Team 11624

2021 HiMCM Problem A: Storing the Sun

Summary

Today, the earth faces a monumental challenge in the form of Climate Change – the steady increase in global average temperatures. This is a direct result of carbon emissions, the release of greenhouse gases into Earth's atmosphere. One of the biggest sources of carbon emissions in the United States is residential energy, which constitutes roughly 20% of emissions in the United States (US Energy Information Administration*,* 2021). For this reason, it is ever so important to develop carbon neutral housing solutions so that the levels of these emissions are neutralized. Carbon neutral housing is powered by renewable energy sources, such as wind, solar, and geothermal energy sources. Based on this, the objective of this problem is to construct a model which finds the best energy storage system that accounts for the energy needs of a 1600 square foot house.

The model we propose accounts for the variances in power requirements, and returns the optimal battery and configuration. This is done by calculating the energy requirements for a given year and month from an appliance list we generated using our collected data and then identifying what are essential items for a home. Using information about the usage of electricity through the analysis of existing data, our model can calculate how much energy is required to power the house. Given the quantity of the most efficient batteries, a parallel connection between the batteries was used to maximize the electrical current output, such that the energy demands for all the appliances are accounted for.

We effectively determine the most efficient system using a dual-factor system. This is done by first determining the optimal battery using a decision tree of fifteen existing batteries, and comparing the usable capacity of the determined battery with the daily energy consumption requirement. Our decision matrix can accommodate four distinct battery-performance factors, weighted by the user on a scale of 6-9 based on the significance they give each factor. This allows the model to account for different applications of an energy storage system, adjusted dynamically for multiple-use cases. The quantity of the optimal battery is calculated by ensuring that the usable capacity can match the daily energy requirements. Additionally, we used data from the position of the sun throughout the day in relation to the surface of the Earth to calculate the optimal positioning of a solar panel. Understanding the potential energy input of the system helps tailor the energy storage system to fit the requirements of the house. By finding the most optimal energy storage solution, our model can help design sustainable housing for the future.

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Introduction

Your team is helping to plan the use of solar power to provide electricity to a 1600 square-foot home being built in a remote area. You need to plan for enough energy to support the energy requirements of the home at night and on a cloudy day. You have done some research and found that you can either pull energy from the grid (i.e., a power company) when your solar panels are not producing enough or use an energy storage system. As the house is in a remote area, the cost of connecting to the grid is expensive, so you decide to go off the grid and invest in energy storage.

Despite the increasing need for solar energy, fossil fuels remain the leading source of residential energy. Carbon-neutral housing solutions combat this issue by relying exclusively on renewable energy sources, primarily solar radiation, completely reducing carbon emissions. This means that carbon neutral housing does not have to rely on electrical power grids for their electrical supply and can be freely implemented in remote regions. With the assistance of energy storage systems, houses that rely on solar power can provide residents with electricity at any given time, including the night and on cloudy days. With an optimized design, carbon neutral housing solutions can satisfy standard residential energy requirements while simultaneously aiding the environment.

Restatement of the Problem

Given the importance of transitioning from standard energy systems to solar power, we have responded to the request to develop a mathematical model to solve the following:

I. Determine the energy needs of the house and analyze the solar-power storage requirements
II. Develop a mathematical model for choosing the best battery storage system for an off-grid home
III. Choose the best battery storage option(s)
IV. Adapt and generalize our battery storage model for any home
V. Attempt to incorporate cement as a battery for our model, and identify some of the advantages and disadvantages of using cement batteries as a battery storage option
VI. Identify additional information needed to model and compare the use of cement batteries to other batteries

Global Assumptions

1) **Assume that solar panels are all placed correctly in the right direction in accordance with the sun's position.** We made this assumption because for the optimal solar radiation, or sunlight absorption, the solar panel must be facing the sun.
2) **Controller and inverter are optimized for maximum efficiency and minimum power loss.** To account for the efficiency of our model, we assumed that the controller and

inverter work at 100% efficiency so that we would not have to optimize their functions as well.

3) **The solar panel efficiency is not 100%.** We made this assumption as we do not know the type of solar panel and how it will perform if this is accounted for. Not all solar panels work at the optimal level, so it is a fair assumption that the solar panel efficiency is not 100%.
4) **The height of the house can be adjusted to accommodate the size of the batteries in the attic.** We made this assumption because by doing so, we would not have to set a minimum pitch angle for the roof of the house. To accommodate for the battery in the attic, there needs to be enough height for the battery to sit in. Without having to consider that height, we can allow the roof to sit at lower angles, optimizing the power it can capture when situated closer to the equator.
5) **Batteries will be stored in the attic of the house so the energy storage system will function at normal operating temperatures.** We made this assumption because the inside of the attic has better climate regulation than outdoors, so there is a lesser chance of the system failing due to environmental conditions.
6) **The attic will be able to fit the batteries regardless of the grade of the roof.** This assumption goes hand in hand with assumption #4 as we do not have any restrictions on the height of the house. Due to this, we can design the roof in any way that is feasible so that the batteries will be able to fit in the grade of the roof.
7) **The house can be placed anywhere in the world and cost is measured in USD regardless of location.** This assumption is made because the house will be powered off-the-grid, so the location of the house is not significant for its function. Costs will be measured in USD for the sake of consistency.
8) **The client of this house would only use electricity as a power source.** We are assuming that the house is fully solar-powered and that it only uses the energy from the sun obtained through the solar panels.
9) **The solar panels will be completely unobstructed from the light.** We are assuming that the solar panels are unobstructed so that we do not have to consider environmental obstacles in our model.
10) **Cost is not a user constraint, and the resident can purchase any required hardware for the system.** This assumption is made so that our model does not have to consider cost as a significant factor, and greater emphasis can be placed on the functionality of the model.
11) **The resources required for climate control in the house will not change regardless of ceiling height.** This assumption is made so that we do not have to make additional assumptions about the costs of heating.

