2021 HIMCM PROBLEM A

Team Control Number: 11727

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Summary

Considering the high costs of connecting a house to the national power grid, around 20,000 $ per mile of powerlines, we're asked to evaluate a possible power alternative to relying on the grid for a 1600 ft^2 home. Assuming that the price of sourcing power from the energy company is exorbitant. We researched different types of batteries, LFP, lead-acid, and AGM; citing their specific power ratings. Continuous power, instantaneous power, round-trip efficiency, and capacity. Subsequently, we cataloged nearly all of the appliances used by the average family and their energy consumption per day. To see the spread of instantaneous and continuous power dependencies for each appliance, we added a column. This helped us ascertain whether batteries could handle the amount of energy required for each load, then we transformed this theory into an applied model with a multi-layer synthesis where we could test any battery to any power consumption(combination of appliances). This spits out only the aptest batteries and ranks them by effectiveness for each factor. Next, we assessed the sustainability requirements for a home battery–finding that the charge rate would need to be larger than the discharge rate since there is the cumulative loss of power during the night. This means that the battery needs to produce as much energy consumed during the day and night in the daylight hours.

Despite being given the problems going from a specific solution for the 1600 ft^2 house to a generalized model for all energy consumption and all secondary batteries. We decided to answer the second question first because we could use the insight from a general model and test a sample bank of batteries for the daily consumption of the 1600 ft^2 house. We decided that the Tesla Powerwall 2, a lithium-ion battery, would be the most optimal alternative to grid power. It has the highest capacity of the batteries we analyzed, plus it charges much faster than its lead-acid counterparts. It's also a deep cycle battery, so it can run appliances for a long period of time without dropping voltage.

Finally, we read about the research that Swedish scientists were doing with cement batteries. They found that by using a metal-coated carbon mesh, iron for anodes, and nickel for cathodes, a basic building material, cement, could be turned multi-purpose. It could hold a limited capacity, and namely act as the foundation for a home. The specifications of the rechargeable cement batteries leave much to be desired, the power density is much lower than other secondary batteries. Using these batteries is not viable for a small homestead like the example because there would need to be a lot of cement material before any sizable amount of capacity could be allocated.

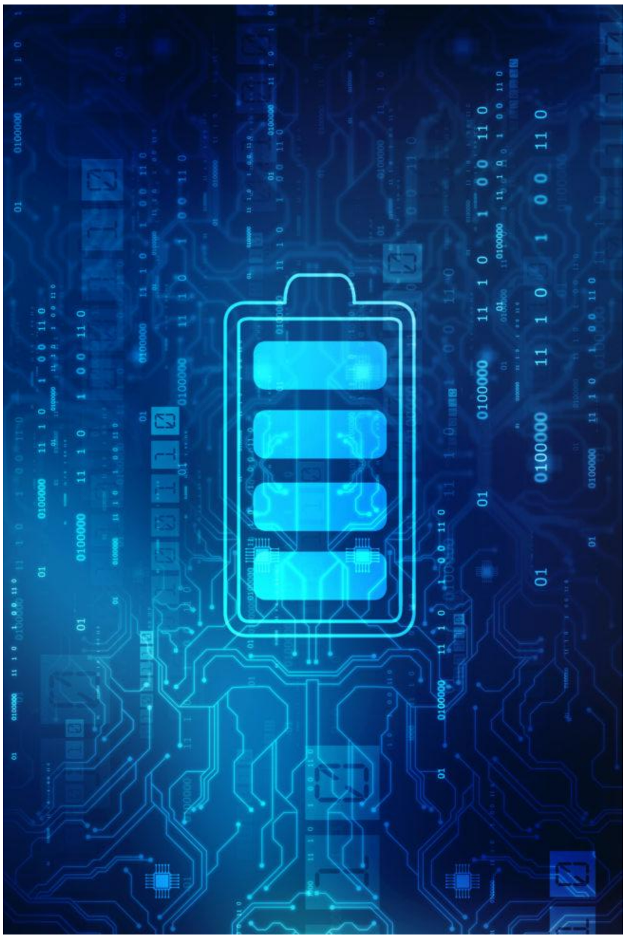
November 2021

OFF-GRID BATTERY MODEL AND EVALUATION

As the world becomes more advanced in green and renewable energy, this also drives the development of storage and batteries with Tech giants like Tesla and LG Chemical taking the lead. In recent years the once seems impossible off-grid house becomes more popular especially in remote areas where transmission towers and electric grid does not cover.

TOT Model Of Batteries

This model provides the customer with a battery combination that is accurate, efficient, and secure. This model first asks for the user to input their normal electricity consumption based on the using time of electrical appliances, as well as the maximum budget that the user can take to go off-grid. Then the system uses this information and the popular choice of batteries in the market, to find all the possible combinations of batteries based on the different types of energy consumptions, then the system goes through two filters: price and capacity, as well as the ranking system of left budget and extra storage, presents the customer the top choice overall combinations.



Cement Battery & Future

In early 2021, Doctor Emma Zhang and Professor Luping Tang from Chalmers University in Sweden have made a breakthrough in cement battery, using gravitational force to storage electricity. This is a great way to store energy in terms of two ways. First, it can uses the tall concrete in the city as well as the unused mine in the rural areas. Second, it can generate substantial amount of energy as higher the building the larger the potential energy thus greater the generated electricity. It also has one major disadvantages, it's not very applicable to normal civilian houses as these houses don't have the height and mine in order to efficiently store energy. In general, cement battery might be very efficient for recharge a city, but not as efficient to supply electricity to a individual house.

