2021 HiMCM
Problem A - Storing the Sun
Team 11616

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Summary

Solar batteries are an important part of adding an off the grid solar power system to a home. They allow for energy to be utilized when the solar panels aren't able to make enough. The main two types of batteries are lead-acid and lithium-ion batteries. Lead-acid batteries are known for being reliable and having low upfront costs, though they require more maintenance. Lithium-ion batteries on the other hand are more expensive but have no maintenance costs and a longer lifetime. While both batteries are good, one ends up being more practical and cost effective depending on the specifics of the home.

With our model, we decided to look at cost effectiveness within the batteries that would be able to work with the given energy usage. We started off by finding the energy usage through a set of questions about a homeowners average routine and appliance specifications. Since this is just a model, these numbers allow for estimates in routine, even if said estimates are a bit inconsistent with reality. Some values were taken to the extreme to cover for situations in which the home would require more energy than usual - such as if the heating system had to run 24 hours of the day. These details allowed us to find the amount of energy usage in kilowatt hours (kWh) and determine the consistent energy usage along with the instant spikes in demand of energy. We then were able to plug these values into the second part of our model. This model additionally asks for the power of their current solar panels, or the ones they plan to buy, and what climate zone they are in. Through this, we determined how many batteries would be needed in order to run the home and how much this would cost. We assumed that people would want to pay the least amount of money so we found the minimum price of the different types of batteries and then printed that battery with its price and amount of batteries needed.

After determining these specifications, we decided that our house should have four Discover AES 7.4 kWh batteries for continuous energy which would cost $26,025.48 and two Discover AES 7.4 kWh batteries for instantaneous energy which would cost $13,006.00. These numbers could be lower, but we were considering extremes to better test our model. Since our model bases its calculations off of user input, it is able to be used with any combination from the homeowner.

Problem Statement

The overall task is to consider energy storage systems for off-the-grid areas using solar power. The purpose of such systems is to store energy when solar power isn't available for use. The most common way to do so is by utilizing batteries, either singular ones or banks of them as a combination. The optimal battery arrangement is dependent on homeowner circumstances.

The house that is being analyzed is a 1600 square-foot house. The first step is to determine the questions to define maximum energy need and use that value to determine the best battery set-up. These are important parameters to establish because of the amount of energy the household requires. Next, a mathematical model must be designed to choose the "best" battery storage system for the home. This model must then be utilized to decide on a storage system.

The next main step is to adjust the model to allow it to be adaptable to any individual's needs and evaluate it. Then the advantages and disadvantages of another type of battery currently being researched - the cement battery - must be analyzed. We must then provide a hypothetical strategy for implementing cement batteries into our model. Following this, the additional information required to add cement batteries to our model must be outlined. The final step is to write a one-page non-technical newspaper article that describes our decision model and recommendations for future opportunities for the use of cement batteries.

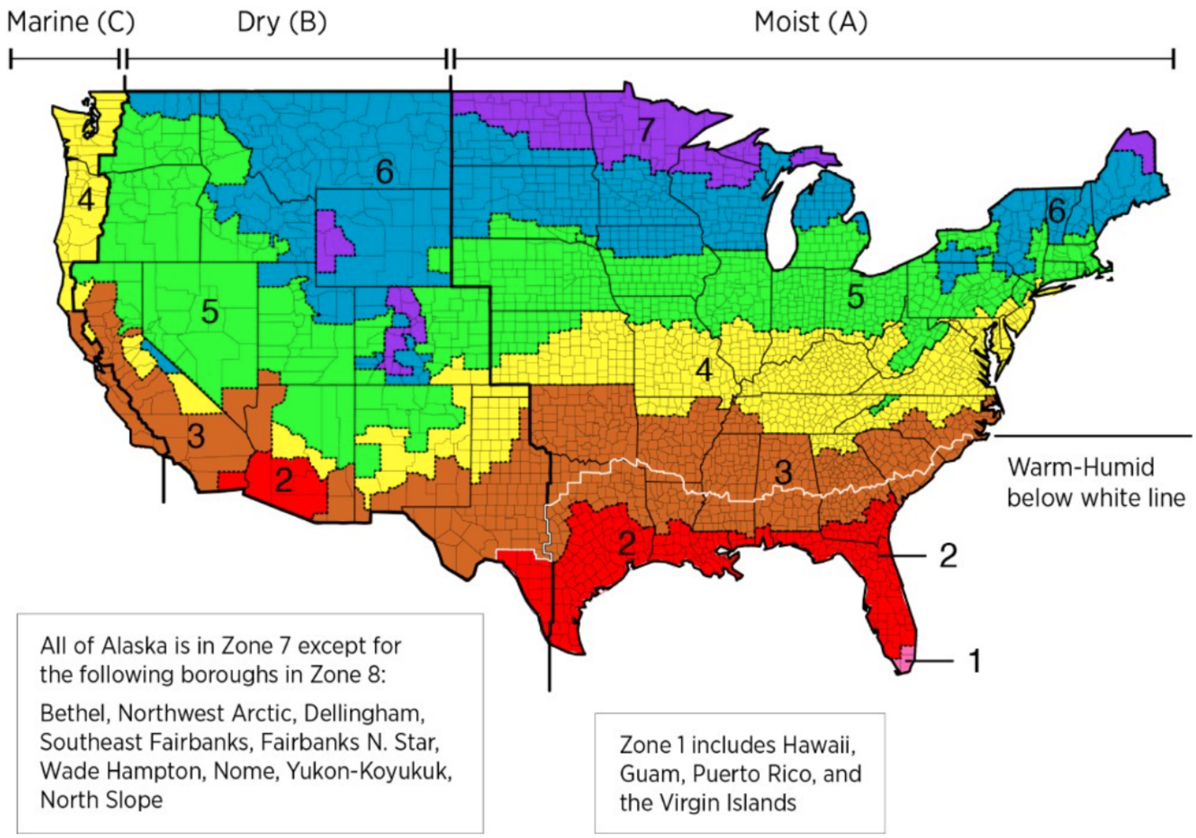
Background and Technical Terms

In order to understand the context of this problem, there are a couple of relevant terms that must first be defined. First, a discharge rate is the amount of energy that is drained from a battery per hour. Second, kWh stands for kilowatt-hours which is a unit of measure for energy from a battery.

We will also take this opportunity to recap some concept definitions that were given to us. Continuous Power Rating is the kW of power that a battery can provide consistently over a long period of time. Instantaneous Power Rating is the kW of power that a battery can provide in short bursts but not over a long period of time. It is important to note that some batteries output instantaneous and continuous power, while others only strictly output continuously. Round-Trip Efficiency is the number of units of electricity a battery can provide for every input. This will usually be presented as a percentage of energy output from a battery over the energy input into the battery. The final crucial term is usable capacity which is the amount of electricity in kWh that a battery is able to store if it is charged 100% of the way through.

One of the most important initial facts is climate zones because they have an effect on hours of available sunlight and the temperature in the region which affects the heating and cooling needed in the home.

A common battery comparison is between Lead-Acid and Lithium Iron Phosphate batteries. Lead-Acid batteries are reliable for full time off the grid service and are relatively cheap. Lithium Iron Phosphate batteries are a type of Lithium ion battery. They have one of the longest lifetimes of solar batteries and are considered extremely safe.



