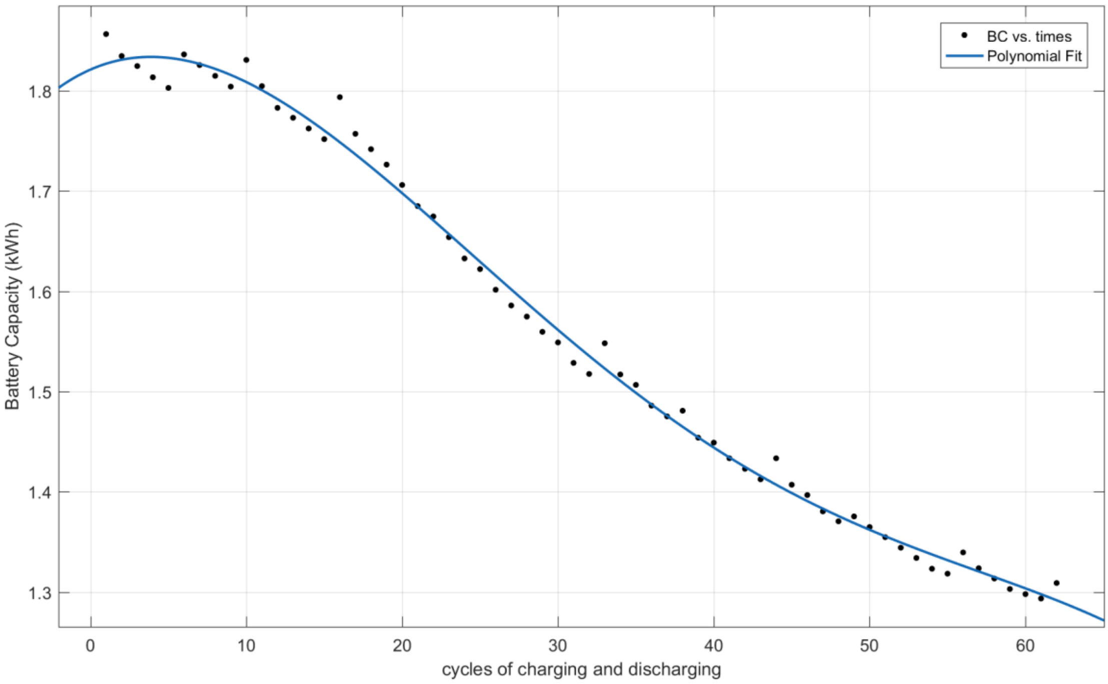

Figure 6. Capacity of batteries at different ages

After curve fitting, we fit the equation with a 4 degree polynomial, as it both has not relatively too many coefficients and can roughly describe the trend of slowly growing up at first and then dropping down:

$$f(x) = p_1 \cdot x^4 + p_2 \cdot x^3 + p_3 \cdot x^2 + p_4 \cdot x + p_5$$

$$p_1 = -1.174e-07(-1.685e-07, -6.635e-08)$$

$$p_2 = 1.917e-05(1.268e-05, 2.565e-05)$$

$$p_3 = -0.0009845(-0.001257, -0.0007115)$$

$$p_4 = 0.006795(0.002519, 0.01107)$$

$$p_5 = 1.821(1.801, 1.841)$$

SSE: 0.0113

R-square: 0.9948

Adjusted R-square: 0.9944

RMSE: 0.01408

5.1.2 Price of the battery

As soon as $f(x)$ is lower than the expected value, the lifespan of the battery ends. Using this method, we can calculate the lifespan of the battery, the price of the battery can also be calculated similarly with a fitted curve.

5.1.3 Reliability of the battery

Similar to the basic model, the reliability of the battery is calculated by the proportion of time when electricity usages exceed the largest Continuous Power Rating of battery.

$$A(x) = k_1 \cdot L(x) + k_2 \cdot B(x) - k_3 \cdot Y(x)$$

Since the longer the life span and reliability, and the shorter the cost per year, the better the battery is, we design this function A to evaluate the battery.

k1, k2, and k3 can be customized by users, and they can choose to use the type of battery with the largest A.