Contents

1 Introduction

1.1 Background

An interesting new option for residential power supply is off-the-grid systems. This is very attractive for people that want, in many cases, a cheaper, more affordable power source alternative. If you live in rural, isolated areas it is difficult and costly to buy electricity from large companies. In this case, the homeowner lives in a small 1600 square foot house and requires relatively less electricity than larger houses. Partially because there are fewer lights, and likely fewer appliances like stoves or washing machines and notably refrigerators. However, the costs of batteries and solar panels can be burdensome. Many large batteries cost in the ballpark of thousands of dollars, plus the cost of installation. We will weigh the benefits of varying types of batteries like FlP*, Lithium-Ion, and Lead Acid; nominally the battery life per charge, continuous and instantaneous power rating, loss of stored power, and amount of storable energy. Our aim is to design the most efficient power storing system that meets the electrical needs of the 1600 square foot house, while also being scalable for homes of different sizes.

1.2 Problem Restatement

Question 1: Where is this home, in which U.S. state? Our home is in Western Massachusetts. We chose this location because the winters can be challenging for a home battery, it gets very cold and we don't get much light between late autumn to February.

Question 2: What types of appliances in the home require energy, by how much? The appliances for our house vary in drawing power, and with the types of power that they require–like instantaneous and continuous power. For specific power consumption of each common home, appliances refer to Constants(A). Some loads/devices that require less power, but consistent input over a longer period of time is represented as a metric per year. Others require instantaneous power because they are high current drawing machines(e.g. Drying machines, heating, stove, and vacuum). Running for short bursts, and doing a lot of work.

Question 3: How many people live in the house? The number of people who live in the 1600 sq ft house is an important factor since the energy consumption from various amenities like washers, dryers, ovens, and dishwashers increases. In our model, we'll need to design an expression that takes an input of the number of people, and applies a predictable power augmentation.

2 Assumptions and Justification

1. In this project, we assume that all houses modeled are in the United States of America. Since we adjust or algorithm for American standards for energy consumption, and prices of American batteries. The examples used are representations of the average rural home and its appliances.

2. Given the same level of quality between different batteries, the homeowner is always, for the sake of this problem, going to choose the cheaper alternative. Therefore, the homeowner would ideally get a cheaper price for the power system than buying electricity from the grid.

3. We assume that the only source of electricity for the small homeowner is solar power and that he/she doesn't have a gas generator. The person lives far enough away from civilization that getting natural gas lines would be infeasible and expensive.

4. The solar panels used in the power system are assumed to be of the same type and quality. This provides continuity on the amount of energy input or E sun that each solar panel can produce. However, the number of solar panels is up to our design and is a feature of our project.

5. We make the assumption that most of the energy consumed in a year is dispensed during winter since the winter months see the least amount of sunlight on average. We believe that the fewer sunlight hours per day, the less energy that the solar panels will store. This is a general assumption for any location in the northern hemisphere.

6. We assume that the person lives in their house for 10 years so that we can gauge whether batteries will need to be replaced depending on their lifetime. This is going to have a bearing on the price of the overall power system.

7. Another assumption is that there will be no energy input from the solar panels during the night and If any, it's negligible. There will only be a power loss during the night from heating, the stove, and other appliances.

3 Variables and Constants

3.1 Energy Consumption

3.1.1 Variables

Definitions	symbols
Total Energy Consumption overall	E_{total}
Total Energy Consumptions for Continuous Appliance	E_{cont}
Total Energy Consumption for Instantaneous Appliance	E_{inst}
Maximum Energy Consumption for Instantaneous Appliance per hour	$E_{i,rate}$
Estimated power for each Appliance	A_n
Quantity	Q_n
Est. Total Time Use (Minutes)	T_n
Specific Electrical Appliance	n
Continuous(Cont.) Appliances	C_n
Instantaneous(Inst.) Appliances	I_n

3.1.2 Constants

Symbol (A_n)	Electrical Appliance	Estimated power (kW)	Cont./Inst.
A_1	Freezer (Yearly)	452.6	C_1
A_2	Refrigerator (Yearly)	438	C_2
A_3	Light (Yearly)	1105	C_3
A_4	Oven (Hourly)	1.2	I_1
A_5	Cloth Washer (Hourly)	0.8	I_2
A_6	Dryer (Hourly)	3.0	I_3
A_7	Water Heater (Hourly)	4.5	I_4
A_8	Dish Washer (Hourly)	1.5	I_5
A_9	Microwave (Hourly)	1.0	I_6
A_{10}	Coffee Machine (Hourly)	1.0	I_7
A_{11}	TV (Hourly)	0.2	I_8
A_{12}	Toaster (Hourly)	1.2	I_9
A_{13}	Hair Dryer (Hourly)	1.5	I_{10}
A_{14}	Vacuum (Hourly)	1.5	I_{11}
A_{15}	Kettle (Hourly)	1.2	I_{12}
A_{16}	Computer (Hourly)	0.5	I_{13}
A_{17}	Stove (Hourly)	1.5	I_{14}
A_{18}	Space Heater (Hourly)	1.5	I_{15}

3.2 Battery

3.2.1 Constants

Name	Usable Capacity (INCLUDED EFFICIENCY)	Cont. Power Charge Rate	Peak Power	Warranty	Cost Install
LG Chem RESU10	8.8 kWh	5.0 kW	7.0 kW	10 years	8,800
LG Chem RESU6.5	5.9 kWh	4.2 kW	4.6 kW	10 years	6,500
Tesla Powerwall	6.4 kWh	3.3kW	3.3 kW	10 years	10,000
Tesla Powerwall 2	13.5 kWh	5.0 kW	7.0 kW	10 years	14,000
Sonnen Eco 10	10.0 kWh	8.0 kW	12.0 kW	10 years	10,000
Enphase Encharge 3	3.36 kWh	1.28 kW	1.92 kW	10 years	5,000

4 Pre Model

4.1 Energy Consumption

4.1.1 Total Energy Consumption

$$E_{total} = \sum_{k=1}^{n}(Q_k \cdot T_k \cdot A_k) = E_{inst} + E_{cont}$$

The first part of this formula shows the relationship between Total Energy Consumption E_{total} and energy consumption for certain electrical appliances, the total energy consumption for a given electrical appliance is the product of the "Quantity" of that appliance, "Time" which is the usage of that appliance, and the constant "A"; this will provide an estimated energy usage in kilowatts for that particular appliance. Using Sigma we can calculate the total energy consumption for all appliances in kWh necessary for an off-grid house. For example, if the user uses all the appliances listed in the constants grid, then the total energy consumption for certain time periods will be the quantity of the using appliances times how long the appliances will be used then times the corresponding constants listed in the table, if the user doesn't use those appliances in that time, then the quantity would simply be 0. The second part of this formula defined the relationship between total energy consumption as the sum of the total energy consumption of instantaneous electrical appliances like stoves, microwaves, and dishwashers where the appliances only required a smaller amount of energy in shorter periods of time, and total energy consumption of continuous appliances like lights, refrigerators, and freezers, where it requires a larger amount of energy last a longer period of time. By labeling all electrical appliances in these two categories, the sum of these two categories is the same as all the used electrical appliances.