Climate Zone regions are based on temperature as well as humidity levels. Source: 2012 IECC – International Energy Conservation Code

Figure 1.1 This is a map of the 7 climate zones of the United States

It is important to preface that although the context of this problem is set in a rural area, this is irrelevant to our model because the location of the house (not including its climate zone) has little to no relevant correlation with hours of sunlight and climate.

Assumptions and Justifications

- The batteries will always be charged to 100% and used completely, therefore keeping the battery lasting longer
    - Justification: We are making this assumption because it is the most cost efficient and the objective of this solution is to find the most cost effective and eliminate unnecessary spending.
- People will want the lowest costing option that still fits their needs
    - Justification: It is unnecessary to use an expensive system if a lower cost one fits your needs.

- The family is living in the house year round
    - Justification: To simplify the second part of our model, we account for the lifetime of the battery as if it is being used everyday. We also assume that the family is using it at maximum functionality to find the best batteries.
- The amount of people in the house is not changing
    - Justification: To simplify the second part of our model, we assume that no extra people are joining or leaving so that the battery lifetime is unaffected.
- The house has a standard 9 foot ceiling (would affect heating/cooling)
    - Justification: Since this is the most common, it is likely that the house would include this.
- Anything that requires energy at a level that is greater than the most often occurring hourly kWh demand results in the battery functioning on its continuous power output
    - Justification: In order to create consistency in our model, we defined a standard for continuous power to differentiate it from instantaneous power demands.
- If they are home, the lights will be on
    - Justification: for simplicity, this allows us to consider the extreme case in which the household is home and needs constant lighting.
- The members of the household who are showering shower in immediate succession
    - For simplicity in our model, this is necessary to account for all showers.
- When charging tech devices (laptops, phones) all the devices of the household charge at the same time
    - Justification: For simplicity in our model, this assumption allows us to account for the extreme cases.
- The household is functioning at its maximum every day of the year
    - Justification: While this is not logically going to be the case, this assumption allows our model to calculate the batteries that it will need for this maximum and the homeowner will, in reality, have extra lifespan.
- The microwave begins running at the same time as the oven
    - Justification: We assume that the family is cooking at the same time, which includes the microwave and oven. Since the microwave is used in short spurts throughout the day, this assumption allows our model to disregard that since it does not affect the outcome.
- Heating systems and cooling systems will not run at the same time
    - Justification: This is counterintuitive.

Variables and Constants

Model Part 1

For the first part of our model, we looked at the details of the homeowner's individual lifestyle. These details fall into five main categories: general times and durations, house information, showers, charging devices, and kitchen. The detailed list of questions for each category can be found in Figure 2.2. Additionally, we request the output kilowattage for each appliance to gather the most accurate data. The continuous and instantaneous power needs are dependent on this data.

To ensure simplicity of our model, the tasks that we account for remain constant.

Model Part 2

Our first variable is the continuous and instantaneous energy amounts. These both involve homeowner input and are reliant on part one of the model. Once the homeowner fills out model one, they will have to take the numbers they get and input them into part two of our model. The next variable is the charging time, which is reliant on the power of the solar panel and climate. Solar panel power is different for each solar panel so this will be something that the homeowner will input themselves. This will allow our model to adapt to any solar panels. The solar panels will affect the charging time because they determine how much energy can be going into the batteries. The climate zone affects the amount of time that the solar panels will get to charge because it affects the total amount of sunlight that the house could get.

Our constants are kWh per cycle, the amount of cycles per life, the cost of replacement, and the base cost which were all either given or found through research.

1. Our Model

1.1 Defining Questions

We began with the three questions offered in the problem:

How many people will be using energy in this home?

This could significantly increase the amount of energy a house will need to operate.

What items in the home will need energy and how much energy will they need?

The number of housewares and their efficiency could increase the amount of energy a house would need.

When will people in the home use energy?

Sharp increases in the amount of energy consumed per hour could call for the use of energy from instantaneous batteries, while the constant energy demands of the house would define requirements for energy from continuous batteries.

We added the following questions and subquestions to our model:

Where is the home located?

Not only will this affect the amount of sunlight a home gets (thus affecting the amount of time the battery has to charge), but it also defines how much energy a house will need to heat or cool.

How many hours per day are the residents of the house active?

The answer to this question can have a variety of different implications, such as affecting light usage or concentration of houseware usage. To account for the potential variation in these answers and prepare for further generalization, we added the following subquestions:

- Which hours are the residents of the home sleeping?
- Which hours are the residents using technology (watching TV, charging devices, using desktop computers)?
- What hours are they doing laundry and showering?
- Which hours are the residents cooking for?
- Which kitchen appliances do they have?

How efficient are the housewares in the home?
The efficiency of the housewares, or the number of kilowatt hours that each item requires to operate, will set the standard for the maximum kilowatts that will need to be used at once.

1.2 The Model Part One

Looking at the necessary devices and amenities for a house, we created formulas and more in-depth questions to develop a model that would calculate the total kilowatts the household uses. The formulas this model utilizes, as seen in Figure 2.1, analyze the hourly kilowatt demand from appliances and other household activities that consume energy. Some of these functions are continuous, such as heating and refrigeration, while others only operate at certain times of the day. We only accounted for the most basic, general tasks that the average household uses.

Task	Idealogy	Formula
Heating / Cooling	average kWh * hours in use * sq ft	(5 * (zone#-1) + 30) * 0.000293071 * 24 * sq ft
Refrigeration	avg kWh * hours in use * number of fridges	0.565 * 24 * qty
Desktop (idle)	avg kWh * hours in use * number of desktops	0.125 * 24 * qty
TV (idle)	avg kWh * hours in use * number of tvs	0.0013 * 24 * qty
Lighting	((((avg lumens per square foot * square footage) / avg lumens in a light bulb) *	((((50 * sq ft) / 800) * 0.06) * hours
Charging Devices (PM)	(avg kWh laptop * laptops * hours charging at night) + (avg kWh * phones * hours	(0.03 * qty * (24 - start time)) + (0.004 * qty * (24 - start time))
Charing Devices (AM)	(avg kWh * laptops * hours charging in the morning) + (avg kWh * phones * hours	(0.03 * qty * (total hours - hours at night)) + (0.004 * qty * (total hours - hours at night))
Dishwasher	avg kWh * hours in use	1.80 * hours
Oven	avg kWh * hours in use	3.00 * hours
Microwave	avg kWh * hours in use	0.515 * 0.5
Washing Machine	avg kWh * hours in use	1.90* hours
Dryer	avg kWh * hours in use	3.00 * hours
Taking Showers	avg kWh per shower * length showers in hours * number of showers	4.00 * hours * qty
TV (in use)	(avg kWh - idling kWh) * hours in use	(0.0583 - 0.0013) * hours
Desktop (in use)	(avg kWh - idling kWh) * hours in use	(0.200 - 0.125) * hours

Figure 2.1 The list of household tasks and the formulas used to calculate the kilowattage they use. We had to factor in the quantity (qty) of some items and hours in operation for others. The homeowner can input their own kWh for each appliance as well.