Analysis of the Problem

After identifying the various steps needed to solve the problem, we decided to first analyze what was given to us to determine our course of action. Our team constructed a list of seventeen different appliances and used those appliances to develop trends about power usage in the house. We looked at the table given and saw that we had data for four sample energy storage batteries. We decided to analyze this data and determine which one of these batteries had the most positive results amongst the other three, and we found it to be the Tesla Powerwall+. From there we understood that we would need to determine the energy consumption in the household and compare the Tesla Powerwall+ to other storage batteries not given to us. This helped us to determine what data would need to be researched for us to determine the optimal battery storage arrangement. From there, we began our model using the data accumulated from different articles.

Part I: The Base Model

This part of the questions requires the construction of a model based on the analysis of a base case of a 1600-square-foot residence. Using this model, we should be able to design an efficient energy storage system and calculate the optimal arrangement for a battery system to supply our off-the-grid home.

To determine how to power a 1600 square foot home, it is important to consider the requirements of the house. The resident of the house needs to be able to live a comfortable life which covers both basic living necessities and other additional luxuries, while also not being unrealistic and account for the appliances that are necessary. We began constructing this basic model by laying out our assumptions and constructing a list of necessary appliances.

Appliances

Fridge	Tank Water Heater	Cooking Range	Lighting - LED 13 Watt	Furnace Fan Blower	Microwave
Ceiling Fan	Dishwasher	Washer	Dryer	Water Kettle	Satellite Dish
Router	Water Pump	Laptop (Charging)	Toaster	Garbage Disposal	

Figure 1: The Appliances

Assumptions for Part I

1) **There is only one person living in the house.** For this model presented, we only found the energy consumption for one resident. In later models, we will account for varying numbers of people in the house to find the varying energy consumption levels.
2) **The appliances the user will use are limited to the conceived list.** We decided that the appliances above are the bare necessities to have in an off-the-grid house that is trying to reduce the energy consumption amount.
3) **There are a total of 20 lightbulbs in the house**. This assumption is made since the size of the house is 1600 square feet.
4) **Only certain appliances will be used at once (Ex: The washer and dryer will not be used simultaneously).** We used our common knowledge to make this assumption as you must use some appliances in logical order, and not at the same time, such as a washer before a dryer.
5) **The energy rating of the appliances will be set in accordance with average values of that type of appliance.** This assumption is made to prevent anomalies in appliance performance that could impact the energy usage calculations.
6) **The appliances are consistently used for the same amounts of time every week.** This assumption is made on the basis that appliances meant for certain tasks will be used at the same rate. For example, it is unlikely that a single resident will wash their clothes more than once a week.
7) **The layout and dimensions of the house are not fixed.** This assumption is made because there is no benefit in assuming that the house has a fixed layout. Allowing flexibility between layouts enables different arrangements of the energy system.

I.I: Calculating Average Monthly Power Consumption

Taking into consideration the appliances being used by our sole resident, we estimated the average rate of consumption for various durations of time. We used general data collected from various users of commonplace household appliances regarding the power required to run a device, and the amount of time a device is usually run for. Using this data, we found the yearly power consumption of our resident, and predictions were made about their power usage patterns.

Appliances	Hours Per Day	Hours Per Year	Device Wattage (kW)	Daily Consumption (kwH)	Yearly Consumption (kWh)
Fridge	8.0	2920.0	0.500	4.000	1460.000
Tank Water Heater	0.9	334.6	4.500	4.125	1505.625
Cooking Range	2.5	912.5	1.500	3.750	1368.750
Lighting - LED 13 Watt	7.0	2555.0	0.260	1.820	664.300
Furnace Fan Blower	3.0	456.3	0.800	2.400	365.000
Microwave	0.2	60.8	1.000	0.167	60.833
Ceiling Fan	15.0	3193.8	0.120	1.800	383.250
Dishwasher	1.0	365.0	1.400	1.400	511.000
Washer	N/A	52.0	0.800	0.114	41.600
Dryer	N/A	52.0	3.000	0.427	156.000
Water Kettle	0.2	73.0	1.200	0.240	87.600
Satellite Dish	24.0	8760.0	0.025	0.600	219.000
Router	24.0	8760.0	0.007	0.168	61.320
Water Pump	2.3	851.7	0.675	1.575	574.875
Laptop (Charging)	1.5	547.5	0.100	0.150	54.750
Toaster	0.1	30.4	1.200	0.100	36.500
Garbage Disposal	0.2	73.0	0.450	0.090	32.850
Total	**89.900**	**29997.500**	**17.537**	**22.926**	**7583.253**
				Avg. Per Month	**631.938**
	People	1		LB Count =	20
	Based on Season				

Figure 2: Average Monthly Power Consumption for One Resident

We can see that by making predictions for the daily and weekly usage of appliances, we can then predict the average consumption of each device over the span of a year and then use that value to calculate the monthly average. The figure above details the seventeen different appliances that we deemed necessary, and the rate of energy consumption for each of them. The parameters highlighted in yellow will change significantly in energy consumption based on the number of residents living in the house, and those highlighted in green signify the appliances that will only provide significant operation in certain months of the year. For example, as the number of residents increases from one to two, the quantity of clothes doubles. Therefore, it is safe to assume that the power consumption of the washing machine is directly proportional to the number of people using it. Additionally, furnaces are more frequently used in the summer, and the ceiling fan is more frequently used in the summer. These factors were accounted for in our data frame, which is attached in the separate appendix of calculations.