Also, we focus on houses connected to the power grid, where the option of using power from the grid is also available. Whether connecting to the grid or using solar power is suggested by cost estimations of both choices, including initial costs and routine costs.

Initial costs of connecting to the grid is calculated by:

$$distance\ to\ the\ nearest\ grid\ connection \cdot price\ of\ wire\ per\ length$$

Initial costs of using solar power are calculated by:

$$C \cdot P$$

Routine costs of connecting to the grid is calculated by:

$$electricity\ price \cdot electricity$$

Routine costs of using solar power are calculated by:

$$\frac{C \cdot P}{L}$$

By comparing the initial and routine costs of connecting to the grid, we can decide whether connecting to the grid or using solar power is better for the user.

5.2 Model Evaluation

The main changes are aimed at different types of batteries, different users’ preferences, and possible connections to the grid.

Using different fitting curves other than the $F(L_0) = a \times e^{-b \cdot L_0} + c$ function, our method can fit all kinds of batteries. And by leaving three parameters for users to set, our model is more personalized. We also give users a choice whether to connect to the electrical grid, and by calculating their costs, this can provide a precise comparison for the user.

6 Cement Battery Model

6.1 Pros & Cons and General Plan

According to “rechargeable concrete batteries”, its major advantages are:

The huge potential of building the bulk of great buildings with such types of cement, thus cutting down the amount of space needed and the length of wires needed, since power can be directly transferred from solar cells on the building to the cement battery with a shorter distance.

Electricity passing through the building can also generate heat, which can raise the house temperature, economizing on the house heating.

Since the cement battery has a high reliability, it is an ideal choice for backup batteries.

While its disadvantages include:
higher costs than regular batteries, lower energy density, and the inconvenience of repairing.

The essay did not mention the battery wearing out, but if the cement battery breaks down when it is used in the structure of houses, it can be hard to repair the battery.

Suppose that our house is made of steel reinforced concrete.