Some formulas were simply the average kilowatts per hour the appliance required multiplied by the hours it was in use. However, some tasks required attention to many different factors for each task to determine the formula - such as the amount of people using these comforts. For heating, we had to find the British Thermal Unit (BTU) it takes to heat a house in a given climate zone since the heating and cooling will differ based on the temperature in the region and then convert that to kWh. We chose to multiply by 24 to find an extreme, which ensured that the house could run the heat for 24 consecutive hours should the need arise. We found that cooling a home takes 20 BTU per square foot, which will always be less than the BTU it will take to heat a home. Because of this, we only calculated heating and grouped cooling into that since heating and cooling do not run at the same time in a house. Another challenging task is accommodating the lighting in the house. Since we are looking for an extreme case, we wanted to simulate this by assuming the person would be home during the day and have the lights on for the whole time they are awake. To do this, we initially get the lumens per house by looking at the square footage and multiplying it by the average number of lumens per square foot. We then find how many lightbulbs the house will need to support that amount of lumens by dividing the total lumens by average lumens per light bulb. Afterwards, the kilowattage for those lightbulbs is found and the kW it will take based on how many hours the lights are on can be calculated.

For charging devices, we decided to break it up into night and morning, since many families will charge devices overnight. To get the night time kW, we used the time the homeowner begins charging their devices and found the hours to midnight. Then, using the leftover hours they still need to charge their device, we found how long it would charge for in the morning. In terms of microwaving, we simplified the process by charging a flat kWh on whether they have a microwave or not since the times are very small and energy used is miniscule. The average household uses the microwave for about 30 minutes a day and we grouped it into the same time period as the oven for simplicity. Since we wanted to keep our model as simple as possible, we decided to keep the idle kWh continuous for the TVs and desktops and add on the extra kWh for usage by taking the usage and subtracting the already-accounted for kWh from the idle amount. Focusing on the extreme case, we set the number of TVs in the house to run at the same time. On the same note, we assume that when desktops are running, they are all running at the same time.

Reference Cell Questions

General Times and Durations	
When do you go to bed?	22
When do you wake up?	7
When do you watch TV?	17
How long do you watch TV for?	2
When do you start to wash your clothes?	12
How long is the wash cycle?	0.75
How long is the dry cycle?	1
When do you use your desktop?	10
How long do you use your desktop for?	2

House Information	
How many people live in your house?	3
Which climate zone are you in?	5
How many sq. ft is your house?	1600

Showers	
How many people shower each day?	3
At what time do you begin showering?	9
How long does each person shower for?	0.3

Charging Devices	
When do you charge your devices?	22
For how many hours do you charge your devices?	6
How many laptops do you charge?	3
How many smartphones do you charge?	3
How many desktops do you have?	3
How many TVs do you have?	1

Kitchen	
Do you have a microwave? (0 for no, 1 for yes)	1
How long do you run your dishwasher for?	2
When do you run your dishwasher?	11
How long do your run your oven for?	2
When do you run your oven?	16
How many refrigerators do you have? (freezers group in)	1

Figure 2.2 The questions requested from the homeowner to get the most accurate kWh they would be using - with answers pertinent to our sample home

In order to go about figuring out which combination of continuous and instantaneous batteries would be needed, we needed to first find the maximum kWh required by the house and then break it into the continuous levels and instantaneous spikes. To do this, we have to look at the kilowattage that each appliance requires. We implemented a place for the homeowner to input the kilowattage for their appliances to get a more specific idea of exactly how much kW would be required for the house to run them. We also accounted for the times during which they are functioning. We used our formulas and the homeowner's answers to the questions to determine these factors as seen in Figures 2.3 and 2.4.

Hourly Energy Usage Based on Tasks	Task Name	kW / Hour	Appliance Output (in kWh)	Total kW Used in a Day	Start Time	Hours of Operation
Continuous	Heating / Cooling	23.447	23.447	562.72	0	*24.0*
	Refrigeration	0.565	0.565	13.560	0	*24.0*
	Desktop (idle)	0.375	0.125	9.000	0	*24.0*
	TV (idle)	0.001	0.0013	0.031	0	*24.0*
Instantaneous	Lighting	6.000	0.06	90.00	7	15.0
	Charging Devices (PM)	0.102	0.017	0.204	22	2.0
	Charing Devices (AM)	0.102	0.017	0.408	0	4.0
	Dishwasher	1.800	1.800	3.600	11	2.0
	Oven	3.000	3.000	6.000	16	2.0
	Microwave	0.515	0.515	0.258	16	0.5
	Washing Machine	0.900	0.900	0.675	12	0.8
	Dryer	3.000	3.000	3.000	6	1.0
	Taking Showers	4.000	4.000	3.600	9	0.9
	TV (in use)	0.057	0.057	0.114	17	2.0
	Desktop (in use)	0.225	0.075	0.450	10	2.0
Total		44.089		693.62		

Figure 2.3 The list of tasks and resulting kW based on the hours spent on the task (in reference to the homeowner input to the questions) To gauge which activities will be running at the same time, we account for the start time. To get kWh, we took the total kW used in a day and divided it by 24 hours in a day.