From the data, we found the hours per year that each appliance is used and multiplied that by the device wattage to find the yearly consumption amounts for each appliance. Then, we added up the yearly consumption values and we got a total of 7583.253 kWh for a household with one person. After that, we divided the total by 12 to get the monthly consumption which came out to be 631.938 kWh. This is a major change from the average annual electricity consumption for a U.S. residential utility customer which was an average of about 893 kWh per month (*Frequently Asked Questions,* 2021). Our model has a monthly consumption amount which is drastically lower than normal, showing that we are saving more energy and being more efficient**.**

I.II: Solution for Energy Storage System

I.II.I: Evaluation of Consumption Criteria

To optimize the battery storage system for our model, we first had to determine the battery to use depending on the criteria we ranked to be the most important. Taking into consideration that we want to maximize energy output from the battery pack to power the appliances, we initially only considered the characteristics of the batteries that were related to battery performance - continuous power rating(kW), instantaneous power rating (kW), and usable capacity (kWh). We were given data about batterie from 4 different battery types, SGLA, FLA, LFP, and NMC.

Appliances	Instantaneous Power (W)	Continuous Power (W)	Continuous Power (kW)
Fridge	2200.0	500	0.500
Tank Water Heater	N/A	4500	4.500
Cooking Range	N/A	1500	1.500
Lighting - LED 13 Watt	N/A	0	0.000
Furnace Fan Blower	1400.0	800	0.800
Microwave	N/A	1000	1.000
Ceiling Fan	70.0	120	0.120
Dishwasher	1500.0	1400	1.400
Washer	2250.0	800	0.800
Dryer	1800.0	3000	3.000
Water Kettle	3000.0	1200	1.200
Satellite Dish	N/A	25	0.025
Router	15.0	7	0.007
Water Pump	2100.0	675	0.675
Laptop (Charging)	N/A	100	0.100
Toaster	N/A	1200	1.200
Garbage Disposal	1000.0	450	0.450
Total (kW)	**15.3**	**17.3**	

Figure 3: Power Ratings for Appliances

Battery

Trojan L-16 -SPRE 6V 415	Crown Battery 215Ah 12V	Crown Battery 235Ah 6V	Crown Battery 390Ah 6V	MK 8L16LTP FLA 370 AH (20HR)6V
Discover AES	Electriq PowerPod 2	SIMPLIPHI POWER PHI 48V	Smart Lithium Iron Phosphate Battery	Tesla Powerwall+
Deka Solar 8GCC2 6V 198	8G30H-DEKA	8GTE35-DEKA	8G27-DEKA	8G31-DEKA

Figure 4: Potential Batteries

I.II.II: Selection of the battery

We then added four additional batteries for each battery type, to draw comparisons to batteries that were not incorporated in the data. With finalized data from 15 batteries, a decision matrix was then used to find the optimal battery based on the criteria.