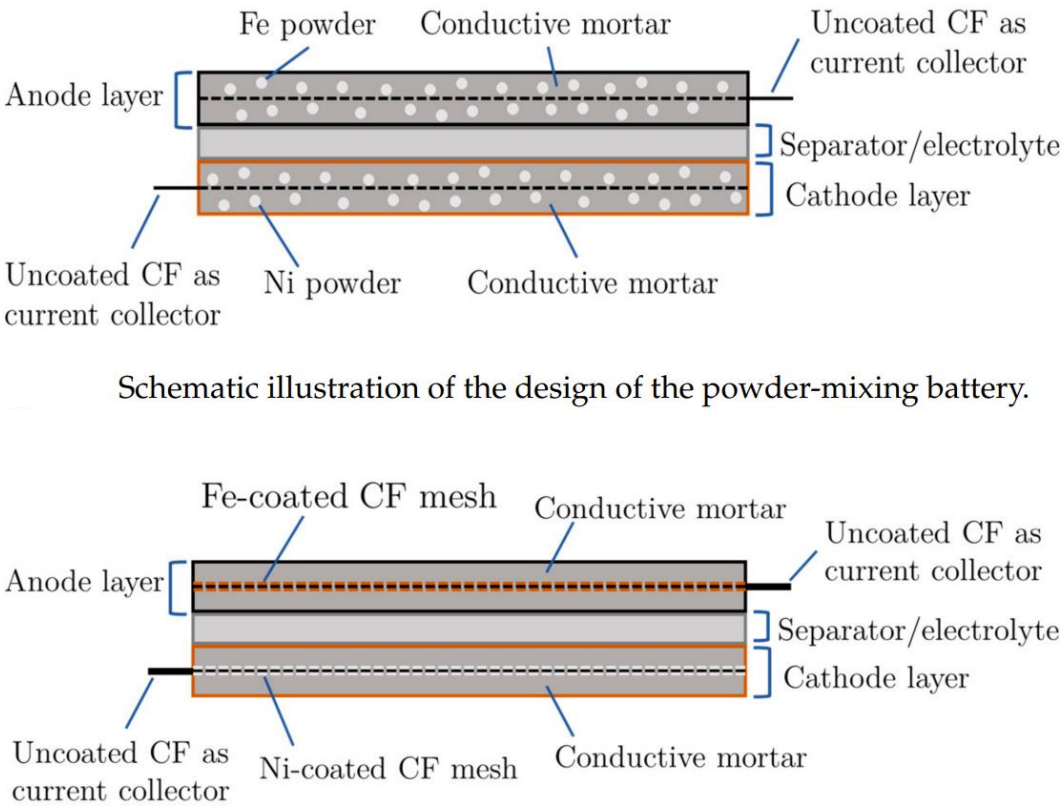

Figure 7. Two structures of the cement battery

The first plan is to use the powder-mixing method, and to include the reinforcement inside the cement, while using ways such as Impressed Current Cathodic Protection (ICCP) to protect it from corrosion by connecting it to an inert, less noble, metal and passing low-level current through it using an external power source (Polder, 1998).[4]

The second plan is to embed metal-coated carbon fiber into the cement, and the fibers act as the reinforcement.

Carbon fibers are resistant to salts, more chemically stable than glass fibers in an alkaline environment. Moreover, Carbon fibers are low in density, especially compared to steel fibers; their strength-to-density ratio is one of the highest among all fiber types. Carbon fibers have much higher specific strength and stiffness than metallic fibers and for this reason their use for strengthening and stiffening building materials such as plastics and concrete, are attractive.

Therefore, using cement with metal-coated carbon fiber to build houses can be beneficial to the steadiness of the house.

Then we will prove the possibility for cement batteries to store the solar energy for a house.

Assume that all the walls, floors and ceilings can be filled with cement batteries.

We still choose a house with a size of about 1600 square inches. The plan of the house is shown below. We use the plan to calculate the volume available for implanting in batteries, and then calculate the needed energy efficiency.

Figure 8. A typical floor plan of a 1600 square feet

The length of all the walls is about 78.8m, consisting of 48.5m of outside walls and 30.3m of inside walls

The thickness of the outside walls is 25cm, while the thickness of the inside walls is 15cm.

The thickness of the floors and ceilings is 10cm, and the height of one story is 3m.

Therefore, the volume of all the walls, floors and ceilings is approximately:

$$VL_{cement} = VL_{out\ wall} + VL_{in\ wall} + VL_{floor\ and\ ceiling}$$
$$= 78.8 \times 0.25 \times 3 + 48.5 \times 0.15 \times 3 + 148 \times 2 \times 0.1 = 70.775m^3$$

The energy density needed to achieve is:

$$D_n = \frac{N}{VL_{cement}}$$

$$N = 51.7kWh$$

So,

$$D_n = \frac{51.7}{70.775} = 0.73Wh/L$$

Then we calculate the energy density of the battery.

Cell	Discharge Cycles	Battery Capacity (mAh)	Energy (mWh)	Energy Density * (Wh/m²)
Ni-1/Fe-3 (Powder-mixing)	1 (at 6 h)	5.6	4.3	0.5
Ni–CF/Fe plate	1 (at 8 h)	22	23	2.8
	2 (at 8 h)	20	19	2.3
Ni–CF/Fe–CF	1 (at 6 h)	42	50	6.2
	1 (at 8 h)	51	56	6.9
	1 (at 12)	64	64	7.9
	1 (at 22)	89	73	9.0
	2 (at 6 h)	44	52	6.4
	3 (at 6 h)	43	49	6.1
	4 (at 6 h)	43	49	6.1
	5 (at 6 h)	43	49	6.1

* The area of the electrode is 9 cm × 9 cm.