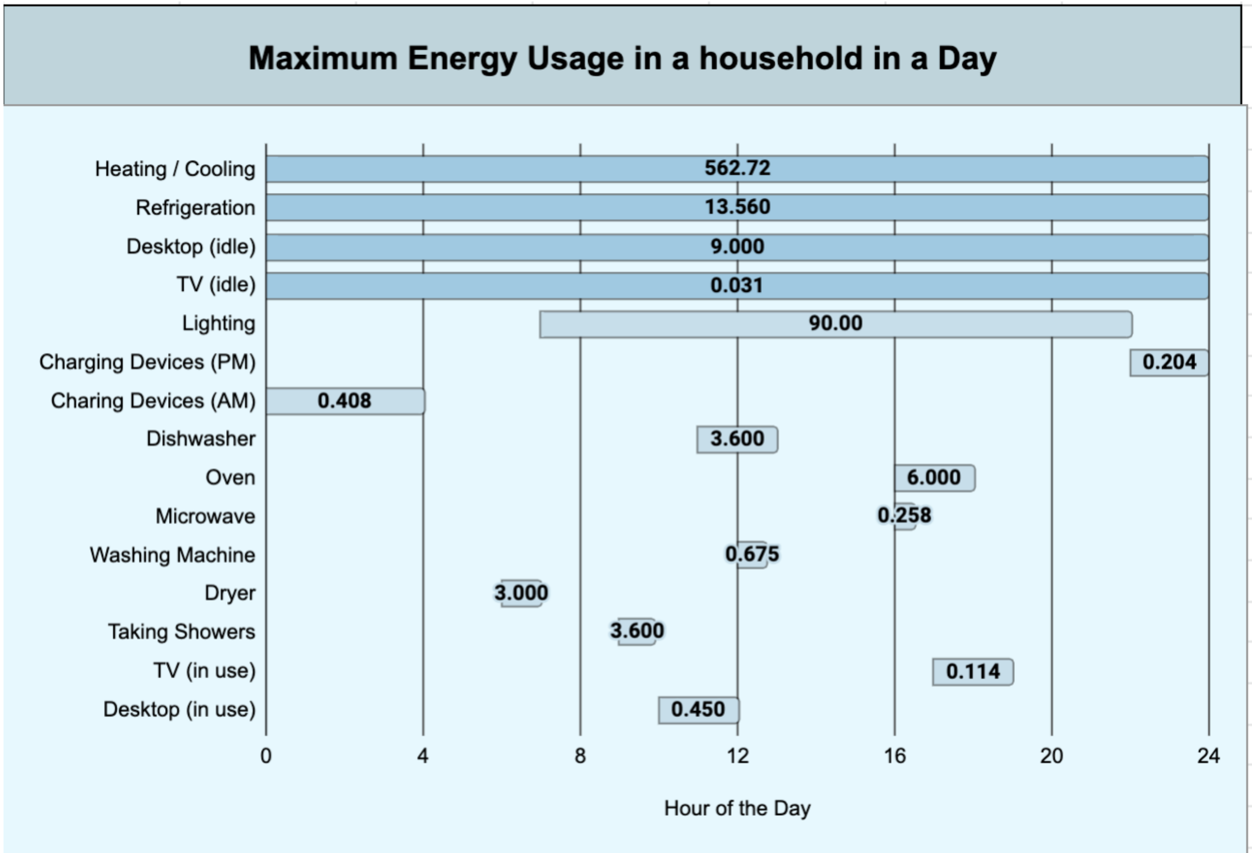


Figure 2.4 The model for the timings of when each energy-consuming activity is in action.

Using these values, we added up the total kWh for each hour of the day to identify the continuous totals and instantaneous peaks that our battery would need to accommodate as seen in Figure 2.6. and determined the maximum kW needed in a day.

kWh HOUR of DAY	heating/cooling	lighting	refrigeration	TV (idle)	desktop (idle)	charging devices PM	charging devices AM	dishwasher	oven	microwave
1	23.447	0	0.565	0.001	0.375	0	0.102	0	0	0
2	23.447	0	0.565	0.001	0.375	0	0.102	0	0	0
3	23.447	0	0.565	0.001	0.375	0	0.102	0	0	0
4	23.447	0	0.565	0.001	0.375	0	0.102	0	0	0
5	23.447	0	0.565	0.001	0.375	0	0	0	0	0
6	23.447	0	0.565	0.001	0.375	0	0	0	0	0
7	23.447	6.000	0.565	0.001	0.375	0	0	0	0	0
8	23.447	6.000	0.565	0.001	0.375	0	0	0	0	0
9	23.447	6.000	0.565	0.001	0.375	0	0	0	0	0
10	23.447	6.000	0.565	0.001	0.375	0	0	0	0	0
11	23.447	6.000	0.565	0.001	0.375	0	0	1.800	0	0
12	23.447	6.000	0.565	0.001	0.375	0	0	1.800	0	0
13	23.447	6.000	0.565	0.001	0.375	0	0	1.800	0	0
14	23.447	6.000	0.565	0.001	0.375	0	0	0	0	0
15	23.447	6.000	0.565	0.001	0.375	0	0	0	0	0
16	23.447	6.000	0.565	0.001	0.375	0	0	0	3.000	0.515
17	23.447	6.000	0.565	0.001	0.375	0	0	0	3.000	0
18	23.447	6.000	0.565	0.001	0.375	0	0	0	3.000	0
19	23.447	6.000	0.565	0.001	0.375	0	0	0	0	0
20	23.447	6.000	0.565	0.001	0.375	0	0	0	0	0
21	23.447	6.000	0.565	0.001	0.375	0	0	0	0	0
22	23.447	6.000	0.565	0.001	0.375	0.102	0	0	0	0
23	23.447	0	0.565	0.001	0.375	0.102	0	0	0	0
24	23.447	0	0.565	0.001	0.375	0.102	0	0	0	0

washing machine	dryer	shower	tv (used)	desktop (used)	kWh/HOUR TOTAL	Plateau 1 - is this continuous?	Plateau Level	Remaining Energy	Energy Between Plateau 1 and 2
0	0	0	0	0	**24.490**	C	24.490	0	
0	0	0	0	0	**24.490**	C	24.490	0	
0	0	0	0	0	**24.490**	C	24.490	0	
0	0	0	0	0	**24.490**	C	24.490	0	
0	0	0	0	0	**24.388**	C	24.388	0	
0	3.000	0	0	0	**27.388**	I	24.490	2.898	2.898
0	3.000	0	0	0	**33.388**	I	24.490	8.898	
0	0	0	0	0	**30.388**	I	24.490	5.898	5.898
0	0	4.000	0	0	**34.388**	I	24.490	9.898	
0	0	0	0	0.225	**30.613**	I	24.490	6.123	
0	0	0	0	0.225	**32.413**	I	24.490	7.923	
0.900	0	0	0	0.225	**33.313**	I	24.490	8.823	
0	0	0	0	0	**32.188**	I	24.490	7.698	
0	0	0	0	0	**30.388**	I	24.490	5.898	5.898
0	0	0	0	0	**30.388**	I	24.490	5.898	5.898
0	0	0	0	0	**33.903**	I	24.490	9.413	
0	0	0	0.057	0	**33.445**	I	24.490	8.955	
0	0	0	0.057	0	**33.445**	I	24.490	8.955	
0	0	0	0.057	0	**30.445**	I	24.490	5.955	
0	0	0	0	0	**30.388**	I	24.490	5.898	5.898
0	0	0	0	0	**30.388**	I	24.490	5.898	5.898
0	0	0	0	0	**30.490**	I	24.490	6.000	
0	0	0	0	0	**24.490**	C	24.490	0	
0	0	0	0	0	**24.490**	C	24.490	0	

Round 1 Continuous Energy Total	587.657
Round 1 Continuous Energy Level	24.490
Round 2 Continous Energy Level	5.898
Round 2 Continuous Energy Total	32.388
Remaining Energy	73.575
Model 1I Input	105.963

Figure 2.5 Each task or appliance and the amount of energy it demands by the hour. Beyond the "kWh/HOUR TOTAL" column are the plateau levels, which we used to define which times of day we would need continuous and instantaneous energy.

In order to visualize this, we graphed this data. To find times in which we would need continuous energy, we found the mode of the energy demands of each hour. This established the baseline amount of times in which we would be needing continuous energy from the battery. Any energy demands beyond that would need to be supported by the instantaneous battery.