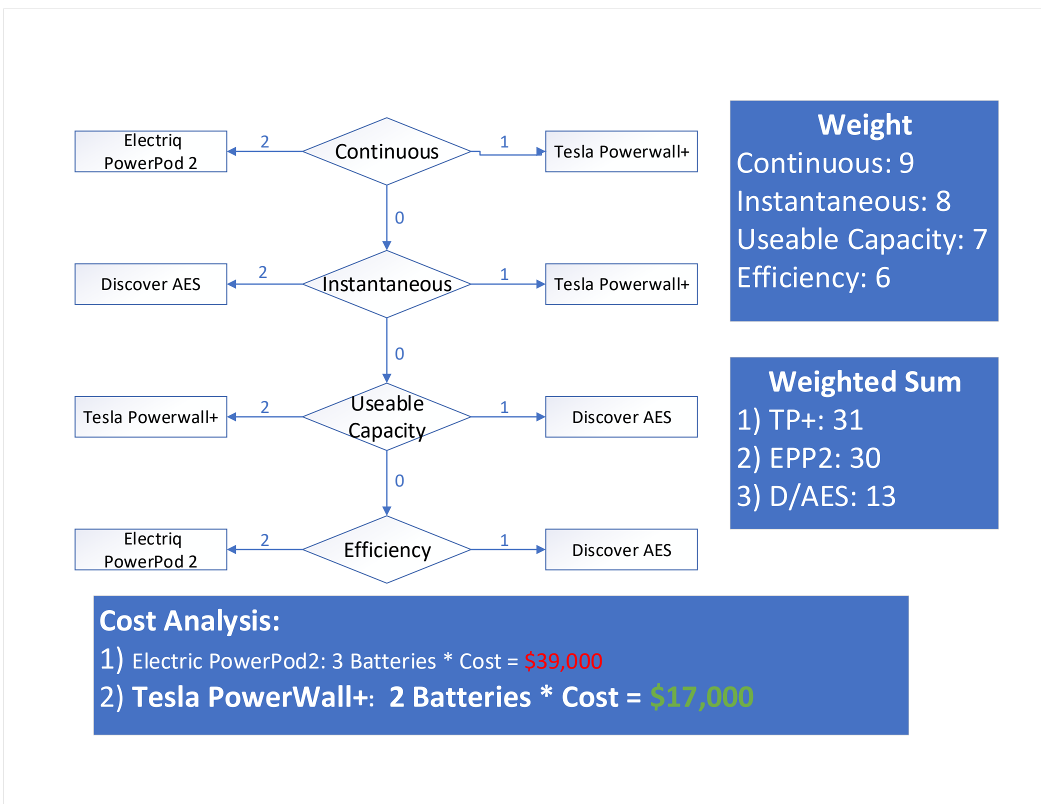


Figure 5: Weighted Summation Flow Chart

We ranked the criteria using a 9-6 weighting system, with the continuous power rating (9), instantaneous power rating (8), usable capacity (7), and round-trip efficiency (6). We classified continuous power rating higher than instantaneous rating because it is more important to have a reliable continuous power flow than it is to have an instantaneous flow. Furthermore, usable capacity is only relevant when solar radiation cannot sustain the energy requirements of the house, which is why we decided it is less important than power flow. Efficiency was also a factor we considered, due to the importance of conserving as much energy as possible. Cost was used as a tiebreaker criterion, which helped decide between two alike effective batteries with similar features.

Using these ranked criteria, we multiplied the assigned weights with the value of the battery with 1 or 2, which were assigned based on the top two optimal batteries for each criterion. Using the weight system, we got weighted sums of 31 for the Tesla Powerwall+, 30 for the Electriq PowerPod 2, and 13 for the Discovery AES battery. Since the weighted sums of the Tesla and Electriq batteries were close, we used to cost as the final tie breaker, by multiplying the number of batteries of each type that would be used in the system, times the cost of a single battery of that type – the quantity of batteries calculated is explained in section 1.4.

I.II.III: Battery Bank Optimization using Tesla Powerwall

With the identification of the optimal battery for our system, we found the configuration and quantity of batteries that allowed for the greatest maximum current produced to supply the needs of the appliances used in the home. Given the kWh battery capacity of 13.5, we found the kWh that the house required each day using the total kWh per day, which we derived from multiplying the wattage of the device (in kW) and the number of hours each appliance ran on average in a household to get the kWh per day, or the daily energy consumption (Citation). The total daily kWh initially came out to be 22.926 kWh needed to power all the appliances, based off need, in a single need, and given the capacity of 13.5 kWh of the tesla battery, two are needed to facilitate the entire energy consumption. However, to account for the 10% energy loss in the system, the system kWh requirement per day should be increased by 10%, to produce a total daily kWh of 25.2185.

$$W_{daily} = \sum_{k=1}^{17} W_{device[k]} * t_{device[k]}$$

W – Wattage: Measured in Kilowatts(kW)

k – device$_{[k]}$: An element in the list of devices from device 1 to 17

t – Time: The number of hours the appliance runs each day

Two tesla batteries would provide an increased 27 kWh capacity to facilitate the increased energy demand. With the two tesla batteries, we needed to maximize the amount of electric current produced to meet the energy demands of all the appliances. We connected the batteries using a parallel combination so that the voltage of the battery bank would be the same as any of the individual batteries, but the electric current capacity would be multiplied by the number of batteries to produce a high amount of current. The current produced from the battery bank would be equal to the amperes of the two batteries summed together ($I_1 + I_2$), which can be used to get the total energy production capacity.