4.1.2 Instantaneous/Continuous Energy Consumption

Continuous

$$E_{cont} = \sum_{i=1}^{n}(T_i \cdot C_i \cdot Q_i)$$

Instantaneous

$$E_{inst} = \sum_{i=1}^{n}(T_I \cdot I_i \cdot Q_i)$$

These two equations explored the total usage of Continuous and Instantaneous Appliances separately. The only difference between these two equations and the total consumption equations is that we separate the possible appliances into two categories, C_i for continuous appliances like refrigerators and heaters, and I_i for instantaneous appliances like stoves and microwaves.

4.1.3 Schedule Adopted Consumption

Continuous

$$E_{c,rate} = \sum_{k=1}^{n}(Q_k \cdot \frac{C_k}{1000})$$

Instantaneous

$$E_{i,rate} = \max\left(\left(\sum_{k=1}^{n}(Q_k \cdot \frac{I_k}{1000})\right)_i\right)$$

These two equations represent the rate of energy consumption in continuous and instantaneous cases. To calculate the rate we add up the total energy consumption and divide it by 1 hour, for hourly rates. In the continuous case, the energy consumption rate will be constant, so we can just find the constant consumption and divide it by 1 hour. For the instantaneous case we would add up the energy consumption rates for each hour and list them out in a histogram. We then take the maximum of those values to ensure the model will meet their needs.

5 Mathematical Model

5.1 Model Overview

The model we have decided to implement is a filtration system and a ranking system.

First we start from the inputs; budget, energy use, and schedules. These inputs will be fundamental to the filtration system which will allow for a proper optimization.

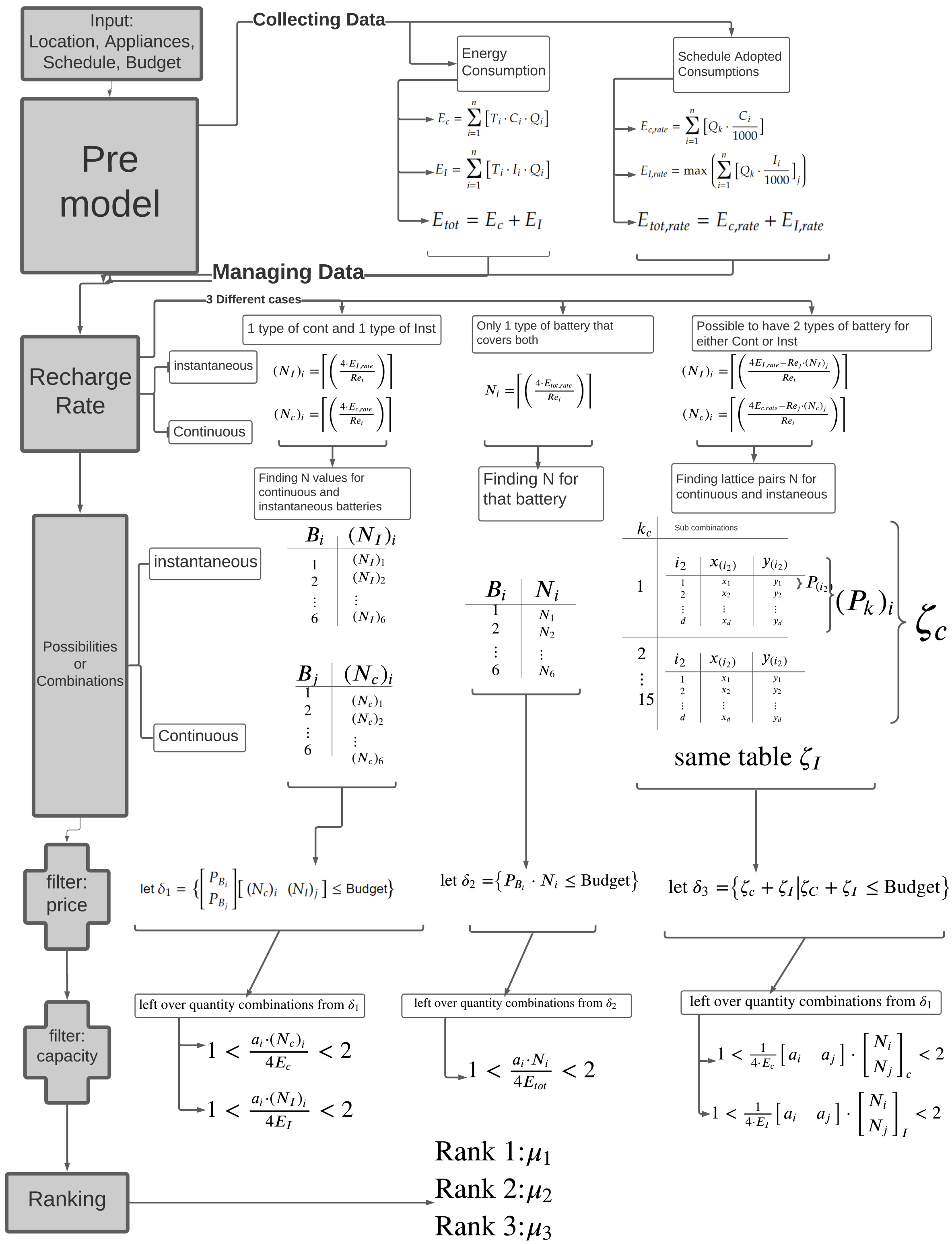
Those inputs would make their way into the Pre-Model section. This section collects and manages that data to allow for the model to work more smoothly.