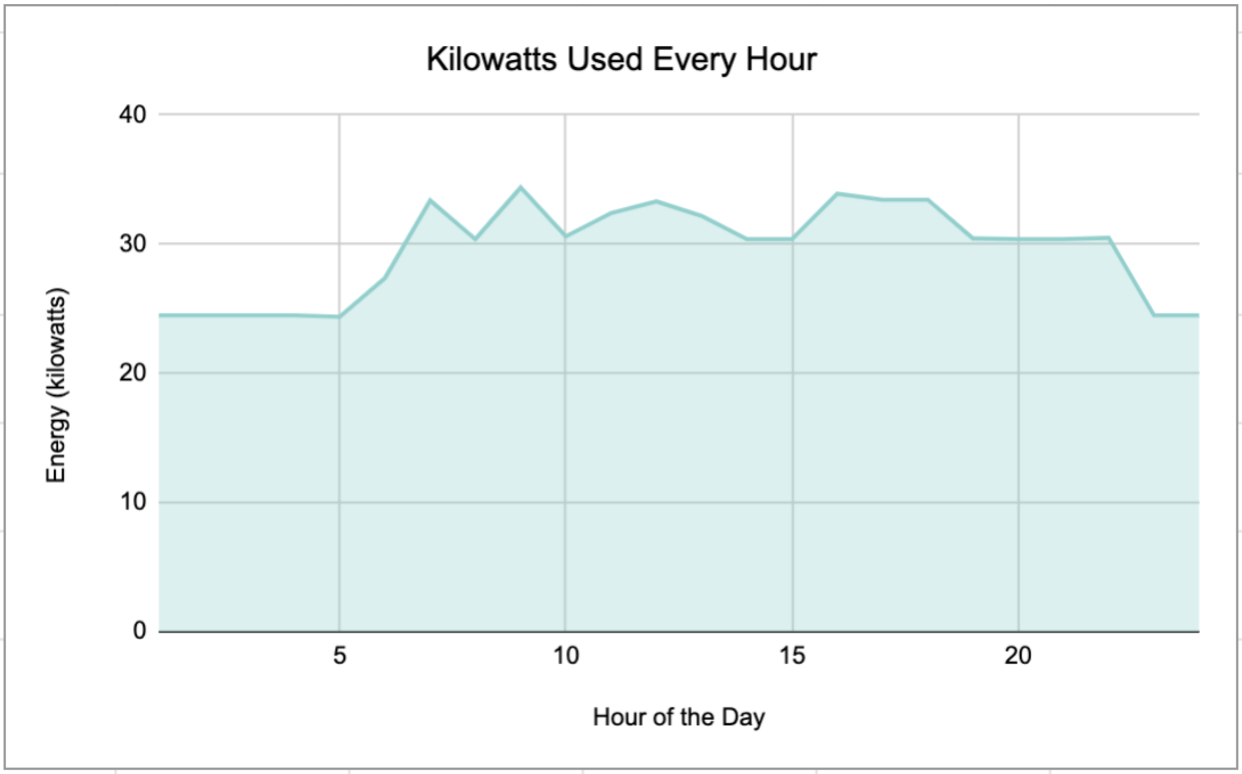
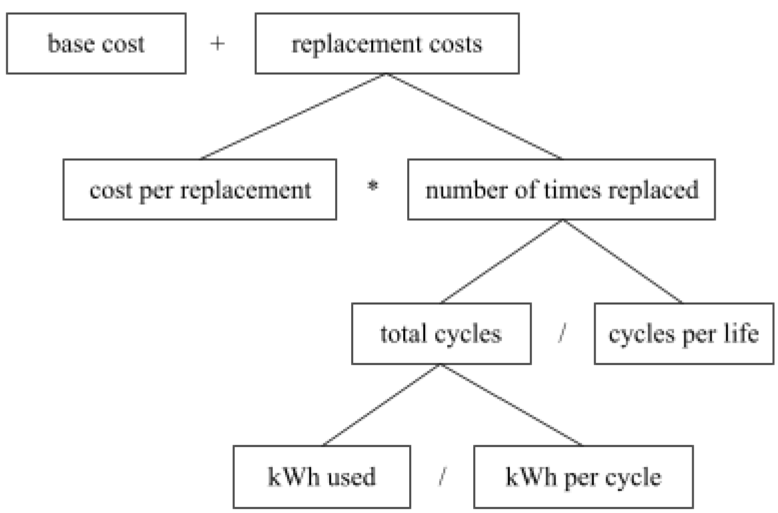


Figure 2.6 The kWh chart based on the hourly usage of kW.

Based on these values, we were able to move forward to determining the best combination of batteries to support our energy needs.

1.3 The Model Part Two



base cost + cost per replacement*((kWh used/kWh per cycle)/ cycles per life))

Figure 2.7 - Breakdown of the equation that will give the total cost for one solar panel.

We first started by assigning our constants as named above in the Variable and Constants section. After this we looked at total charging time by finding the amount of sunlight and comparing that to the length of time each battery takes to charge. At this stage, the code eliminated any batteries who could not fully charge during the given hours of sunlight.

The batteries that were able to charge were then put through three equations, the first one being to get the total cost for one battery, the second being to get the total amount of batteries needed, and the final being the total price for all of the batteries. Using the equation broken down in Figure 2.7, we used the user input of kWh (as found in part one of the model) and divided that by the total kWh per cycle (which was given information), in order to find the total amount of cycles that the battery would have to be able to go through within the day. We then took this number and divided it by the total cycles per life to find the amount of days that this battery would be able to work. Through this we would be able to find out how often these batteries would need to be replaced. From that we would multiply by the cost of replacement in order to find the total replacement costs. We would add this to the base cost to find the total cost for one battery. We then divided the total energy used by the max energy that the battery is able to give off in order to find the total amount of batteries needed. After this, we will find the total final price by multiplying the price for one battery by the number of batteries. We then repeated this process with all the continuous and instantaneous batteries so that we found the price and amount of batteries for each. We kept our continuous and instantaneous parts of this model separate so if a battery was capable of supporting both types of energy, it would be counted in both groups.

Using this information we used an Array in order to find the minimum cost. With this information we printed the battery that would cost the least and how many the homeowner would need. We have one type of battery that would be used for instantaneous power and one that would be used primarily for continuous power. While these batteries could usually intercross, we felt it was important to make sure to account for the specific energy needs of the homeowner and let them decide if they want to combine or not.

1.4 Choosing a Battery

Using the schedule of a typical American family, we inputted answers to our predetermined questions in the decision portion of our spreadsheets. (See Figure 2.2)

Questions relative to the time in which activities begin are based off of a 24-hour scale (e.g. 12:00 am = 0 & 11:00 pm = 23) while questions about the length of time of the activities are inputted by the hour (e.g. 1 hour = 1 & 24 hours = 24). Decimals are accepted by both types of cell for allotting minutes to start times (e.g. 1:30 pm = 13.5) or for describing activity lengths by the increment of an hour (e.g. 45 minutes = 0.75).

We decided to choose four of the Discover AES 7.4 kWh batteries with an expected price of $26,025.48 to cover our needs for continuous energy and two of the Discover AES 7.4 kWh batteries with an expected price of $13,006.00 to cover our needs for instantaneous energy. These batteries also have a high round-trip efficiency (over 95%) which is important because less energy will be lost which will keep the cycle lengths long and allow for more time between the repairs.

2. Adjusting the Model

Overall, the ability to enter information that is subject to change based on circumstance will make any model more generalized and adaptable. For part one of our model, the model is already sufficiently generalized. As explained earlier, the spreadsheet portion of our model has reference cells which can be edited according to the circumstantial information provided by the homeowner and the kWh their appliances require. For part two of our model, we adjusted and generalized the original model by importing the Scanner class to create an opportunity for homeowner input.

The model asks for what climate zone the homeowners are in, based on figure 2, the power of their solar panels, and their instantaneous and continuous energy use. We then implemented the scanner into each of these situations so that the program would make decisions based on what was chosen by the homeowner. Other than this, the program was designed so that the addition of scanners would not require other changes with the use of if-else systems.

3. Cement Batteries

3.1 Advantages and Disadvantages

Cement batteries are a way of storing energy within the very cement of the structure that is being powered. Concrete, which is very similar to cement, is a good conductor on its own, but it gets especially good when you factor in the metal that it is commonly mixed with. The majority of places that have concrete in them also have some sort of metal structure which means a battery can be created out of the structure that is already there. While this would be the main use for our specific goal, these cement batteries can be taken to a much larger scale and create great potential for storing renewable energy. Another big deal with the concrete batteries is the fact that there is a chance that eventually, they will be able to store rechargeable energy.

