HiMCM Problem A: Storing the SUN

Summary

Residents of remote areas have difficulty deciding on using electricity from the grid or an energy storage system. Due to the expensive costs of connecting to the grid, it was decided that a solar energy system would be the most advantageous option. However, designing this system brings into question what kind of batteries will be needed.

To design a model for the solar battery storage of a 1600 sq ft house, the team defined the factors that would be taken into account when calculating the total energy needs. We concluded that the energy usage of appliances in the home would depend on the number of residents. Our first model was calculated using the average energy usage of each appliance per day, considering that there would be four people living in the home. Calculations for battery pricing and an expanded battery chart were used to create a weighted average ranking based on each of the factors that we determined would contribute to the overall value of each battery. We found that overall, the Dakota Lithium Deep Cycle LIFePO4 battery was the most effective.

To account for the uniqueness of different off-the-grid houses, our team designed a more customizable model. This model asks the residents for their priorities and needs. Based on the residents' preferences and the specific trait of each battery, we adapted model one to recategorize the batteries and offer the residents the type of battery that best fits their needs. While we again found that the Dakota Lithium battery was the best overall, we created a ranking of the top 3 batteries for each given situation to give the homeowner more options.

Our model's main weakness is that we did not factor in solar input or how that would relate to the practicality of our energy storage system. This weakness is combated by the fact that we accounted for the worst possible situation where there is no sunlight present for 7 days along with cold temperatures that reduce the capabilities of the batteries.

Cement batteries at first seemed very ineffective to our team. We analyzed the fact that concrete is not a good heat insulator and how cement batteries' energy densities compared to commercial batteries'. However, we found multiple redeeming qualities of cement batteries that current commercial batteries are not able to counter. These qualities helped us to determine that concrete batteries could be effective in creating solar battery storage systems. Next, our team looked into how cement batteries could be incorporated into a house. We found that in order to determine how much energy can be stored within the batteries, we need the surface area available for the concrete. This information was used to help create an algorithm for the total energy able to be stored using the cement batteries in any given home. Finally, our team discussed what further information would be necessary to incorporate the cement batteries into our battery ranking model.

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News Article

Nov. 2021

OFF-THE-GRID: COULD YOU AFFORD IT?

Team 11622

While many of us may have had the desire to go out and live away from the world at some point in our life, not many are willing to give up the many benefits that come with modern living. Electricity is truly a luxury that many people could not live without- but living off the grid doesn't mean you would have to give it up completely. The development of solar technologies allows many people to live in remote areas while still enjoying all the same electronic appliances as we do. The only problem? Solar power systems that have to ability to completely replace the electrical grid can get incredibly costly.

Think about it- in order to have a fully solar-powered house, one would need to buy panels, batteries, inverters, and all the associated electrical components. One of the main (and most important!) costs that comes with setting up this solar system is the cost of all the batteries. There are many options to choose from with the type and pricing of batteries. Some last a long time, but are also very expensive. Others may seem like a good price, but they might not be powerful enough to keep your whole home running at once. There are many factors that go into choosing the "best" battery, but it's also specific to the buyer's individual situation. So how do you decide what battery to choose? We've simplified the whole process. Just answer the next two questions to find the proper chart. Each chart tells an approximate price for the battery system based on a 1600 sq ft 4 people living situation

Where do you live? If you live in a cold region, the battery you choose has to be able to handle the temperatures. Some batteries do not run as well when they are in an area that is below 32 degrees. Still, some of these batteries can be more cost-effective when you don't have to take climate into account. If you live in a region where you can regularly expect freezing temperatures at any point in the year, choose a chart that is labeled for cold areas. If not, feel free to choose between the hot or cold charts based on your preference.

How long do you want to live off the grid? As mentioned before, some batteries last a really long time but can be pricey. The opposite is also true: some batteries have a short life but cost much less than most other batteries. Knowing how long you plan to live in your off-the-grid home can allow you to find the most cost-effective battery for you! If you plan to live in your off-the-grid home for 20 years or less, choose short-term. Otherwise, go with one of our long-term charts.