Table 5. Performances of cement batteries at different discharging cycles (ages)

For the cement batteries, the highest battery energy possible is 73mWh.

The volume is $35cm^3$, so the energy density is $\frac{73mWh}{35cm^3} = 2.09Wh/L$

This shows that in the best condition, the energy restored can meet the needs of solar energy restoration for a house.

But this result is based on a high level of production, since the calculations use the cement batteries that have the highest energy density, and the walls need to be filled with batteries, meaning that there will be several layers of cement batteries in one layer of wall. This is a high requirement for craftmanship.

6.2 Additional Information Needed & Model

The two types of solar energy restoring batteries will be compared by costs, energy density, and efficiency.

6.2.1 Cost

Main costs of the cement battery include the cost of carbon fibers, the cement, and the cost of electroplating.

Since the battery can be used to replace the original building material in the house, the cost of the original material that the cement battery replaced should be offset.

Table 3. Mix proportion of the cement-based electrolyte separator.

Cement (g)	Fine Sand (g)	Alkaline Solution (g)	Ion Exchange Resin (g)	Total Volume (cm^3)
22	15	12	8	35

Compositions of the alkaline solution.

KOH (85.6%) (g)	$LiOH{\cdot}H_2O$ (>98%) (g)	Deionized Water (g)
245.3	12.6	756.3

Table 6. Compositions of the cement mixture

The cost of the cement is calculated according to the tables above.

	Cement	Fine Sand	KOH	LiOH	Deionized Water	Ion Exchange Resin
mass(g)	22	15	2.9436	0.15	9.0756	8
Price per mass	0.0005	0.0005	0.006	0.18	0.001	0.007
Price(yuan)	0.011	0.0075	0.0177	0.03	0.0090756	0.056

Table 7. Prices of cement mixture

The cost of carbon fibers is about 14 USD/square meter, and for each piece 90mm * 90 mm * 2 of carbon fiber is needed.[5]

The costs are:

$$14 \times 0.09^2 \times 2 = 0.23\ USD$$

The cost of electroplating is calculated according to the tables below.

Cathode	Anode	Bath Solution	Current and Duration
CF mesh	Ni plate	250 g/L $NiSO_4{\cdot}7H_2O$ 20 g/L $NiCl_2{\cdot}6H_2O$ 25 g/L H_3BO_3	1.0A for 4 h
CF mesh	Zn plate	74 g Zn granulate 1 L acetic acid 20 g NaCl 15 g sugar	1.0A for 4 h
CF mesh	Fe plate	180 g/L $FeSO_4{\cdot}7H_2O$	1.2A for 6 h

Table 8. Electroplating process

One Ni–CF cathode and one Fe–CF anode are required to be electroplated in each piece.

The voltage of electroplating is about 5V.

So the cost of electricity is:

$$Cost = Power \cdot Price\ per\ power = U \cdot I \cdot t \cdot Price\ per\ power = 11.2\ USD$$

Compared with the first two items, the cost of electroplating is already much higher. If the cement pieces are to be produced in large batches, the cost of electroplating also includes cost of machines and factories, which further raises the cost.

The cost of cement batteries mostly lies in electroplating.

Cost of cement batteries is much higher than that of traditional batteries, not only because of its high research and manufacturing costs, but also because it is hard to meet the needs of a 1600-square-feet house using the power restored in the total amount of cement in the house.

6.2.2 Energy density

Cell	Discharge Cycles	Battery Capacity (mAh)	Energy (mWh)	Energy Density * (Wh/m²)
Ni-1/Fe-3 (Powder-mixing)	1 (at 6 h)	5.6	4.3	0.5
Ni–CF/Fe plate	1 (at 8 h)	22	23	2.8
	2 (at 8 h)	20	19	2.3
Ni–CF/Fe–CF	1 (at 6 h)	42	50	6.2
	1 (at 8 h)	51	56	6.9
	1 (at 12)	64	64	7.9
	1 (at 22)	89	73	9.0
	2 (at 6 h)	44	52	6.4
	3 (at 6 h)	43	49	6.1
	4 (at 6 h)	43	49	6.1
	5 (at 6 h)	43	49	6.1

* The area of the electrode is 9 cm × 9 cm.