$$totalCapacity = I_1 + I_2$$

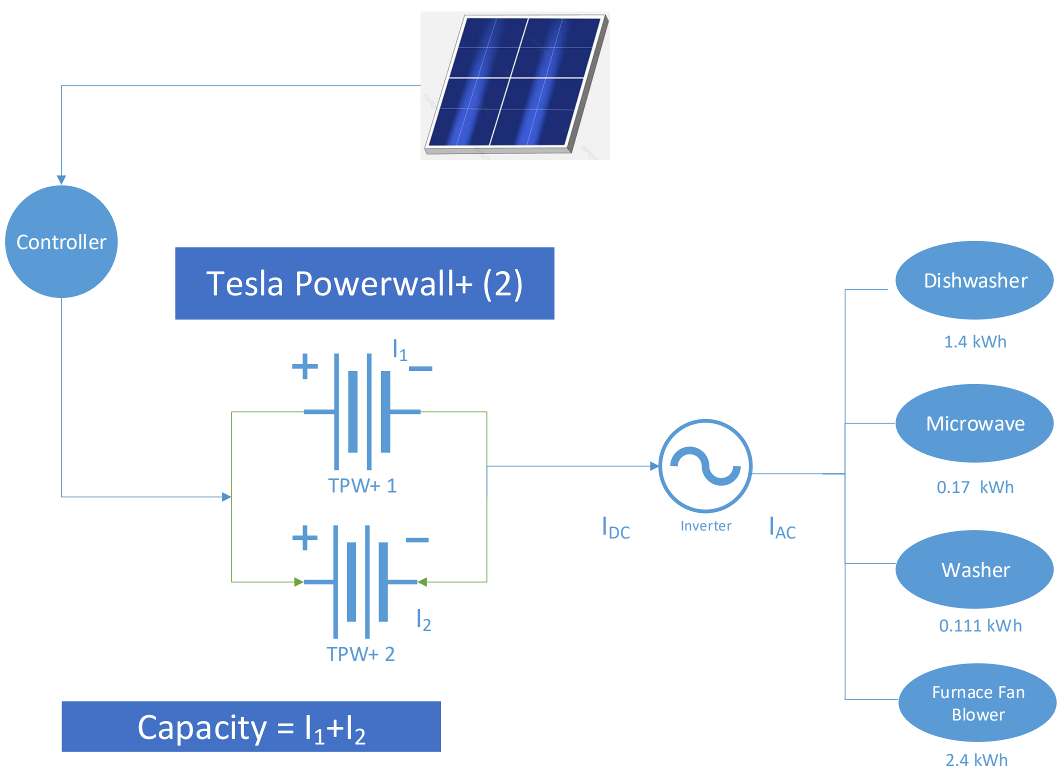


Figure 6: Schematic of Model 1

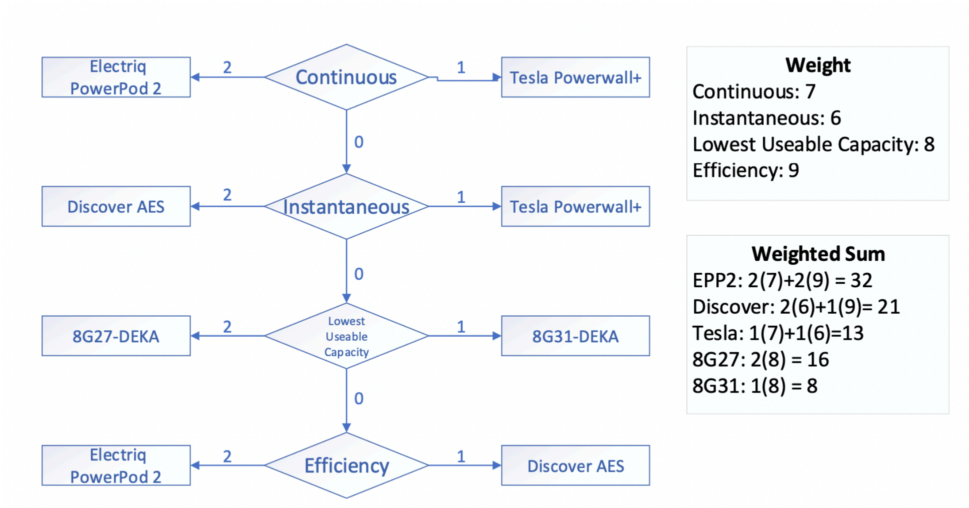
The battery system is optimized for the max current output using the selection of a Tesla Powerwall and a parallel connection between the two batteries

Part II: Extending the Model

II.I: Application of the decision tree

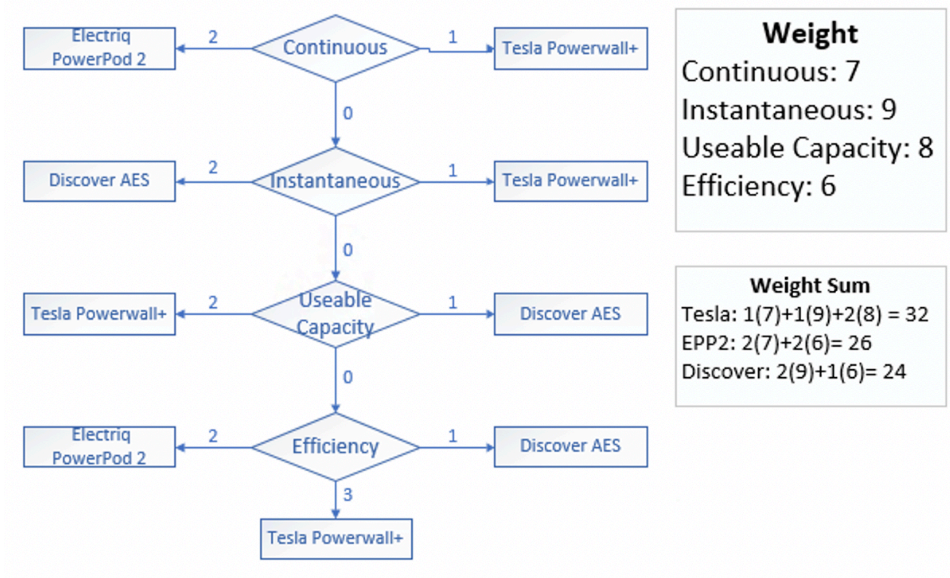
To apply our model to individual needs and preferences for optimal energy storage, a user can simply change the weights for the different criteria, and then use the methodologies presented above. The weights 9-6 can be applied according to the criteria: continuous power rating, instantaneous power rating, useable capacity, and efficiency. The weighted sums of the battery types can then be calculated based off the weights assigned, as explained earlier in Part 1. Once the battery is determined, the useable capacity of the battery is compared to the set daily kWh requirement of 25.2185, to find the quantity of those batteries needed. Once the quantity of that specific type of batteries are determined, they can simply relate to each other via parallel connection to maximize the current output of the battery to meet the energy demands.

Test Case #1: Optimizing for energy efficiency and finding the lowest battery capacity



Electriq PowerPod 2 would be the best battery when optimizing energy efficiency, shown by the following decision matrix

Test Case #2: Optimizing for Instantaneous Rating and Battery Capacity to power many appliances at once.