Cold, Short-Term	Hot, Short-Term	Cold, Long-Term	Hot, Long-Term
1. Dakota Lithium Deep Cycle LiFePO4 Battery - $230,930	**1.** Dakota Lithium Deep Cycle LiFePO4 Battery - $207,873	**1.** Dakota Lithium Deep Cycle LiFePO4 Battery - $230,930	**1.** Dakota Lithium Deep Cycle LiFePO4 Battery - $207,873
2. Tesla Powerwall+ - $229,500	**2.** Discover AES 7.4 kWh - $272,076	**2.** Tesla Powerwall+ - $229,500	**2.** Tesla Powerwall+ - $204,000
3. Discover AES 7.4 kWh - $304,466	**3.** Tesla Powerwall+ - $204,000	**3.** Discover AES 7.4 kWh - $304,466	**3.** Discover AES 7.4 kWh - $272,076

Still too pricey for you? New advances in solar battery technology could be a solution. Recently, Swedish scientists discovered the possibility of rechargeable cement batteries. This would mean that energy could be stored in the very foundation of homes and buildings. Cement batteries could bring solar into new widespread popularity because it would be easy to incorporate into new structures, save a lot of space, and has so far proven to be incredibly safe. While the specific costs of implementing this new technology are currently unknown, making concrete batteries could help make environmentally safe energy alternatives such as solar much more affordable.

Assumptions

- Assume the solar panels used will provide enough energy to sustain the amount of electricity required for batteries.
- Assume house can store all needed batteries (lower volume is preferred though)
- Assume all lithium-ion/lead-acid batteries respond to temperatures the same.
- Assume that this house is in the United States of America.
- Assume that the longest span of non-sunny days is seven days. During these seven days, the solar panels receive no energy input.
- Assume that the batteries are able to be fully charged before the seven-day no energy period.
- Assume that the customer wants more continuous power rating and instantaneous power rating.
- Assume that the residents can only buy one brand of battery.
- Assume that the 1600 sqft model is in an environment where the winter gets below 32 degrees Fahrenheit.
- Assume that the given usable capacity of the battery accounts for depth of discharge, efficiency, and charge/discharge rate restrictions

I. Model 1

The questions that we addressed and acknowledged in the first model are:

- How many people will be using energy in this home?
- What appliances are people-dependent and independent?
- What items in the home will need energy and how much energy will they need per day?
- When will people in the home use energy?

Information about the batteries is found in the table below. The table includes batteries given by the problem, as well as batteries we researched and added. [1, 2, 3, 4, 5, 6, 7, 8, 9]

Battery	Battery Cost	Battery Type	Weight	Dimension	Continuous Power Rating	Instantaneous Power Rating	Round-Trip Efficiency	Usable Capacity	Life span
	(USD)		(lbs.)	(L×W×D in inches)	(kW)	(kW)	(%)	(kWh)	(years)
Deka Solar 8GCC2 6V 198	$368	SGLA	68	10.25 × 7.1 × 10.9	0.049 kW (for 20 hrs.) 0.017 kW (for 100 hrs.)	Not Available	80-85%	1.18	5
Trojan L-16 -SPRE 6V 415	$492	FLA	118	11.7 × 6.9 × 17.6	0.19 kW (for 10 hrs.) - 0.023 kW (for 100 hrs.)	Not Available	80-85%	2.5	7.5
Discover AES 7.4 kWh	$6,478	LFP	192	18.5 × 13.3 × 14.7	6.65 kW	14.4 kW (for 3 sec)	>95%	7.4	20
Electriq PowerPod 2	$13,000	LFP	346	27.5 × 50 × 9	7.6 kW	9 kW (for 60 sec)	96.60%	10	10
Tesla Powerwall +	$8,500	NMC	343.9	62.8 × 29.7 × 6.3	7 kW	10 kW (for 10 sec)	90.00%	13.5	10
Blue Ion 2.0	$19,140	LFP	602	42.5 x 23.75 x 24	8 kW	10 kW (30 min) 11 kW (5 min) 17 kW (1 sec)	98%	16	20
IQ Battery 3	$3,000	LFP	116	14.45 in x 26.14 in x 12.56 in	1.088 kW	1.632 kW (for 10 sec)	96%	3.36	10
Dakota Lithium Deep Cycle LiFePO4 Battery	$3,299	LFP	77	20.5 x 10.5 x 8.66	4.8 kW	9.6 kW (for 10 sec)	>95%	4.9	15

To find the amount of electricity consumption of a residential home, we found the average number of people in a household. Additionally, we calculated the average annual electricity consumption using the data from the U.S. Energy Information Administration (EIA) from the year 2015 [10]. According to Statista, there are 2.54 people per household [11]. The EIA also states that all households in all U.S regions use, on average, 10049.5 kiloWatthours (kWH) annually [10]. We calculated it by averaging the electricity consumption in each region. With these statistics, we can correlate the number of household members with the electricity usage. The EIA website also contains percentages of electricity consumption for different appliances. For example, the most intensive appliance, the air conditioner, uses 16.9% of all annual electricity consumption [10]. For a 1600 square feet, off-the-grid house, we calculated the number of people that would fit in the home comfortably. According to the Engineering Toolbox, an average person requires from 100-400 square feet to feel comfortable [12]. Since the data is for apartments, we decided to choose the upper end of the range which is 400 square feet. With this, we assume the number of people living in the 1600 sq ft house to be 4 people.