Table 9. Energy density of different types of cement batteries

For the cement batteries, the highest battery energy possible is 73mWh

The volume is $35cm^3$, so the energy density is $\frac{73mWh}{35cm^3} = 2.09Wh/L$

While for the original batteries, the energy density is much higher. Even the least efficient lead acid batteries reach an energy density of about $50Wh/L$.

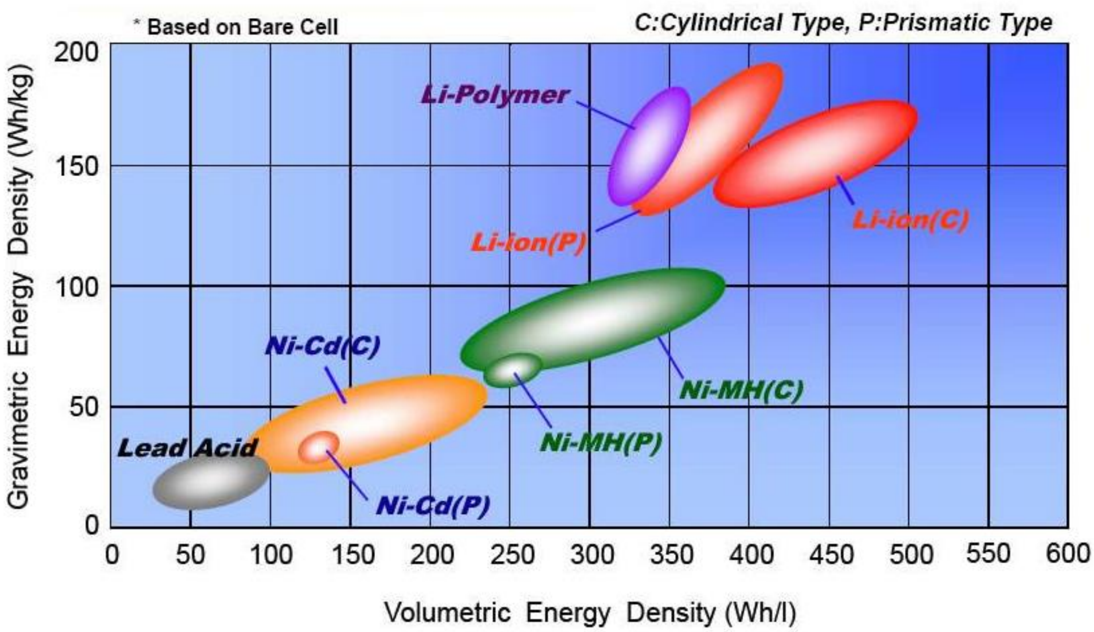

Figure 9. Energy density of different types of batteries (Photo Credit: NASA)

6.2.3 Round-trip efficiency

For cement batteries, the length of wires(l) is approximately the length of the house, which is about 12m.

The ρ for copper wires is $1.75 \times 10^{-8}\Omega \cdot m$, $S = 4mm^2$, $U = 220V$, and the average power P is

$$\frac{56.05kWh}{24h} = 2.34kW$$

The round-trip efficiency of cement batteries (T1a) is 0.7, and round-trip efficiency of wires is (T2a) is $\frac{P-I^2*R}{P}$

$$T = T1(battery) * T2(wires) * T3(converter) = 0.7 * \frac{P - I^2 * R}{P} * 0.9$$
$$= 0.7 * \frac{P - \left(\frac{P}{U}\right)^2 \frac{\rho l}{S}}{P} * 0.9 = 0.628$$

From the Generalized Model, we conclude that the best type of battery for storing solar energy overall is lead-acid battery.