The Tesla Powerwall+ only has the second highest instantaneous rating but it would be the best battery overall according to the above decision matrix as it also has a high useable capacity which is important for supplying many appliances at once.

Additionally, by using the following method, our model can account for both personal preference and environmental anomalies. Remote locations such as those beyond the Arctic and Antarctic Circle experience extended periods of continuous sunlight, along with continued periods of darkness. Moreover, our model cannot be considered adequate if it is unable to account for a variety of unique solutions, where the personal power requirements are different. Given a different list of appliances for a specific user, this decision matrix can be weighted to fit the preferences of other users, therefore allowing it to be more robust while simultaneously maintaining its accuracy.

II.II: Optimizing Tilt Angle on Roof

After finding the energy storage system, which we identified to be the Tesla Powerwall+, the next step we took to solve this problem was to find the optimal tilt angle for which the solar panels will be positioned on the roof of the house. The tilt angle is a critical parameter for installing fixed-tilt panels as the photovoltaic, the conversion of light into electricity using semiconducting materials, panel output increases with increasing exposure to direct sunlight (Jacobson et al., 2018). We utilized formulas from a Stanford research article, *World estimates of PV optimal tilt angles and ratios of sunlight incident upon tilted and tracked PV panels* *relative to horizontal panels*, to find what the optimal tilt angle would be for all latitudes on Earth. According to the researchers, there are two different equations that can be used to find the optimal tilt angle for any given location, with one for the northern hemisphere and the other for the southern hemisphere. Furthermore, at the equator, the latitude is 0°, so the tilt angle will also evaluate to $0°$.

(Φ = latitude angle) from: *World estimates of PV optimal tilt angles and ratios of sunlight incident upon tilted and tracked PV panels relative to horizontal panels.*

$$\boldsymbol{If\ Latitude > 0: Optimal\ Tilt\ Angle\ (Northern\ Hemisphere)} \\ \boldsymbol{= 1.3793 + \Phi\big(1.2011 + \Phi(-0.014404\ +\ \Phi 0.000080509)\big)}$$

$$\boldsymbol{If\ Latitude < 0: Optimal\ Tilt\ Angle\ (Southern\ Hemisphere)} \\ \boldsymbol{= -0.41657 + \Phi\big(1.4216 + \Phi(0.024051\ +\ \Phi 0.00021828)\big)}$$

Then, to create a method through which we can simulate the tilt angle for any given latitude, we decided to write a Java algorithm (see the Appendix) to evaluate these formulas more efficiently. After that, we used Mathematica to graph the equations to give us a visual representation of the derived 3rd-order polynomial fit of optimal tilt versus latitude from the article (Jacobson et al., 2018).

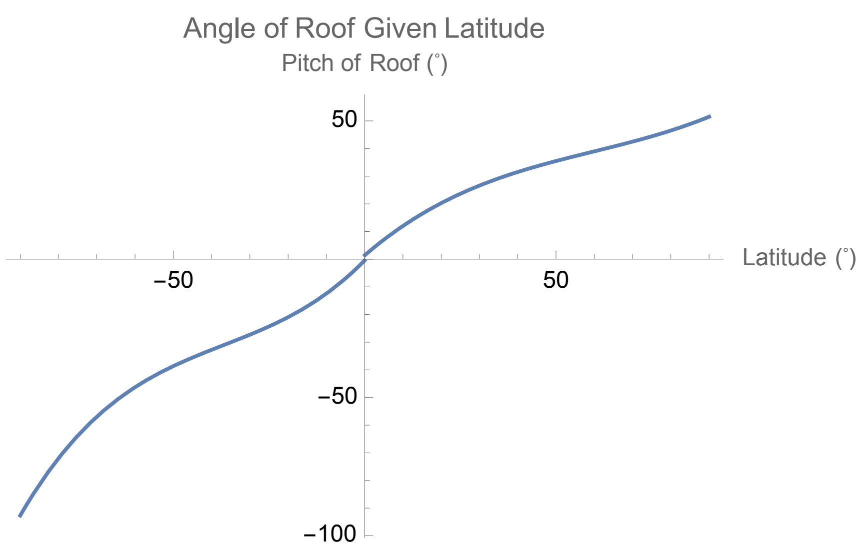


Figure 7: Graphing the Optimal Pitch of the Roof Given Latitude

Using the graph and Java algorithm, we are now able to find the optimal year-round tilt angle for the solar panel at any given latitude. No matter where you want to build this home, our algorithm/graph will be able to calculate the angle at which the highest amount of sunlight will be absorbed. This is important in obtaining the maximum amount of energy production as solar radiation is key in powering up the batteries and as a result, the home itself.