Since the average household size is 2.54 individuals and the average amount of electricity used annually per household is 10.049.5 kWh, we can infer that having 4 people would increase the electricity consumption. The ratio of 4 people to 2.54 people is 1.6, which can then be used to find the increase in electricity consumption. However, electricity consumption would not increase proportionally because certain appliances' wattages do not depend on the number of people living in a house. For example, having 4 people compared to 2 people would not substantially increase the usage of dehumidifiers. However, since the EIA included the percentage of electricity consumption in different appliances, we can assign the 1.6 ratio to the appliances that do increase with more household members. For example, lighting usage will increase as the number of inhabitants increases from 2.54 to 4. With more people living in a house, more rooms have lights on, therefore increasing light usage. Appliances that have this characteristic will be labeled as "dependent," and appliances that do not have this characteristic will be labeled as "independent."

To calculate the electricity consumption, we multiplied the dependent appliances by the percentage increase (1.60) and by each appliances' respective percent usage. For the independent appliances, we did not include the ratio multiplier. We summed the electricity consumption of each appliance to find the total annual consumption, then calculated the daily usage by dividing by 365.25 days. The chart below shows our calculations:

Appliances (Increase with More People)	Percentage Usage	Appliances KWh
Air Condition	0.169	2674.6
Space Heating	0.148	2342.2
Water Heating	0.137	2168.2
Lighting	0.103	1630.1
TVs and related	0.069	1092.0

Clothes Dryers	0.045	712.2
Ceiling Fans	0.018	284.9
Air handlers for heating	0.016	253.2
Cooking	0.014	221.6
Microwaves	0.011	174.1
Air handlers for cooling	0.008	126.6
Dishwashers	0.006	95.0
Clothes Dryers	0.004	63.3
Evaporative coolers	0.003	47.5
all other miscellaneous	0.133	2104.9
	Independent Annual Sum	13990.2
	Independent Daily Use	38.30

Appliances (Dependent)	Percentage Usage	Appliances KWh
Refrigerators	0.07	703.465
Separate Freezers	0.016	160.792
Dehumidifiers	0.012	120.594
Pool pumps	0.01	100.495
Humidifiers	0.006	60.297
Hot tub heaters	0.004	40.198
Hot tub pumps	0.001	10.0495
	Dependent Annual Sum	1195.8905
	Dependent Daily Use (Same)	3.27

Total Annual Consumption	15186.1

Total Daily Consumption	41.58

Then, we decided how many days our battery pack needs to provide energy for. We base this decision on a theoretical scenario of a prolonged period of cloudy days that impeded proper solar panel function. News channel WGN-TV [13] reported an 8 days sunless streak in Chicago, Illinois, USA on January 30, 2017. This fell one day short of a 9 days sunless streak recorded in January, 1992. Unbound Solar [14] suggested storing energy for five days of autonomy. It is unlikely that the house will experience sunless periods of time for as long as in Chicago, yet 5 days seemed too short of a time to prepare for. Therefore, we decided to store enough energy to provide for 7 days of autonomy. This would provide enough power in case of a long-term sun deficiency and give a buffer for shorter periods of low energy production.

Another factor that we have to take into consideration is the temperature's effect on batteries. According to RELiON [15], temperatures below 32 degrees Fahrenheit cause lead-acid batteries to suffer a 50% reduction in capacity and lithium-ion batteries to suffer a 10% decrease. This means that only 50% of a lead-acid battery's power and 90% of a lithium-ion battery's power are available for use. To cover for the loss of capacity, we calculated a "cold multiplier," a ratio of the required storage capacity to the desired energy output, that would allow the battery to operate at 50% or 90% capacity while still providing sufficient energy for the house. While the cold multiplier only applies in winter, our battery bank must be sufficient for the worst-case scenario where the temperature is affecting the battery's output.