One big advantage is that many houses already have concrete in them as part of the original build. This means that the storage system would already be available to them which would take out the additional work and storage of having to add a new energy storage system in.

The main disadvantage is the fact that these are still a very new type of energy storage. They are only able to store around 0.8 Wh/liter of energy which is much lower than other batteries and are not fully tested. While the idea is great, it might be a slightly risky investment for homeowners.

To incorporate them into a home, we would add them in as another set of equations into our model which would allow us to be able to compare the price of cement batteries with the price of the other models. By doing this, we would be able to do a cost comparison of the models and then pick out the most cost efficient for the specific situation. Since our model is broad and involves homeowner input, this could easily be adapted to fit any specific home and its energy needs.

3.2 Additional Information Required to Implement Cement Batteries

In order to model and compare the use of cement batteries to the current available batteries for solar power storage, we would need to know the amount of kWh it was able to store, the amount of cycles in a lifetime, the cost of installation, the cost of replacement, and whether it is continuous or instantaneous. Once we know these specifics, we can use our equation in order to find the cost. Once we find the cost we will be able to compare it to the cost of the other solar batteries. If it is the lowest cost, we will know that it is the best solution for the homeowner. Knowing whether it is continuous or instantaneous will help us consider what batteries it will be up against and what type of energy it will need to handle.

Solar Storage, Statistics, and Cement; Picking Batteries Has Never Been Easier

Why Solar?

With the issue of climate change rapidly worsening and costs of living soaring higher than ever, more and more people are looking to go off the grid and become self-sufficient. Without an electricity company constantly pumping energy to their home, homeowners must utilize solar panels to support their daily life.

Energy Storage

Of course, it is not sunny *all* of the time, which sprouts a risk in this constant reliance on the sun. Just because the sun has gone down does not mean that homeowner energy needs have ceased. This is where the importance of an effective energy storage system becomes prevalent. The best storage system must store enough energy to power the home on days in which energy demand is high but also cost the homeowner as little as possible.

User-Friendly Decision Making

To decide upon the optimal number and brand of batteries to power a home, the homeowner needs to do very little work. When using the model, they simply input key details about their daily schedule and energy usage. Even the kilowattage of each appliance can be edited to customize the decision.

Kilowatt Hour Calculation

From the provided information, trends are interpreted on which hours the home will be using the most energy. This helps establish which hours rely solely on continuous power and which will also require instantaneous power.

The Final Choice

In congruence with the energy demand by the hour, climate data is analyzed to see when the home will be relying on its battery storage system. This finalizes the exact energy storage requirements and then matches it with the best batteries for the output requirements and sunlight availability.

Cement Batteries

There is an even newer form of energy storage on the horizon - cement batteries. These batteries have a variety of benefits that make them appealing to almost every homeowner, predominately the fact that they are already integrated into the very foundation of many American homes. With a little bit more analysis and simple integration into the code, the model will soon be able to analyze and compare current batteries on the market with these new cement batteries.

Strengths and Weaknesses

Overall, our model is very homeowner-specific as we request their input for a multitude of variables to create the most accurate recommendation. We account for many combinations of instantaneous and continuous batteries to give the homeowner the most cost-effective recommendation.

However, our model is limited as the tasks are limited in the first analysis of the kilowattage. The extent to which this affects our accuracy is unknown. We looked at the most common household appliances to focus on a more generalized demographic, and we included the major appliances that require the most kWh. More minor activities are considered negligible for this model, creating minor inaccuracies. We also make certain assumptions, such as the house has a 9 foot ceiling, the amount of people in the house is not changing, and the family lives in the house year-round. The first of these assumptions would change the heating requirements, as it takes more energy to heat a taller room. More research would need to be done to incorporate this factor into our research. The amount of people living in the house would mainly affect the lifespan of the batteries, impacting the second part of the model. Our model also only accounts for all the lights being on at the same time, which is not always the case and would increase the lifespan of the batteries.

For the second part of the model, the main weaknesses come with the fact that we do not account for the battery degradation which would mean that our numbers are off when looking at the total battery life overtime. This becomes a problem as the lifespan of the battery goes on as the number of kWh it could hold and produce would change. While this is a weakness, it does not change our numbers a ton since we round up with the amount of batteries the homeowner should buy, therefore giving some buffer room. We also do not account for different combinations of batteries within the continuous and instantaneous suggestions, however, most homes do not require an overly large number of batteries and this creates a simplified purchase, leading us to the conclusion that this is not a major weakness, rather it is a point that could be extended in the future.

Conclusion

After thoroughly analyzing many battery options for storing solar power, we found the best option for our 1600 square foot house, in climate zone 5 with the specified details, would be 4 Discover AES 7.4 kWh batteries to use for continuous power and 2 Discover AES 7.4 kWh batteries to use for instantaneous power. A bank of batteries best supports our house due to our consistent and instantaneous energy needs. We came to this conclusion by first analyzing how much power our house would need and then considering how much instantaneous power would be needed compared to the continuous power supply in order to find the most cost-effective storage system in regard to sunlight and solar panel efficiency.

The first part of our model is key for the proper recommendation of batteries. We consider a multitude of factors to keep the kWh outcome as home-specific as possible. By considering homeowner circumstances through their lifestyle choices, we were able to determine the instantaneous power needs and continuous power demands to use in order to provide the homeowner with the most effective battery combination.

The second part of our model picks up where the first part ends. It considers the kWh output for instantaneous and continuous energy and power of the solar panels transferred to the batteries, along with the climate zone that the house is located in. All of this information is accounted for in tandem with information for individual batteries to do a cost analysis for each battery and output the cheapest battery and the number of batteries that must be bought.

Our conjoined user-specific model is overall effective as we consider both continuous and instantaneous battery combinations based on home-specific factors that can be easily changed at the homeowner's convenience. We also allow for some combinations of batteries with instantaneous energy output and continuous energy flow. While we did simplify our model, we found that we accommodated the most general functions necessary to get an accurate recommendation.

Possible Future Paths

One future plan is to make these two components into one model to make it as easy as possible for the homeowners. We would also want to look at other batteries to determine if our solution is really the best on the market. We would also want to expand on the tasks, since our pre-set list does not encompass all of the energy-requiring activities in a house. Another addition to create the most accurate solution would allow the homeowner to specify exact bursts or spliced periods of times when the lights are on, since it is common for different lights in a household to be on at different times. Looking further into the degradation of the batteries would help us better understand the amount of batteries we would need to improve the accuracy of our model. In addition, we may want to look at different sub-combinations of batteries to provide the homeowner with the absolute best battery storage system. We could also consider analyzing the best solar panels for the homeowner based on their lifestyle and climate zone. Overall, in the future we would like to edit our model to account for more variables and specificities.