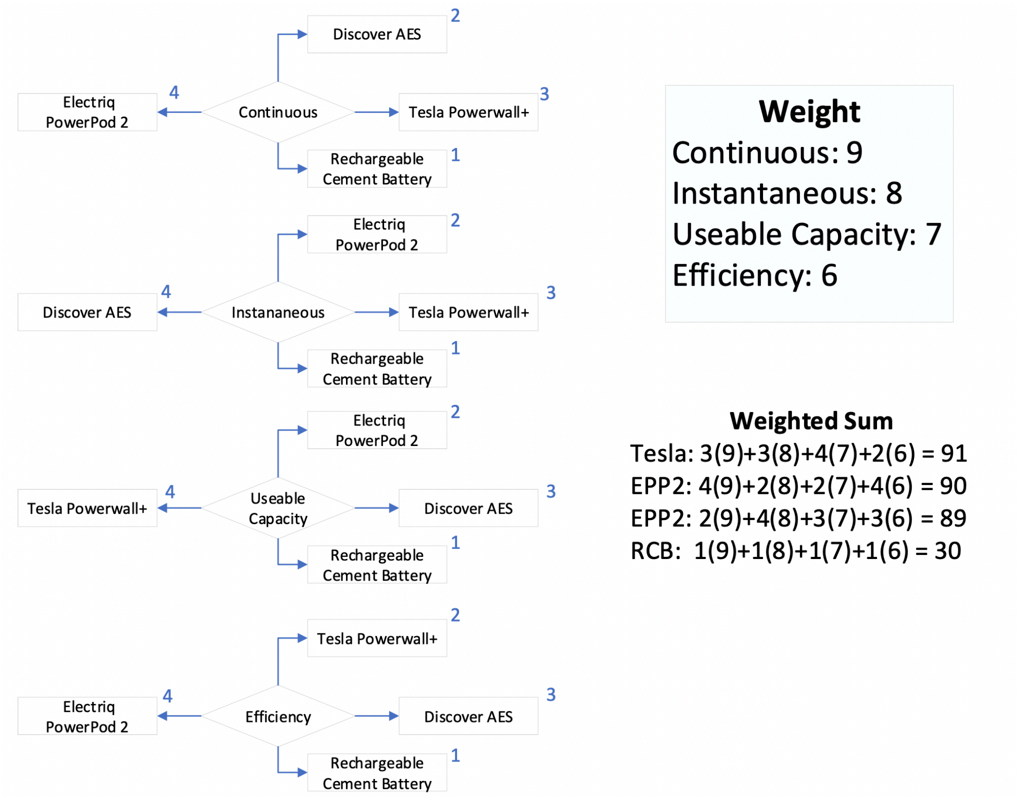
Part III: Incorporating Cement Batteries

Advanced building materials of the future are being envisioned to provide multifunctional smart features such as self-powering for increased energy efficiency and storage (Zhang et al., 2021). Based on a similar concept, scientists in Russia have discovered the use of cement batteries which utilize concrete to collect and store renewable energy.

This innovative approach tries to use cement to absorb the energy that is constantly shining on the ground every day. Cement batteries have advantages such as being modular—the ability to create batteries as needed—and cost-effective as cement and the supplies needed to create electrodes for batteries are cheap. Furthermore, these batteries are also easy to get around the world and they are part of the foundation of the house, so it is easy to find a source to store them (Zhang et al., 2021). However, these batteries have weaknesses which make them not as effective as regular batteries just yet. The current of the battery system will be limited to the current of each cement battery cell which is quite low compared to normal batteries. Each cell cannot provide more than a total of 60 mWh which is not even enough energy to supply a lightbulb for an hour (Zhang et al., 2021). This is an alarming statistic which shows that these batteries are not developed enough to be utilized in a major setting such as for the design for an off-the-grid house. Additionally, from our analysis of Table 13 from the given article on cement batteries, only 6 trials decreased the energy output by 14%, which means that this battery cannot tolerate enough discharges that would come from the nature of a solar-powered house (Zhang et al., 2021). A solar-powered house requires a battery with much larger capacity and efficiency to have a considerable impact for improving energy conservation.

Due to the cements batteries' inability to provide enough power for a house, the cement battery cannot be used as the main energy supply. However, it can be used as a backup energy source made from excess materials. After constructing the house, cement and other materials can be used to construct the battery to help with powering small items.

Comparing the cement battery to other batteries



Use of a decision tree to find the weighted sums of the cement block for different criteria

We used the decision tree developed in part 1 to calculate the appropriate weighted sums for the cement battery.

Conclusions

The model we present uses a parallel connection of two Tesla Powerwall+ batteries for the optimal battery system. Using the table of appliances, we deemed to be necessary for a house, we found the yearly and monthly energy consumption values from the research we were able to find. Then, we found specific aspects of solar panels, such as orientation which will allow for maximum energy production. We created a computer algorithm to determine the optimal year-round solar panel tilt angle at any given latitude. This model uses calculations about the position of the sun in the sky to optimize the position of the solar panel, such that it is in the most direct path of sunlight throughout the year.

From there, we formulated a decision matrix with a criterion with information from 15 different batteries to decide what battery is the most efficient, which we found was the Tesla PowerWall+. The user can change the weight of each criterion (scaled from 6-9) to match what they want, and the algorithm will output the best battery to use to satisfy that demand. In our preliminary model, the amount of energy consumption for each day was calculating by summing the energy consumptions of each of the appliances to get a daily kWh requirement of 22.926 kWh, and since each tesla battery has a capacity of 13.5 kWh, two batteries are needed to fulfill the daily requirements. Given the two tesla batteries, we optimized their electrical current output through a parallel connection to power the appliances.