Our next step was to account for the round trip efficiency of each battery. The round trip efficiency percentage shows what percentage of energy is actually being outputted by the battery and what percentage is being lost. We calculated an inefficiency multiplier to account for the lost energy by using the equation (1), solving for *w* to find how much energy we would need to store for the battery to output the desired amount. We then divided the *w* by *p*, the desired output, to find the inefficiency multiplier. Our results are shown in the table below.

$$\frac{p}{w} = \frac{\%}{100} \tag{1}$$

Battery Type	Round-Trip Efficiency (%)	Inefficiency Multiplier
Deka	80-85%	1.25
Trojan	80-85%	1.25
Discover	>95%	1.053
Electriq	96.60%	1.0352
Tesla	90.00%	1.111
Blue Ion	98%	1.02
IQ Battery 3	96%	1.0417
Dakota	>95%	1.053

With this information, we found the total amount of energy that we needed to store for each battery. We found our totals by multiplying the daily energy consumption by 7 days and then our multipliers. Our results are shown in the table below.

41.5 8kWh/day	7 days autonomous

Battery Type	Inefficiency Multiplier	Cold multiplier (32 degrees and below)	Total Battery Energy Needed in Storage (kWh) FOR 7 DAYS
Deka	1.25	2	727.7
Trojan	1.25	2	727.7
Discover	1.053	1.111	340.5
Electriq	1.0352	1.111	334.8
Tesla	1.111	1.111	359.3
Blue Ion	1.02	1.111	329.8
IQ Battery 3	1.0417	1.111	336.9
Dakota	1.053	1.111	340.5

By taking the amounts of storage needed for each battery brand and dividing them by the batteries' specific usable capacity, we found how many batteries we needed to store energy for 7 days of autonomy. We rounded this number to the nearest whole number as it is impossible to buy a fraction of a battery. Then, we calculated the upfront price to buy the required number of batteries by multiplying the number of batteries and the battery unit price given in the battery information table. We also calculated the cost of the batteries after 10 years by dividing 10 with the battery's greatest possible lifespan to get the number of times a person would have to replace the batteries. We then multiplied the number of needed replacements by the price to get the cost after 10 years. Our results are shown in the table below.

Battery Type	# of Batteries (Rounded Up)	Cost for all batteries ($)	Cost after 10 years
Deka	617	$227,056	$454,112
Trojan	292	$143,664	$191,552
Discover	47	$304,466	$152,233
Electriq	34	$442,000	$442,000
Tesla	27	$229,500	$229,500

Blue Ion	21	$401,940	$200,970
IQ Battery 3	101	$303,000	$303,000
Dakota	70	$230,930	$153,953

After determining the short-term and long-term battery costs for each brand, we determined which battery was the best for the first model house. We needed to factor in the other battery parameters, such as the instantaneous and continuous power ratings. We decided to create a ranking system for each criteria and take the weighted averages of the rankings for each battery to determine which battery is the best fit. Our criteria were long-term costs (after 10+ years), short-term costs, the volume of the battery bank (volume of one battery * number of batteries), the continuous power rating, and the instantaneous power rating. We ranked these criteria based on their importance on a scale of 1 to 5, with 5 being the most important. Our team discussed how to rank our criteria and decided to focus on long-term costs, so we gave that criteria a level 5 importance rating. Our second important factor was continuous power rating. Continuous power rating determines the number of appliances a house can run for an extended period of time [16]. Since the battery bank was to prepare for a long period of time without sun, we placed more importance on continuous power rating so the house could run more appliances over those seven days of autonomy. Our third most important factor was volume, as a lower volume of batteries would save on storage and installation costs. Our fourth most important factor was the instantaneous power rating, which determined the amount of energy that could be released in short bursts [16]. This is useful for energy-intensive appliances that require a large amount of energy to start up and then run on a lower amount. We did not prioritize this criterion because we assumed that the house would reduce its usage of high-intensity appliances during periods of energy shortage. Our least important criterion was short-term cost because we were prioritizing long-term cost and cared less about what was being spent upfront.

Then, we ranked the battery brands within these criteria on a scale from 1-8, with 8 being the best. Our rankings are in the tables below.

Importance:	Battery Type	Cost for all batteries ($)	Rating
1	Trojan	143,664	8
	Deka	227,056	7

Tesla	229,500	6
Dakota	230,930	5
IQ Battery 3	303,000	4
Discover	304,466	3
Blue Ion	401,940	2
Electriq	442,000	1