Then we move on to the Recharge (charge) rate which would set up the model by providing all possible combinations. The combinations will be split up into 3 different sections for simplicity.

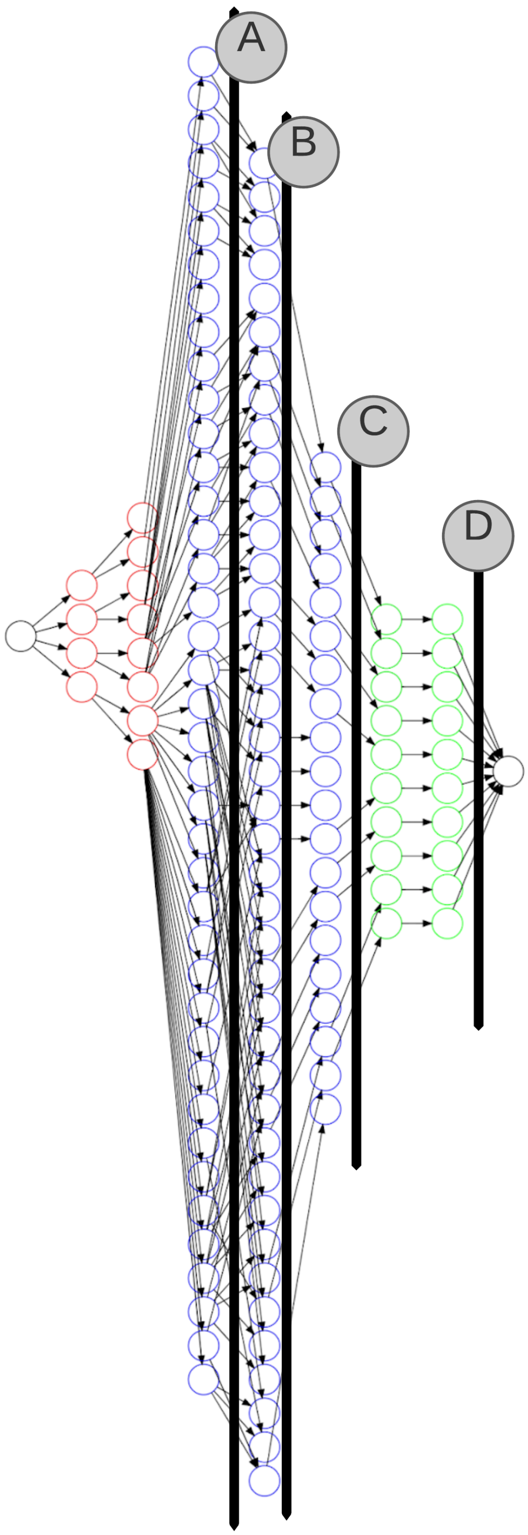
Once we have all of the possible combinations we can run them through filters. Through each filter the possible combinations will decrease, giving us a more narrow answer. The first filter is the price filter which relies on their budget; if the price exceeds the budget, then that combination is filtered out. The next filter is the usable capacity filter; for the combinations that do not meet the storage needs it would be filtered out.

Finally running through those filters would not leave us with a definite answer, that's why we implemented a ranking system. This ranking system will take several factors, average capacity, left over price, and size.

This will then output the top 3 ranks which would allow for the person to choose, if they have another preference.



Input: Location, Appliances, Schedule, Budget
Pre model
Collecting Data
Energy Consumption
Schedule Adopted Consumptions
$E_c = \sum_{i=1}^{n} [T_i \cdot C_i \cdot Q_i]$
$E_I = \sum_{i=1}^{n} [T_i \cdot I_i \cdot Q_i]$
$E_{tot} = E_c + E_I$
$E_{c,rate} = \sum_{i=1}^{n} [Q_k \cdot \frac{C_i}{1000}]$
$E_{I,rate} = \max \left(\sum_{i=1}^{n} [Q_k \cdot \frac{I_i}{1000}]_j \right)$
$E_{tot,rate} = E_{c,rate} + E_{I,rate}$
Managing Data
3 Different cases
Recharge Rate
1 type of cont and 1 type of Inst
Only 1 type of battery that covers both
Possible to have 2 types of battery for either Cont or Inst
instantaneous
Continuous
Finding N values for continuous and instantaneous batteries
Finding N for that battery
Finding lattice pairs N for continuous and instaneous
Possibilities or Combinations
instantaneous
Continuous
Sub combinations
same table ζ_I
filter: price
let $\delta_1 = \{ \begin{bmatrix} P_{B_i} \\ P_{B_j} \end{bmatrix} [(N_c)_i \ (N_I)_j] \leq \text{Budget} \}$
let $\delta_2 = \{ P_{B_i} \cdot N_i \leq \text{Budget} \}$
let $\delta_3 = \{ \zeta_c + \zeta_I | \zeta_C + \zeta_I \leq \text{Budget} \}$
filter: capacity
left over quantity combinations from δ_1
left over quantity combinations from δ_2
left over quantity combinations from δ_1
$1 < \frac{a_i \cdot (N_c)_i}{4E_c} < 2$
$1 < \frac{a_i \cdot (N_I)_i}{4E_I} < 2$
$1 < \frac{a_i \cdot N_i}{4E_{tot}} < 2$
Ranking
Rank 1: μ_1
Rank 2: μ_2
Rank 3: μ_3



A	Price Filter
B	Usable Capacity Filter
C	Ranking
D	Top Options

5.2 Recharge rate and the number of batteries

5.2.1 Scenario 1: Only 1 type of continuous and 1 type instantaneous battery

$$Re_i \cdot (N_c)_i = 4E_{c,rate} \tag{1}$$

$$\Rightarrow (N_c)_i = \left\lceil \left(\frac{4E_{c,rate}}{Re_i} \right) \right\rceil \tag{2}$$

The equation (1) relates the maximum energy use rate from **continuous** appliances ($E_{c,rate}$). Re_i is the charge rate of a particular battery [Appendix B], and the 4 allows for extra energy to be accumulated, see appendix A. $(N_c)_i$ is the quantity of the corresponding continuous battery. Equation (2) manipulates equation 1 so that we can get rounded up natural number for the required number of batteries.