Appendix

Appendix 1. Java Code for battery Decision

```
public class Model1a {
	public static void main(String[] args) {
		Scanner userInput  = new Scanner(System.in);
		System.out.println("How much continous energy do you use? (please do this in kWh)");
		double continuouskWh = userInput.nextDouble();
		System.out.println("How much instantaneous energy do you use? (please do this in kWh)");
		double instantaneouskWh = userInput.nextDouble();
		System.out.println("What power output do your solar pannels have? (please do this in kWh)");
		double solarPanelPower = userInput.nextDouble();
		System.out.println("What climate zone are you in?");
		System.out.println("climate zone: ");
		double climate = userInput.nextDouble();
		userInput.close();
		//initializing variables
		double hoursOfCharge = 0;
		//hours of sun for each climate zone
		if (climate==1) {
			hoursOfCharge = 2927.0;}
		else if (climate==2) {
			hoursOfCharge = 2626.0;}
		else if (climate==3) {
			hoursOfCharge = 2928.9;}
```

```
else if (climate==4) {
            hoursOfCharge =2682.2;}
else if (climate==5) {
            hoursOfCharge = 3524.3;}
else if (climate==6) {
            hoursOfCharge = 2677.2;}
else if (climate==7) {
            hoursOfCharge =2722.7;}
//how long each battery will take to charge fully (10 is a place holder)
                        double DSTimeToCharge = 1.18 / (solarPanelPower*hoursOfCharge) * 2;
                        double TTimeToCharge = 2.5 / (solarPanelPower*hoursOfCharge) * 2;
                        double DTimeToCharge = 7.4 / (solarPanelPower*hoursOfCharge) * 2;
                        double ETimeToCharge = 10 / (solarPanelPower*hoursOfCharge) * 2;
                        double PTimeToCharge = 13.5 / (solarPanelPower*hoursOfCharge) * 2;
//figuring out equation for the Deka Solar
double CDSkwhPerCycle = 0.049*24;
double CDScyclePerLife = 1000;
double CDScostReplacement = 3375;
double CDSbaseCost = 433;
double CDStotalCycles = continuouskWh / CDSkwhPerCycle;
double CDSnumReplaced = CDStotalCycles / CDScyclePerLife;
double CDSreplacementCost = CDScostReplacement*CDSnumReplaced;
double CDSbatteryCostUnRound = Math.round((CDSbaseCost+CDSreplacementCost)*100);
double CDSbatteryCost = CDSbatteryCostUnRound/100;
double CDSbatteryTotal = continuouskWh/CDSkwhPerCycle;
double CDSbatteryTotalCostUnRound=Math.round(CDSbatteryTotal*CDSbatteryCost*100);
double CDSbatteryTotalCost=CDSbatteryTotalCostUnRound/100;
double CDSbatteryNumUnRound =Math.round(CDSbatteryTotalCost/CDSbatteryCost);
double CDSbatteryNum =CDSbatteryNumUnRound;
double CDSbatteryTotalCostFinal=CDSbatteryNum * CDSbatteryCost;
//figuring out the equation for the Trojan
double CTkwhPerCycle = 0.19*24;
double CTcyclePerLife = 500;
double CTcostReplacement = 3300;
double CTbaseCost = 1042;
double CTtotalCycles = continuouskWh / CTkwhPerCycle;
double CTnumReplaced = CTtotalCycles / CTcyclePerLife;
double CTreplacementCost = CTcostReplacement*CTnumReplaced;
double CTbatteryCostUnRound = Math.round((CTbaseCost+CTreplacementCost)*100);
double CTbatteryCost = CTbatteryCostUnRound/100;
double CTbatteryTotal = continuouskWh/CDSkwhPerCycle;
double CTbatteryTotalCostUnRound=Math.round(CTbatteryTotal*CTbatteryCost*100);
double CTbatteryTotalCost=CTbatteryTotalCostUnRound/100;
double CTbatteryNumUnRound =Math.round(CTbatteryTotalCost/CTbatteryCost);
double CTbatteryNum =CTbatteryNumUnRound;
double CTbatteryTotalCostFinal=CTbatteryNum * CTbatteryCost;
//figuring out the equation for the Discover
double CDkwhPerCycle = 6.65*24;
double CDcyclePerLife = 7100;
double CDcostReplacement = 6503;
double CDbaseCost = 6503;
double CDtotalCycles = continuouskWh / CDkwhPerCycle;
double CDnumReplaced = CDtotalCycles / CDcyclePerLife;
double CDreplacementCost = CDcostReplacement*CDnumReplaced;
```

```
double CDbatteryCostUnRound = Math.round((CDbaseCost+CDreplacementCost)*100);
double CDbatteryCost = CDbatteryCostUnRound/100;
double CDbatteryTotal = continuouskWh/CDkwhPerCycle;
double CDbatteryTotalCostUnRound=Math.round(CDbatteryTotal*CDbatteryCost*100);
double CDbatteryTotalCost=CDbatteryTotalCostUnRound/100;
double CDbatteryNumUnRound =Math.round(CDbatteryTotalCost/CDbatteryCost);
double CDbatteryNum =CDbatteryNumUnRound;
double CDbatteryTotalCostFinal=CDbatteryNum * CDbatteryCost;
//figuring out the equation for the Electriq
double CEkwhPerCycle = 7.6*24;
double CEcyclePerLife = 71000;
double CEcostReplacement = 13025;
double CEbaseCost = 13025;
double CEtotalCycles = continuouskWh / CEkwhPerCycle;
double CEnumReplaced = CEtotalCycles / CEcyclePerLife;
double CEreplacementCost = CEcostReplacement*CEnumReplaced;
double CEbatteryCostUnRound = Math.round((CEbaseCost+CEreplacementCost)*100);
double CEbatteryCost = CEbatteryCostUnRound/100;
double CEbatteryTotal = continuouskWh/CEkwhPerCycle;
double CEbatteryTotalCostUnRound=Math.round(CEbatteryTotal*CEbatteryCost*100);
double CEbatteryTotalCost=CEbatteryTotalCostUnRound/100;
double CEbatteryNumUnRound =Math.round(CEbatteryTotalCost/CEbatteryCost);
double CEbatteryNum =CEbatteryNumUnRound;
double CEbatteryTotalCostFinal=CEbatteryNum * CEbatteryCost;
//figuring out the equation for the Powerwall+ *check cycles per life*
double CPkwhPerCycle = 7*24;
double CPcyclePerLife = 10000000;
double CPcostReplacement = 13500;
double CPbaseCost = 13500;
double CPtotalCycles = continuouskWh / CPkwhPerCycle;
double CPnumReplaced = CPtotalCycles / CPcyclePerLife;
double CPreplacementCost = CPcostReplacement*CPnumReplaced;
double CPbatteryCostUnRound = Math.round((CPbaseCost+CPreplacementCost)*100);
double CPbatteryCost = CPbatteryCostUnRound/100;
double CPbatteryTotal = continuouskWh/CPkwhPerCycle;
double CPbatteryTotalCostUnRound=Math.round(CPbatteryTotal*CPbatteryCost*100);
double CPbatteryTotalCost=CPbatteryTotalCostUnRound/100;
double CPbatteryNumUnRound =Math.round(CPbatteryTotalCost/CPbatteryCost);
double CPbatteryNum =CPbatteryNumUnRound;
double CPbatteryTotalCostFinal=CPbatteryNum * CPbatteryCost;
//if able to charge
if (DSTimeToCharge <= hoursOfCharge || TTimeToCharge <= hoursOfCharge || DTimeToCharge <=
hoursOfCharge || ETimeToCharge <= hoursOfCharge || PTimeToCharge <= hoursOfCharge) {
if (CDSbatteryTotalCost<CTbatteryTotalCost && CDSbatteryTotalCost<CDbatteryTotalCost &&
CDSbatteryTotalCost<CEbatteryTotalCost && CDSbatteryTotalCost<CPbatteryTotalCost) {