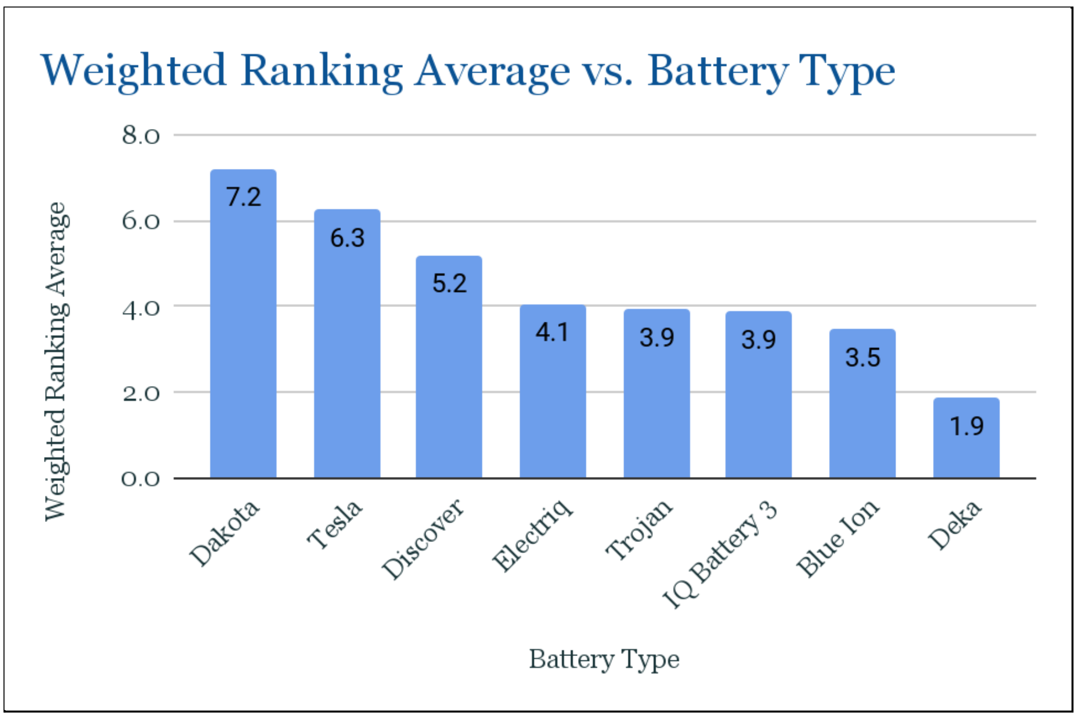
Importance:	Battery Type	Cost after 10 years ($) COLD	Rating
5	Tesla	229,500	8
	Dakota	230,930	7
	Trojan	287,328	6
	IQ Battery 3	303,000	5
	Discover	304,466	4
	Blue Ion	401,940	3
	Electriq	442,000	2
	Deka	454,112	1

Importance:	Battery Type	CPR (cold)	units	Ranking
4	Dakota	355.2	kW	8
	Discover	312.55	kW	7
	Electriq	258.4	kW	6
	Tesla	189	kW	5
	Blue Ion	168	kW	4
	IQ Battery 3	109.888	kW	3
	Deka	10.489	kW for 100 hr	2
	Trojan	6.716	kW for 100 hr	1

Importance:	Battery Type	IPR (cold)	units	Ranking
2	Blue Ion	210	kW for 30 min	8
	Electriq	306	kW for 60 sec	7
	Dakota	355	kW for 10 sec	6
	Tesla	270	kW for 10 sec	5
	IQ Battery 3	110	kW for 10 sec	4
	Discover	329	kW for 3 sec	3
	Deka	NA	N/A	1
	Trojan	NA	N/A	1

Importance:	Battery Type	Volume	units	Ranking
3	Dakota	75.51	cubic ft.	8
	Discover	98.38	cubic ft.	7
	Tesla	183.6	cubic ft.	6
	Trojan	240.097	cubic ft.	5
	Electriq	243.49	cubic ft.	4
	IQ Battery 3	277.294	cubic ft.	3
	Deka	283.24	cubic ft.	2
	Blue Ion	294.4	cubic ft.	1

Using these rankings and importance levels, we took a weighted average of the rankings in each criteria for each battery brand and compared them. The battery with the highest average was the best choice for our house. The rankings are displayed below in the graph.



The Dakota brand batteries were the best fit for our model 1 house. The battery had the highest weighted average for all of our criteria. It provides a good continuous and instantaneous power rating for a low long term cost while also not taking up too much space. With our model, we determined that 70 Dakota Lithium Deep Cycle LiFePO4 batteries costing $230,930 upfront was the overall best battery bank for a 1600 square foot house that houses four people to store enough energy to last seven days without solar panel function.