B_i	$(N_c)_i$
1	$(N_c)_1$
2	$(N_c)_2$
$\vdots$	$\vdots$
6	$(N_c)_6$

Table 2.1

Running the equation through each of the 6 batteries (B_i), we will get a table (Table 2.1) that shows the corresponding required amount of batteries ($(N_c)_i$).

$$Re_i \cdot (N_I)_i = 4E_{I,rate} \tag{3}$$

$$\Rightarrow (N_I)_i = \left\lceil \left(\frac{4 \cdot E_{I,rate}}{Re_i} \right) \right\rceil \tag{4}$$

Similarly we can do the same concept of relating quantity with maximum energy use rate by the **Instantaneous** appliances ($E_{I,rate}$).

B_i	$(N_I)_i$
1	$(N_I)_1$
2	$(N_I)_2$
$\vdots$	$\vdots$
6	$(N_I)_6$

Table 4.1

We would make the same table labeled as (Table 4.1) but for **instantaneous**.

Let δ_1 be defined as follows,

$$\delta_1 = \left\{ \begin{bmatrix} P_{B_i} \\ P_{B_j} \end{bmatrix} \cdot \begin{bmatrix} (N_c)_i & (N_I)_j \end{bmatrix} \leq Budget \right\} \tag{5}$$

δ_1 is a set different prices that results from the "price filter." With those prices we can determine what combination of $N's$ come out. That combination will consist of a **continuous** value (N_c) and a **instantaneous** value(N_I).

$$1 < \frac{a_i \cdot (N_c)_i}{4E_c} < 2 \tag{6}$$

$$1 < \frac{a_i \cdot (N_I)_i}{4E_I} < 2 \tag{7}$$

Taking the remaining prices, we can find the N combinations from it, then we split them up into 2 sections: the **continuous** (N_c) and the **instantaneous** (N_I). The combinations that do not satisfy the inequality would get filtered out by the "Usable capacity filter." a_i represents the usable battery capacity [Appendix B], $(N_c)_i$ represents the quantity of that particular battery; this applies to the(N_I) case as well.E_c and E_I is the energy consumption; see Appendix A for the usage of 4. Since this is a ratio of batteries to the usage, we want the ratio to be in between 1 and 2. If the ratio is less than 1 that means that there isn't enough storage for the usage, and if it is greater than 2 that means that there is double the amount required, which is costly.

5.2.2 Scenario 2: Only 1 type of battery that covers both instantaneous and continuous needs.

$$Re_i \cdot N_i = 4E_{tot,rate} \tag{8}$$

$$\Rightarrow N_i = \left\lceil \left(\frac{4E_{tot,rate}}{Re_i} \right) \right\rceil \tag{9}$$

B_i	N_i
1	N_1
2	N_2
$\vdots$	$\vdots$
6	N_6

Table 9.1

Let δ_2 be defined as follows,

$$\delta_2 = \left\{ P_{B_i} \cdot N_i \leq Budget \right\} \tag{10}$$

$$1 < \frac{a_i \cdot N_i}{4E_{tot}} < 2 \tag{11}$$

We can repeat the same exact process but this time with only **1 type of battery.** The equation (9) relates the total energy use rate ($E_{tot,rate}$).From that equation we get a table of values, then that set runs through the "Price Filter" and afterward through the "Usable Capacity Filter." After this process we would get a set of filtered values.

5.2.3 Scenario 3: Possible to have 2 types of batteries for either continuous or instantaneous

To begin with we examine the instantaneous case,

$$Re_i \cdot (N_I)_i + Re_j \cdot (N_I)_j = 4E_{I,rate} \tag{12}$$

$$\Rightarrow (N_I)_i = \left\lceil \left(\frac{4E_{I,rate} - Re_j \cdot (N_I)_j}{Re_i} \right) \right\rceil \tag{13}$$

The scenario starts with a general equation (12) that correlates the instantaneous appliance usage rates ($E_{I,rate}$) with the charge rates of batteries. Since there are 2 variables in the same equation we can use Desmos [Appendix C] to find the lattice points.

k_c	Sub Combinations		
	i_2	$x_(i_2)$	$y_(i_2)$
	1	x_1	y_1
1	2	x_2	y_2
	$\vdots$	$\vdots$	$\vdots$
	d	x_d	y_d
	i_2	$x_(i_2)$	$y_(i_2)$
2	1	x_1	y_1
$\vdots$	2	x_2	y_2
15	$\vdots$	$\vdots$	$\vdots$
	d	x_d	y_d

Table 13.1

Under the column "Sub combinations" we will find a table of lattice points. We call N_i as the "$x_{(i_2)}$" and N_j as the "$y_{(i_2)}$", this will allow Desmos [Appendix C] to output a table of values. On the left side we have a column called "k_c", this represents a certain combination of 2 batteries (eg. N_1 and N_2). Notice that k_c only goes up to 15, that is because that is all the combinations of $N's$ that 2 are not the same, and not having repeats.

i_2	$x_(i_2)$	$y_(i_2)$
1	x_1	y_1

$$P_i \cdot x_(i_2) + P_j \cdot y_(i_2) = P_{i_2} \tag{14}$$

Since we are just considering only one lattice pair we can change the $x_{(i_2)}$ into N_i and the $y_{(i_2)}$ into N_j. This will give us our first set of prices P_{i_2}.