For lead-acid batteries, we assume the distance from the house to the battery is 100m, so l=100m.

The ρ for copper wires is $1.75 \times 10^{-8} \Omega \cdot m$, $S = 4mm^2$, $U = 220V$, and the average power P is

$$\frac{56.05kWh}{24h} = 2340W$$

The round-trip efficiency of lead-acid batteries is 0.85,

$$T' = T1'(battery) \cdot T2'(wires) \cdot T3(converter) = 0.85 \cdot \frac{P - I^2 * R}{P} \cdot 0.9$$

$$= 0.85 \cdot \frac{P - \left(\frac{P}{U}\right)^2 \frac{\rho l'}{S}}{P} \cdot 0.9 = 0.749$$

The round-trip efficiency of cement batteries is still lower than that of original batteries.

The advantage of cement batteries having a shorter wire length is not that obvious as the wire efficiency of cement batteries is 0.997 while the wire efficiency of lead-acid batteries is 0.979.

By synthesizing the three aspects, we conclude that cement batteries are inferior to original batteries. There is still room for improvement, especially in the energy density of the battery.

6.3 Conclusion

In the basic model, we calculate on the basis that number of solar cells can be any value depending on our need. We conclude that the total power of the house is 56.05kWh, and the power needed to store in batteries is 51.7kWh.

We also conclude that $Y = \frac{P}{L}$, where $L = \frac{ln(\frac{a}{N-a+C})}{b}$, and $P = C \cdot 8$,

The most economic choice of battery capacity (C) will be the point where Y is minimized.

In the generalized model, we further consider different types of batteries, different users' preferences, and possible connections to the grid. We try our method on the example battery data, so that the lifespan of the battery can be calculated with the battery data and the expected minimum value of battery capacity.

In the cement model, we analyze the pros and cons of cement batteries. We make two plans with the two types of batteries: for powder-missing, we use Impressed Current Cathodic Protection (ICCP) to protect it from corrosion, and for metal-coating, we conclude that it is beneficial to the steadiness of the building.

Then we analyze the feasibility of using concrete batteries to store solar energy for the house. We conclude that it is possible, but it has a high price and a high demand for craftmanship.

We compare cement batteries with conventional types of batteries and conclude that they have a low energy density, medium round-trip efficiency, and a higher cost that is mainly caused by the electroplating process. The main room for improvement lies in the energy density of the battery.

News Article

With the rapid growth of science and human needs, traditional energy resources like carbon burning will finally meet a limit and can no longer meet the need of mankind. So there comes a growing need for a both economic and eco-friendly energy resource. Existing resources include solar energy, wind energy, wave energy and so on, the most mature of which is no doubt solar energy. Yet, however, there has not been a common solution to selecting the optimic overall energy system, making it only accessible to the very minority.

Recently, models are developed to help select the most suitable energy storage solution for house in any location and of any area. The models can evaluate most popular energy solution, including its energy storage system and battery model. It takes into account the energy from both the solar panels and the grid. With this model, everyone can calculate the most suitable energy storage solution, however his house is.

There are three models in all. The first two are aimed at exploiting the currently existing technologies and batteries, while the last at evaluating a novel type of battery. Its material is cement, making a built-in energy storage system viable. Though the calculation proves that cement itself, even if employed with the maximum quantity, cannot supply all the appliances in a house, the new battery helps reduce the electricity pulled from the grid and in turn reduce the cost.

Appendix

[1] Sunlight Intensity Time Function and Weather Factors Influencing Photovoltaic Generation. Huang Wei, Zhang Tian, Han Xiangrong, Su Hongyu.

[2] Data from ameresco solar.com

[3] PCoE Datasets

[4] First Steps in Developing Cement-Based Batteries to Power Cathodic Protection of Embedded Steel in Concrete. Niall Holmes, Aimee Byrne, Brian Norton.

[5] High Qualify Carbon Fiber Net Carbon Fiber Mesh for Concrete Reinforcement