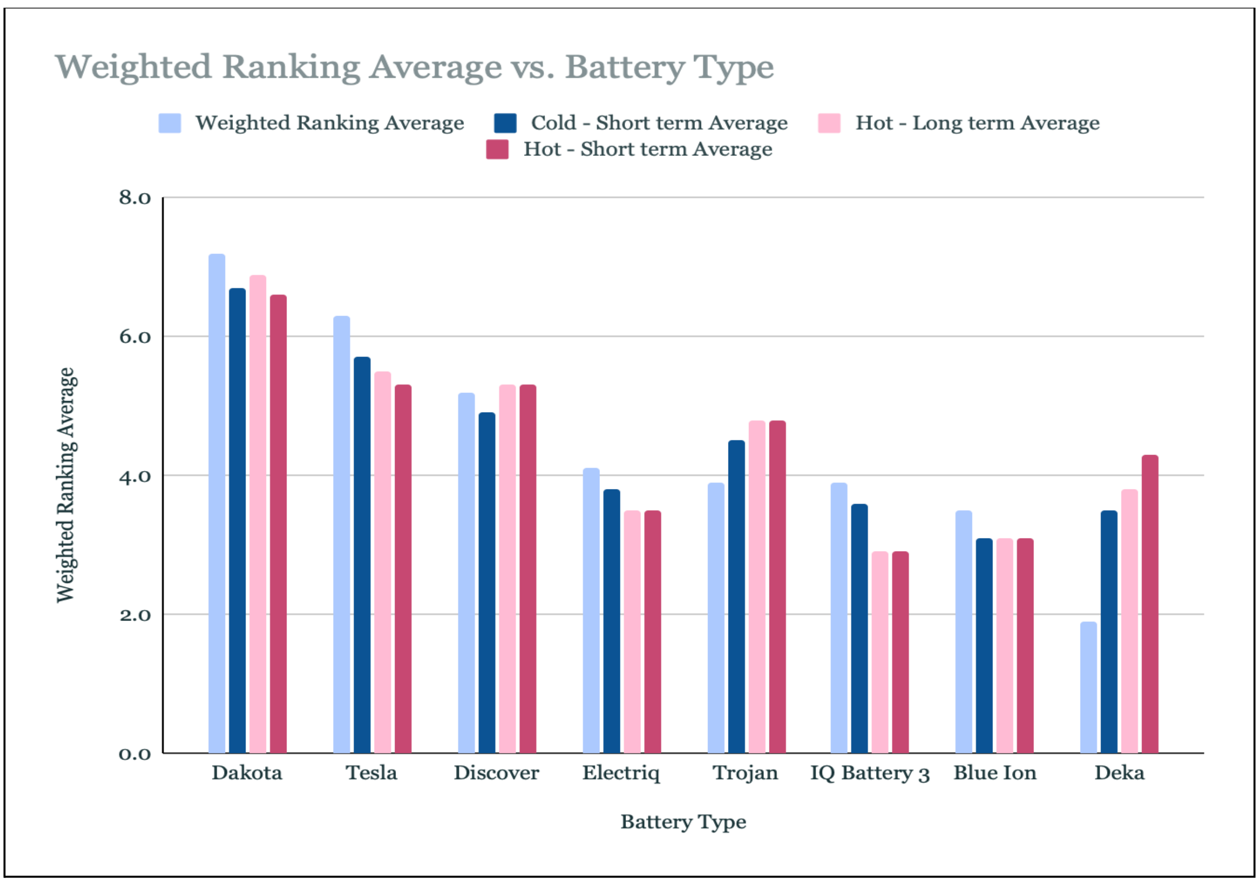
II. Model 2

To generalize our first model, our team looked at our consideration of winter temperatures and their effects on battery performance. Not all states in America experience temperatures below 32 degrees F, so we calculated a separate required storage amount excluding the cold multiplier for states with warm climates. We used the new "hot" storage amount to calculate the number of batteries, as well as the short and long term costs. These results are shown in the table below.

Battery Type	Inefficiency Multiplier	Total Battery Energy Needed in Storage (kWh) FOR 7 DAYS NO COLD MULTIPLIER	Rounded # of Batteries	Cost ($) of Batteries	Cost after 10 years ($) HOT
Deka	1.25	363.8	309	$113,712	143,776
Trojan	1.25	363.8	146	$71,832	272,076
Discover	1.053	306.5	42	$272,076	207,836
Electriq	1.0352	301.3	31	$403,000	363,660
Tesla	1.111	323.4	24	$204,000	204,000
Blue Ion	1.02	296.9	19	$363,660	227,424
IQ Battery 3	1.0417	303.2	91	$273,000	273,000
Dakota	1.053	306.5	63	$207,837	403,000

We reconsidered our weighted ranking system and added a second, separate importance level for short term cost priority, in case people were not planning to live in their off grid home for a long time and therefore would rather spend less on their batteries upfront. Finding the ranked averages for each combination of the criteria resulted in the best batteries for four possible combinations: cold winter and long term priority, cold winter and short term priority, hot winter and long term priority, and hot winter short term priority. The ranked averages for the batteries are shown in the graph and table below.