i_2	$x_(i_2)$	$y_(i_2)$
1	x_1	y_1
2	x_2	y_2
$\vdots$	$\vdots$	$\vdots$
d	x_d	y_d

$$\Rightarrow (P_k)_i = \{(P_{(i_2)})_i\} \tag{15}$$

We can put the previous set of prices into another set, we will call that set $P_{(k_i)}$. This set will include all of the sub table prices.

$$\zeta_c = \{(P_k)_i\} \tag{16}$$

This ζ_I houses a large set of values which is better represented in Table 13.1. This ζ_c only represents the table for the instantaneous case.

$$Re_i \cdot (N_I)_i + Re_j \cdot (N_I)_j = 4E_{c,rate} \tag{17}$$

$$\Rightarrow \zeta_c = \big\{(P_k)_i\big\} \tag{18}$$

We can follows the same steps going from the Instantaneous case (Equation (12) to Equation (15)) except this time the set of values will apply to the continuous case (ζ_c).
Let δ_3 be defined as follows,

$$\delta_3 = \big\{\zeta_c + \zeta_I \big| \zeta_c + \zeta_I \leq Budget\big\} \tag{19}$$

From that equation we can get a filtered set of prices (δ_3), which is consisted of a continuous set (ζ_c) and an Instantaneous set (ζ_I).

$$1 < \frac{1}{4E_c}\begin{bmatrix} a_i & a_j \end{bmatrix} \cdot \begin{bmatrix} N_i \\ N_j \end{bmatrix}_c < 2 \tag{20}$$

$$1 < \frac{1}{4E_I}\begin{bmatrix} a_i & a_j \end{bmatrix} \cdot \begin{bmatrix} N_i \\ N_j \end{bmatrix}_I < 2 \tag{21}$$

Now that we have a filtered set we can gather the quantity combinations and put those through a storage filters. We separate the filter into the continuous filter and the instantaneous filter. The $1x2$ matrix is the matrix of corresponding battery constants [Appendix B], and the $2x1$ matrix is corresponding matrix which when multiplied would give out a $1x1$ matrix, therefore a constant. If that combination of battery fails the inequality it is filter out.

5.2.4 Putting all of the scenarios together.

$$Rank = [Budget - Price] \cdot [\Delta Storage] \cdot [Volume] \tag{22}$$

$$\Rightarrow G = [w_1] \cdot [(w_2] \cdot [\frac{1}{w_3}] \tag{23}$$

Where w_1 is the Budget-Price, and the larger the number the better. w_2 is the left over storage which the more the better. And w_3 the volume, which the less means the better so we use an inverse function.

$$G = \prod_{i=1}^{3} w_i \tag{24}$$

By taking each product we will get a rank for each remaining combination.

$$(\mu_1) = \max\big(G_i\big) \tag{25}$$

$$(\mu_2) = \max\big(G_i \big| G_i \neq \max(G_i)\big) \tag{26}$$

$$(\mu_3) = \max\left(G_i \middle| G_i \neq (\mu_1) \neq (\mu_2)\right) \tag{27}$$

Rank	Combination
(μ_1)	
(μ_2)	
(μ_3)	

Table 27.1

This ranking system will will provide the top 3 in Table 27.1, where the best one is represented as (μ_1) and the worst of the three is represented as (μ_3).

Name	Dimension [in] (h·w·d)	Volume [in^3]
LG Chem RESU 10	35.7·29.7·8.1	8588.349
LG Chem RESU6.5	17.8·25.8·4.7	2158.428
Tesla Powerwall	51.3·34·7.2	12558.24
Tesla Powerwall 2	45.3·29.6·5.75	7710.06
Sonnen Eco 10	57·26·19	28158.00
Enphase Encharge 3	14.45·26.14·112.56	42516.5

Table of Dimensions

This is the table of Dimensions and Volumes. This table will go into the volume variable w_3.

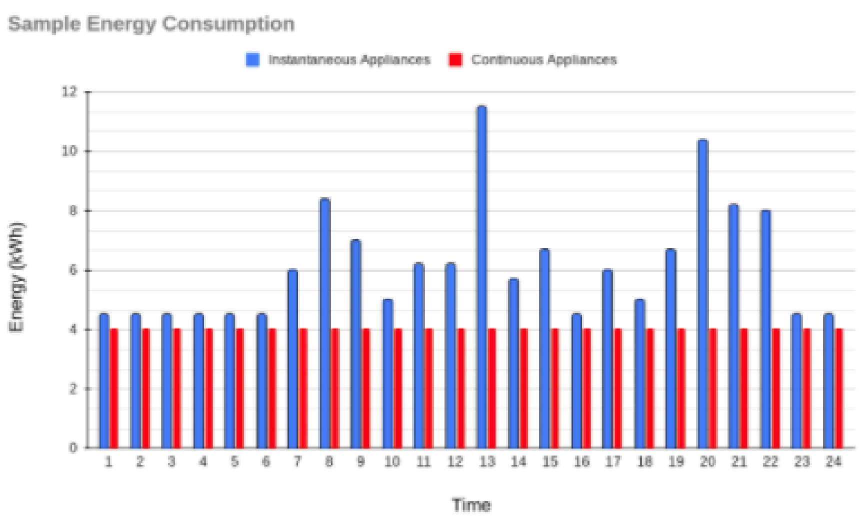
6 Application

6.1 Schedules and Energy Consumption

The user will first input their schedule by plugin the quantity in use for each electrical appliance for that specific hour, note that this step includes the number of people living in the house, as said for cell phone the user would plug in number 4 for that hour which indicate that there are four people who live in this house. Then the data would transfer into hourly energy consumption using the Energy Consumption constants listed in the Pre-model sections.