    System.out.println("the best continous battery for you is the: Deka Solar 8GCC2 6V 198");
    System.out.println("You would have to buy: " + CDSbatteryNum + " batteries.");}
else if (CTbatteryTotalCost<CDSbatteryTotalCost && CTbatteryTotalCost<CDbatteryTotalCost &&
CTbatteryTotalCost<CEbatteryTotalCost && CTbatteryTotalCost<CPbatteryTotalCost) {
    System.out.println("the best continous battery for you is the: Trojan L-16 -SPRE 6V 415");
    System.out.println("You would have to buy: " + CTbatteryNum + " batteries.");}
else if (CDbatteryTotalCost<CDSbatteryTotalCost && CDbatteryTotalCost<CTbatteryTotalCost &&
CDbatteryTotalCost<CEbatteryTotalCost && CDbatteryTotalCost<CPbatteryTotalCost) {
    System.out.println("the best continous battery for you is the: Discover AES 7.4 kWh");
```

```
                System.out.println("You would have to buy: " + CDbatteryNum + " batteries.");}
            else if (CEbatteryTotalCost<CDSbatteryTotalCost && CEbatteryTotalCost<CTbatteryTotalCost &&
CEbatteryTotalCost<CDbatteryTotalCost && CEbatteryTotalCost<CPbatteryTotalCost) {
                System.out.println("the best continous battery for you is the: Electriq PowerPod 2");
                System.out.println("You would have to buy: " + CEbatteryNum + " batteries.");}
            else if (CPbatteryTotalCost<CDSbatteryTotalCost && CPbatteryTotalCost<CTbatteryTotalCost &&
CPbatteryTotalCost<CDbatteryTotalCost && CPbatteryTotalCost<CEbatteryTotalCost) {
                System.out.println("the best continous battery for you is the: Tesla Powerwall+");
                System.out.println("You would have to buy: " + CPbatteryNum + " batteries.");}
            double[] findMin = {CDSbatteryTotalCostFinal, CTbatteryTotalCostFinal, CDbatteryTotalCostFinal,
CEbatteryTotalCostFinal, CPbatteryTotalCostFinal};
                Arrays.sort(findMin);
                System.out.println("your expected price will be: $" + findMin[0] + " ");}
            // figuring out the equation for the Discover
            double IDkwhPerCycle = 14.4*24;
            double IDcyclePerLife = 7100;
            double IDcostReplacement = 0;
            double IDbaseCost = 6503;
            double IDtotalCycles = instantaneouskWh / IDkwhPerCycle;
            double IDnumReplaced = IDtotalCycles / IDcyclePerLife;
            double IDreplacementCost = IDcostReplacement * IDnumReplaced;
            double IDbatteryCostUnRound = Math.round((IDbaseCost+IDreplacementCost)*100);
            double IDbatteryCost = IDbatteryCostUnRound/100;
            double IDbatteryTotal = continuouskWh/IDkwhPerCycle;
            double IDbatteryTotalCostUnRound=Math.round(IDbatteryTotal*IDbatteryCost*100);
            double IDbatteryTotalCost=IDbatteryTotalCostUnRound/100;
            double IDbatteryNumUnRound =Math.round(IDbatteryTotalCost/IDbatteryCost);
            double IDbatteryNum =IDbatteryNumUnRound;
            double IDbatteryTotalCostFinal=IDbatteryNum * IDbatteryCost;
            // figuring out the equation for the Electriq
            double IEkwhPerCycle = 9*24;
            double IEcyclePerLife = 71000;
            double IEcostReplacement = 0;
            double IEbaseCost = 13025;
            double IEtotalCycles = instantaneouskWh / IEkwhPerCycle;
            double IEnumReplaced = IEtotalCycles / IEcyclePerLife;
            double IEreplacementCost = IEcostReplacement * IEnumReplaced;
            double IEbatteryCostUnRound = Math.round((IEbaseCost+IEreplacementCost)*100);
            double IEbatteryCost = IEbatteryCostUnRound/100;
            double IEbatteryTotal = continuouskWh/IEkwhPerCycle;
            double IEbatteryTotalCostUnRound=Math.round(IEbatteryTotal*IEbatteryCost*100);
            double IEbatteryTotalCost=IEbatteryTotalCostUnRound/100;
            double IEbatteryNumUnRound =Math.round(IEbatteryTotalCost/IEbatteryCost);
            double IEbatteryNum =IEbatteryNumUnRound;
            double IEbatteryTotalCostFinal=IEbatteryNum * IEbatteryCost;
            // figuring out the equation for the Powerwall+ *check cycles per life*
            double IPkwhPerCycle = 10*24;
            double IPcyclePerLife = 10000000;
            double IPcostReplacement = 0;
            double IPbaseCost = 13500;
            double IPtotalCycles = instantaneouskWh / IPkwhPerCycle;
            double IPnumReplaced = IPtotalCycles / IPcyclePerLife;
            double IPreplacementCost = IPcostReplacement * IPnumReplaced;
            double IPbatteryCostUnRound = Math.round((IPbaseCost+IPreplacementCost)*100);
```

```
double IPbatteryCost = IPbatteryCostUnRound/100;
double IPbatteryTotal = continuouskWh/IPkwhPerCycle;
double IPbatteryTotalCostUnRound=Math.round(IPbatteryTotal*IPbatteryCost*100);
double IPbatteryTotalCost=IPbatteryTotalCostUnRound/100;
double IPbatteryNumUnRound =Math.round(IPbatteryTotalCost/IPbatteryCost);
double IPbatteryNum =IPbatteryNumUnRound;
double IPbatteryTotalCostFinal=IPbatteryNum * IPbatteryCost;
// if able to charge
if (DTimeToCharge <= hoursOfCharge || ETimeToCharge <= hoursOfCharge || PTimeToCharge <=
hoursOfCharge) {

 if (IDbatteryTotalCost < IEbatteryTotalCost && IDbatteryTotalCost < IPbatteryTotalCost) {
        System.out.println("the best instantaneous battery for you is the: Discover AES 7.4 kWh");
                System.out.println("You would have to buy: " + IDbatteryNum + " batteries.");

        } else if (IEbatteryTotalCost < IDbatteryTotalCost && IEbatteryTotalCost < IPbatteryTotalCost) {
                System.out.println("the best instantaneous battery for you is the: Electriq PowerPod 2");
                System.out.println("You would have to buy: " + IEbatteryNum + " batteries.");

        } else if (IPbatteryTotalCost < IDbatteryTotalCost && IPbatteryTotalCost < IEbatteryTotalCost) {
                System.out.println("the best instantaneous battery for you is the: Tesla Powerwall+");
                System.out.println("You would have to buy: " + IPbatteryNum + " batteries.");}
         double[] findMin = {IDbatteryTotalCostFinal,IEbatteryTotalCostFinal, IPbatteryTotalCostFinal};
        Arrays.sort(findMin);
        System.out.println("your expected price will be: $" + findMin[0] +" ");}
```

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