Battery Type	Weighted Ranking Average	Cold - Short term Average	Hot - Long term Average	Hot - Short term Average
Dakota	7.2	6.7	6.9	6.6
Tesla	6.3	5.7	5.5	5.3
Discover	5.2	4.9	5.3	5.3
Electriq	4.1	3.8	3.5	3.5
Trojan	3.9	4.5	4.8	4.8
IQ Battery 3	3.9	3.6	2.9	2.9
Blue Ion	3.5	3.1	3.1	3.1
Deka	1.9	3.5	3.8	4.3



We also created a flowchart to demonstrate the logic path one would take to find which battery was the best fit for them. The flowchart is below.

Our conclusion was that overall, the Dakota Lithium Deep Cycle LiFePO4 battery was the best choice, with Tesla Powerwall and Discover AES 7.4 kWh batteries coming in second and third, respectively.

Model Evaluation

Our model performs its function and recommends clients the top three batteries that meet their criteria, focusing mainly on their priorities of long term versus short term cost and the low winter temperature of their location. While the rankings for most of the batteries change depending on these criteria, the top three best batteries remain the same no matter what one prioritizes. This makes sense as it is sensible for a company to design a battery that can perform well in a variety of environments and optimize cost such that it is efficient in both long and short term situations.

However, there are some shortcomings. We were not sure how to accurately compare the continuous and instantaneous power ratings of the batteries. We couldn't find a reliable way to compare continuous power ratings and decided that a higher rating was better as one could run more appliances at a given time. The varying periods of time in the units for the instantaneous power ratings made it difficult to draw a clear conclusion as to which battery ranked highest, so our rankings are based more on speculation. If we did not rank the batteries correctly, this could skew our rankings to favor certain batteries over others.

Additionally, we did not account for the depth of discharge of the batteries. Depth of discharge is the percentage of the battery capacity that can be drained from the battery without sacrificing future performance [17]. The recommended depth of discharge for lead-acid batteries is 50%, meaning that one shouldn't drain more than half the battery's capacity if they want to preserve future function. For lithium-ion batteries, the depth of discharge is much higher, ranging between 80% to 95% [17]. The Blue Ion brand battery that we researched sports a 100% depth of discharge [9]. These percentages would affect how many batteries one would have to purchase as more batteries are required to compensate for the "unusable" energy. This would consequently affect short term and long term price, which could rank batteries with higher depth of discharges, like the Blue Ion, above other batteries. However, after doing research on depth of discharge, we found that the phrase "usable capacity" refers to the amount of energy one can discharge safely from the battery and already accounts for lost energy due to depth of discharge restrictions and battery inefficiencies. This is stated in our assumptions.. Thus, we chose to exclude depth of discharge in our calculations.

III. Cement Batteries

A study conducted by Zhang & Tang (2021) [19] found that the layering of the carbon fiber mesh of electroplated Ni-CF as the cathode Fe-CF anode had the highest energy density of 7Wh/m^2 or 0.8 Wh/L.

Incorporating Cement Batteries into Structures

To incorporate the cement batteries into a structure, a carbon-fiber mesh of electroplated Ni-CF would be embedded into the walls of a structure. This would allow the cement batteries to be fabricated on a large scale, therefore, be able to store more electricity. In order to be able to incorporate cement batteries into an off-the-grid home, we would need to be able to determine the amount of energy the carbon mesh in the cement can store.

To calculate how much energy can be stored, the surface area available for the carbon mesh to be embedded needs to be calculated. The surface area is dependent on the width, length, and height of the structure. The total surface area of a structure is the surface area of the 4 walls and the floor excluding the area of openings in the walls, shown in equation (2). The roof is excluded from this surface area calculation due to its irregularities across different structures. The area available for the cement battery carbon mesh to be embedded can be calculated using equation (3).

$$T = n \cdot (l \cdot h) + n \cdot (w \cdot h) + (w \cdot l) \tag{2}$$

$$A = T - T(r) \tag{3}$$

T is the total surface area of a structure excluding the roof's surface area. l is the length of the structure and w is the width of the structure. n is the number of walls with the correlating l or w. A is the area available for the mesh to be applied to the structure and r is the ratio of openings area to wall area. With these variables, the area available for the cement battery mesh can be calculated for any given house. Continually, using this information, we could theoretically determine the amount of energy that can be stored in the given home.