Appliance (the ones that are not used all the time)	CONSTANT W	Schedule											
		12:00 AM	1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM
Oven	1200	0	0	0	0	0	0	0	0	0	0	1	1
Washer(Clothes)	800	0	0	0	0	0	0	0	0	0	0	0	0
Dryer	3,000	0	0	0	0	0	0	0	0	0	0	0	0
Cell Phone (Charge)	3.68	4	4	4	4	4	4	4	0	0	0	0	0
Water Heaters	4500	0	0	0	0	0	0	0	0	0	0	0	1
Jaccuzi	3000	0	0	0	0	0	0	0	0	0	0	0	0
Dish washer	1500	0	0	0	0	0	0	0	0	0	0	0	0
microwave	1000	0	0	0	0	0	0	0	0	0	0	0	0
Coffee machine	1000	0	0	0	0	0	0	0	0	1	0	0	0
TV	200	0	0	0	0	0	0	0	0	0	0	0	0
toaster	1200	0	0	0	0	0	0	0	1	0	0	0	0
hair dryer	1500	0	0	0	0	0	0	1	0	0	0	0	0
vacuum	1000	0	0	0	0	0	0	0	0	0	0	0	0
Kettle	1200	0	0	0	0	0	0	0	1	0	0	0	0
Computer	500	0	0	0	0	0	0	0	0	0	1	1	1
stove	1500	0	0	0	0	0	0	0	1	1	0	0	0

Transfer the result from the table into the following Chart which is the schedule adopted Energy Consumption for the daily use of a sample house. The blue bars represent the energy consumption from the Instantaneous appliances like the microwave, the red bar represents the energy consumption from the Continuous Appliances like a heater. The maximum for Instantaneous Appliances of this sample occurs at 1:00 pm, where the peak consumption was 11.5 kWh for that specific hour, and the energy consumption for Continuous Appliances is constant at 4.066 kWh throughout each hour.



6.2 Number of Batteries

Plugin values in the equations, and (NI)i=ceil4EI, rateRei so we can figure out the number of batteries needed in order to match the rate of the energy consumption. For example, for LG Chem 10 battery, if we use this specific battery to match continuous electricity consumption, we know E_c,rate which is 4.066 kW/hour, we also know the Re_i , which is the charge rate of a battery, in this case, is 5 kW, means that for 1 LG Chem 10 battery, it can gain 5 kW of electricity maximum for each hour. Calculating the results, a total of 4 LG Chem batteries are needed to match the continuous energy consumption. We can replicate this process for all batteries in Continuous as well as for Instantaneous, but instead of continuous power for continuous batteries, we use peak power for instantaneous usage.

6.3 Price Filter

Next, we can figure out the total price of the batteries by simply multiplying the number of batteries by their respective price to figure out the total price of that battery. The following figure contains all the information we just included.

Continuous	4.066	Constant kW	# of Batteries	Price Constant	Total Price
LG Chem 10	B1	5	4	8800	35200
LG Chem 6.5	B2	4.2	4	6500	26000
Tesla 1	B3	3.3	5	10000	50000
Tesla 2	B4	5	4	14000	56000
Sonnen 10	B5	8	3	10000	30000
Emphase	B6	1.28	13	5000	65000
Instanteneous	11.5	Constant kW	# of Batteries	Price Constant	Total Price
LG Chem 10	Ba	7	7	8800	61600
LG Chem 6.5	Bb	4.6	10	6500	65000
Tesla 1	Bc	3.3	14	10000	140000
Tesla 2	Bd	7	7	14000	98000
Sonnen 10	Be	12	4	10000	40000
Emphase	Bf	1.92	24	5000	120000

Given this graph, we can have in total 36 different combinations of instantaneous and continuous batteries add up their corresponding price based on the number of batteries we can get the total price for that specific combination of batteries. These prices then went to the price filter, in which the total price is greater than the input budget (100,000) gets filtered out, and the combinations that remained proceed to the next filter: storage and capacity. The following table reviews this relationship with the highlighted cell to represent the combinations that passed the price filter.

	Continuous					
Instanteneous	35200	26000	50000	56000	30000	65000
61600	96800	87600	111600	117600	91600	126600
65000	100200	91000	115000	196000	95000	130000
140000	175200	166000	190000	196000	170000	205000
98000	133200	124000	148000	154000	128000	163000
40000	75200	66000	90000	96000	70000	105000
120000	155200	146000	170000	176000	150000	185000

6.4 Storage Filter

With the leftover 10 combinations, given their number of batteries needed from the first filter on recharge rate, we can also calculate the storage for each batteries combination, and based on that we can process the filter using X and X for continuous and instantaneous batteries respectively. Similar to the price filter, the value that passes the filter will be highlighted, and the value that does not pass will not be filled.

With these three tables in hand, we can now filter more values. For example, we know that B1, B4, and B6 do not meet the requirements for storage, these 3 columns will be filtered out completely in the 6x6 table. Similarly, Bd and Be for Instantaneous will also be filtered out of the table. The remaining 4 combinations can be expressed as follows.

6.5 Ranking

Out of these four combinations of batteries, we can rank them based on their leftover budgets, as well as extra capacity. The combinations that has the higher amount of extra capacity will be better for the long term as battery starts decay after years of usage. We can multiply the leftover budget (budget - total price) times the average extra capacity (2 - (capacity1 + capacity2)/2) to calculate their rank values. Higher rank value means a better choice for

		4.066	Continuous	# of Batteries	Storage Constant		Capacity	Filter result
LG Chem 10	B1		5	4	8.8		35.2	2.164289228
LG Chem 6.5	B2		4.2	4	5.9		23.6	1.45105755
Tesla 1	B3		3.3	5	6.4		32	1.967535662
Tesla 2	B4		5	4	13.5		54	3.320216429
Sonnen 10	B5		8	3	10		30	1.844564683
Emphase	B6		1.28	13	3.36		43.68	2.685686178
		11.5	Instanteneous	# of Batteries	Storage Constnt		Capacity	
LG Chem 10	Ba		7	7	8.8		61.6	1.339130435
LG Chem 6.5	Bb		4.6	10	5.9		59	1.282608696
Tesla 1	Bc		3.3	14	6.4		89.6	1.947826087
Tesla 2	Bd		7	7	13.5		94.5	2.054347826
Sonnen 10	Be		12	4	10		40	0.8695652174
Emphase	Bf		1.92	24	3.36		80.64	1.753043478