Strengths & Weaknesses

Strengths:

1) Our model considers the varying amount of sunlight at various locations on the Earth.
2) Parallel connections were used to maximize current.
3) Our model maximizes the roof pitch or tilt angle for different geographical locations in conjunction with sunlight hours in each region to better increase solar panel energy production.
4) Our model effectively utilizes a decision matrix to compare 15 different batteries to find the optimal battery storage system.
5) We utilized many software applications (Excel, Mathematica, Vizio, Eclipse IDE (Integrated Development Environment)) efficiently to make a robust and complete model

Weaknesses:

1) We did not validate some of our equations/formulas with other similar equations/formulas to assess for accuracy
2) We did not have sufficient context for optimizing our battery storage system
3) Our project goes a bit out of the scope of the project – we focused a lot on tilt angle and solar radiation, which were not required in the project directions

4) Our model does not optimize the cost of the system, and as a side effect generates an expensive solution. We accounted for the cost as a tiebreaker method between similar battery results, but we did not optimize to find the best battery system cost

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Scientists Make Advancements in Sustainable Carbon-Neutral Housing

In the advent of the global warming crisis, it has become increasingly important to decrease the carbon emissions we generate. According to a scientist in the field "One of the biggest sources of carbon emissions in the United States is residential energy, which constitutes roughly 20% of emissions in the United States," an alarmingly high percentage for a sector that can be easily managed. Scholars have studied the issue extensively, and concluded that the best way to deal with this issue is by using renewable energy sources to generate the required electricity for a house.

Stressing the significance of a carbon-neutral housing system, engineers have developed a system that could be implemented such that the house can exist completely independent from the electrical grid. Living "off-the-grid" may sound old-fashioned to those looking to live a comfortable suburban life, yet in fact these systems are capable of providing sufficient levels of electricity for a comfortable lifestyle.

The Tesla Powerwall+ (Image from Tesla)

Solar Power Takes the Housing Industry by Storm (Image from Washington Post)

"One of the most important aspects of a self-sufficient home is the energy storage system, which determines how well the house can operate when solar radiation is not available," asserts a researcher from the HiMCM Institute of Technology. Taking into account the average energy requirements and frequency of usage for many household appliances in the United States, researchers have developed a model which can tailor an energy storage system fit for the personal needs of a homeowner. This model takes into consideration numerous factors such as the number of people living at the house, and the power and specifications of many standard appliances.

The recommendation this model generates gives the user advice regarding what type of battery to incorporate into their energy storage system. These options include innovative, sustainable battery solutions, such as the Tesla Powerwall, or the Smart Lithium Iron Phosphate Battery, both of which greatly decrease the energy lost in the system. Other battery systems were considered, such as the use of cement batteries, which researchers have asserted "is not an adequate solution for this situation."

Further research continues to be done, and both scholars and the general public agree this model has great potential for the future.

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Appendix A

```java
public class OptimalTiltAngle {

    public static void main(String[] args) {
        double latitude = 45;       //this is a value for a location's latitude//
        double optimalAngle;
        if(latitude>0) {            //the northern hemisphere is all latitudes above 0//
            optimalAngle = 1.3793 + latitude*(1.2011 + latitude*(-0.014404 + latitude*0.000080509));
        }                           //the formula obtained from (Jacobson et al., 2018)//

        else if(latitude<0) {       //the southern hemisphere is all latitudes below 0//
            optimalAngle = -0.41657 + latitude*(1.4216 + latitude*(0.024051 + latitude*0.00021828));
        }                                        //the formula obtained from (Jacobson et al., 2018)//

        else {                      //if latitude is 0, it is the equator which has a latitude of 0//
            optimalAngle = 0;
        }
        System.out.println("Optimal Tilt Angle: " +Math.round(optimalAngle*100.0)/100.0);
    }
}
```

Appendix B

Appliance	Hours Per Day	Note	Add. Sources
Fridge	Constant		
Tank Water Heater	(#People*20g*0.33h+30g)/40g	From the source to the right we estimate that the size of the water heater will be 40 gallons. Hot water use per person is really only dependent on showers which we estimate to be 20 minutes per person every day. The number is added to a constant 30g for cleaning use and its divided by 40 gallons to determine how many times the tank has to reheat the water.	Energy.Gov: https://www.energy.gov/energysaver/sizing-new-water-heater
Cooking Range	Constant		
Lighting - LED 13 Watt	7 watts * number of bulbs	The energy consumption of lighting is dependent purely on the number of light bulbs. A 13 Watt light bulb is an efficient alternative to an incandescent 100 watt lighbulb.	
Furnace Fan Blower	5/12 months*(12hours*15 min)	A furnace fan blower is season dependent as it will only be used during colder months which we estimated to five months of the year. From the source to the right, we calculated that if a client sets the heater to 12 hours a day, then the heater will actually only turn on every 15 minutes of that hour.	US Inspect: https://www.usinspect.com/blog/can-running-hvac-fan-continuously-save-energy-costs-part-1-3/#:~:text=Warning%2C%20math%20required!,month%20in%20the%20ON%20mode.
Microwave	0.2	We estimated the microwave will be on for 12 minutes per person each day.	
Ceiling Fan	7/12 months*15 hours * 1.1 watts	Like the furnace fan blower, the ceiling fan is season dependent and running during the 7 remaining months of the year.	
Dishwasher	Constant		
Washer	N/A	We estimated that each person in the household would use both the washer and dryer for 1 hour per week.	
Dryer	N/A		
Water Kettle	Constant		
Satellite Dish	Constant		
Router	Constant		
Water Pump	Number of People*20min+2hours	We estimated that water pump's consumption is dependent upon the number of people taking a shower in the house plus an additional 2 hours for each day.	
Laptop (Charging)	Constant		
Toaster	Constant		
Garbage Disposal	Constant		