Using the product of the energy density of the Fe-Ni carbon-fiber mesh, 7Wh/m^2, and the area available for the mesh to be embedded, the amount of energy that can be stored by the cement batteries can be calculated, equation (4).

$$E = 7\, Wh/m^2 \,(A/10.7639) \tag{4}$$

E is the energy that can be stored by the cement batteries and 10.7639 is the ratio between square feet and square meters. Being able to determine the amount of energy able to be stored in any given house would allow us to incorporate this cement battery system into said house.

Advantages and disadvantages of cement batteries

Advantages	Disadvantages
The cement batteries can be easily applied to new buildings.	Concrete is not a good heat insulator compared to wood.*
The cement battery model will save more space because it is embedded within the walls of a structure compared to commercial detached batteries.	The energy density of a cement battery is less than that of commercial batteries [19]
The cement batteries do not pose any known threat to the safety of the residents [19]	

*It is important to note that even though concrete is not a good heat insulator and can waste heat energy in the winter, concrete can cool the structure in the summer which would lower the air conditioning usage. Depending on where the structure is located (warm or cold region), this disadvantage might be an advantage.

Information needed to compare cement and commercial batteries

1. The cost of fabrication of the Fe-Ni mesh in the cement batteries. Cost is a significant factor in the weighted ranking that our team used to compare commercial batteries. Knowing the cost of the cement battery fabrication is needed to help determine the overall cost of cement batteries.
2. Depth of discharge, efficiency, and charge/discharge rate restrictions of the cement batteries. All of these are specific factors that go into determining the usable capacity of the cement battery [20]. We use usable capacity to help determine the overall cost of the battery system. As overall battery system cost is used to compare batteries, we'd need the depth of discharge, efficiency, and charge/discharge rate restrictions in order to incorporate cement batteries into our current model.
3. The house dimensions. As discussed before, this can be used to determine the amount of energy able to be stored by the cement batteries in a given house. The amount of energy that can be stored in the battery system factors into the total price of the battery and therefore is necessary for incorporation.
4. The instantaneous and continuous power rating of the cement batteries. These are factors in our commercial battery ranking as they relate to how effective and valuable each battery is. In order to add the cement battery to the model, both of these power ratings are needed so that we can create an accurate comparison.

IV. Conclusion

Findings

We decided that the weighted ranking system will stay the same regardless of the size of the house or the amount of energy required. Since all the calculations were done constants, changing the values would only increase/decrease the number of batteries while the correct choice of battery type/brand does not change.

Based on our weighted ranking system, we found the best overall option is the Dakota Lithium Deep Cycle LiFePO4 Battery for model 1 and model 2. For every category such as cold or warm environments, the Dakota battery was the overall best option. However in certain categories, the Dakota battery is not the best. In long term prices for cold conditions, Tesla is the best. For pricing, we found that the Trojan battery was best in short-term warm, long-term warm, and short-term cold conditions. However, a downside to it is that it requires maintenance around every two weeks. For long-term pricing in cold weather, the best option was the Discover AES 7.4 kWh battery. The Dakota battery reaped benefits with its power ratings and superior size. Though we do have a definite answer for the best-in-class battery, the other batteries can be well suited for those who want a cheaper entry-level cost.

Strengths

When calculating electricity consumption in the 1600 sq ft house, we were able to account for the fact that increasing the number of people will not be a proportional increase. By separating the parts that do increase and the parts that do not, we can find a more accurate reading for the amount of electricity a 1600 square foot, 4 people household would use. Another strength is that we accounted for the worst case possible in which there is a full week of no sunlight in the winter. This makes our findings more robust since an individual will feel energy-secure in any situation and can always choose a smaller battery bank if they decide that they do not need that much storage.

Weaknesses

A weakness of our paper is we do not consider the solar power input that is required to build the batteries. We assumed that since the residents have decided to move off the grid, they would have enough property space for solar panels that could cover the house's needs (and more for the battery).

Another weakness is that the comparisons for the continuous power rating and instantaneous power rating between the batteries were somewhat subjective. Since the batteries' units were not consistent for their continuous and instantaneous power ratings, it was challenging to compare them. Additionally, these rankings were also made off the assumption that having a higher continuous/instantaneous battery rating was generally better. Even though the house may never need the benefits of the higher ratings since the models have so many batteries, we simply ranked them based on their potential capabilities.

V. References

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