	Continuous					
Instanteneous	B1*N1	B2*N2	B3*N3	B4*N4	B5*N5	B6*N6
Ba*Na	B1*N1+Ba*Na	B2*N2+Ba*Na	B3*N3+Ba*Na	B4*N4+Ba*Na	B5*N5+Ba*Na	B6*N6+Ba*Na
Bb*Nb	B1*N1+Bb*Nb	B2*N2+Bb*Nb	B3*N3+Bb*Nb	B4*N4+Bb*Nb	B5*N5+Bb*Nb	B6*N6+Bb*Nb
Bc*Nc	B1*N1+Bc*Nc	B2*N2+Bc*Nc	B3*N3+Bc*Nc	B4*N4+Bc*Nc	B5*N5+Bc*Nc	B6*N6+Bc*Nc
Bd*Nd	B1*N1+Bd*Nd	B2*N2+Bd*Nd	B3*N3+Bd*Nd	B4*N4+Bd*Nd	B5*N5+Bd*Nd	B6*N6+Bd*Nd
Be*Ne	B1*N1+Be*Ne	B2*N2+Be*Ne	B3*N3+Be*Ne	B4*N4+Be*Ne	B5*N5+Be*Ne	B6*N6+Be*Ne
Bf*Nf	B1*N1+Bf*Nf	B2*N2+Bf*Nf	B3*N3+Bf*Nf	B4*N4+Bf*Nf	B5*N5+Bf*Nf	B6*N6+Bf*Nf

the user, as it saved the most money and have a reasonable amount of extra capacity prepare for usage and decay. The rank values of the four combinations is as below.

Batteries	Price	Left Budget	Avg Extra Capacity	Rank
4B2 + 7Ba	87600	12400	0.6049060074	7500.834492
4B2 + 10Bb	91000	9000	0.633166877	5698.501893
3B5 + 7Ba	91600	8400	0.4081524412	3428.480506
3B5 + 10Bb	95000	5000	0.4364133108	2182.066554

As the rank value shows the best option if we only choose a battery for each type of category is to purchase four LG Chem 6.5 Battery for Continuous Energy Usage, and purchase 7 LG Chem 10 for Instantaneous Energy Usage.

7 Model Evaluation

7.1 Disadvantages

1. This model can be really complicated if we add more batteries into consideration, and use multiple battery for each category of instantaneous usage and continuous usage.
2. This model only focuses on battery allocations, and does not consider the factor of solar energy and electricity generated by solar panels.
3. This model generalized the usage of electrical appliances, and assume that the current usage is consistent with the future.

7.2 Advantages

1. This model is very accurate if given all the information, because the model covered all possible combinations of batteries, by go through filtering as well as ranking, the user will receive the best possible combinations.
2. This model is very efficient in terms of energy storage as the model specialize batteries for different type of electricity usage.
3. This model is very secure since we prepare the customers with in total of four days without any charge to the battery, in other word the customers won't have to worry about their electricity suddenly run off if there is 4 days continuously without any sunlight.

8 Conclusion

With this paper, we aimed to develop a model to choose the best storage solution for a 1600 ft^2 home. Also, to consider the type of batteries and their pros and cons. Some had larger capacities, some had longer lifetimes per cycle, and some were low maintenance. These were all factors to consider in choosing the ideal home battery. In answering the second question, we applied inputs into our mathematical model so it could function for other conditions; the budget and power consumption of appliances were some inputs used. Using these values, we compare different brand batteries like the Tesla Powerwall 2 to the inputs from the homeowner and try to find the most appropriate storage system. For the home given to us, we wrote down the least propitious circumstances. We assumed that the battery would need to run during winter and that the homeowner would use a majority of their home amenities every day. This created a big current draw, which really challenged the batteries' capacity and charge rate. These conditions left only the most reliable and sustainable batteries. The model that we presented was not very user-friendly, but fortunately, that wasn't a requisite for the paper. We also made a sorting algorithm called the TOT model for batteries that siphoned through many batteries and automatically found the best ones. It also ranked the top three batteries in the last layer of synthesizing, so we could see their various positive attributes.

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10 Appendix

10.1 Appendix [A]: The 4

The 4 is shown in various equation with: $E_{c,rate}, E_{I,rate}, E_{tot,rate}$, E_c, E_I, E_{tot}.
To start we will examine the storage equation:

$$1 < \frac{a_i \cdot (N_I)_i}{4E_I} < 2 \tag{28}$$

E_I is the energy consumed by instantaneous appliances and it is in units of days. In general any location would not receive sunlight everyday, meaning that we would need to store more energy to be prepared for these events.
Connecting back to the assumption of Solar panels we can assume that we will get a net energy after everyday, that net energy will eventually fill the extra battery space. So why 4? After doing some experimenting with numbers we found that 4 days of energy would suffice, greater would be too expensive, and too little could make the system not reliable.
Now we can look at the rate equations

$$Re_i \cdot (N_I)_i = 4E_{I,rate} \tag{29}$$

We had to include 4 to this equation because it is the first equation that gives all of the combinations, so without the 4 is would not provide any reasonable answers for the storage filter.

10.2 Appendix [B]: The battery table

Name	B_i	P_i (cost)	a_i (capacity)	Re_i (recharge rate / charge rate)	N_i (quantity of that battery)
LG Chem RESU10	B_1	P_1	a_1	Re_1	N_1
LG Chem RESU6.5	B_2	P_2	a_2	Re_2	N_2
Tesla Powerwall	B_3	P_3	a_3	Re_3	N_3
Tesla Powerwall 2	B_4	P_4	a_4	Re_4	N_4
Generac PWRcell	B_5	P_5	a_5	Re_5	N_5
Enphase Powerwall	B_6	P_6	a_6	Re_6	N_6
General case when referring to the battery	B_i	P_i	a_i	Re_i	N_i

10.3 Appendix [C]: Desmos Lattice points

We can use Desmos to find the lattice point values. Desmos would provide a table, and our algorithm would take the non negative lattice points. These values would then be inputted in Scenario 3's sub table inside of (Table 13.1).