Reduce, Reuse, Reengineer

Senior Research Project 2019

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Architectural Engineering

6/19/19

Table of Contents

Introduction

Our senior project is a research exploration of renewable energy. We recognized there is a major need in the world for the advancement of green power sources. For our project, we wanted to go beyond what we have learned in our Cal Poly architectural engineering classes and to use some of our own creativity to investigate the possibilities of renewable energy from a structural perspective. The guiding question we asked ourselves was, “as architectural engineering students, how could we shift our world to use more renewable energy?” To start our journey off, was the original inspiration from the work of a German structural engineer named Jörg Schlaich and his design for a renewable power source called solar updraft tower that we touched on in our History of Structures class.

History of the Solar Updraft Tower

In 1982, Schlaich Bergermann Partner, a German structural and solar engineering company, constructed the first solar updraft tower in Manzanares, Spain after receiving sufficient funding from the German Ministry of Research and Technology and the Spanish Utility Union Electrica Fenosa (see Figure 1.). The tower stood 640 feet (195 meters) tall made of corrugated steel with a plexiglass canopy base that stretched 800 feet (244 meters) in diameter. The tower tube was 32.8 feet (10 meters) wide in diameter. This prototype had a peak energy output of 50 kilowatts/hour and average output of 30 kilowatts/hour. It originally had a designed lifespan of three years, yet it held its ground for four extra years. Then in 1989, after being neglected of any maintenance, it collapsed from an intense windstorm. There have been many proposed solar updraft towers such as one in Australia that would stand 0.62 mile tall (1 kilometer) and have a base 6.2 miles (10 kilometers) in diameter (GROSE).

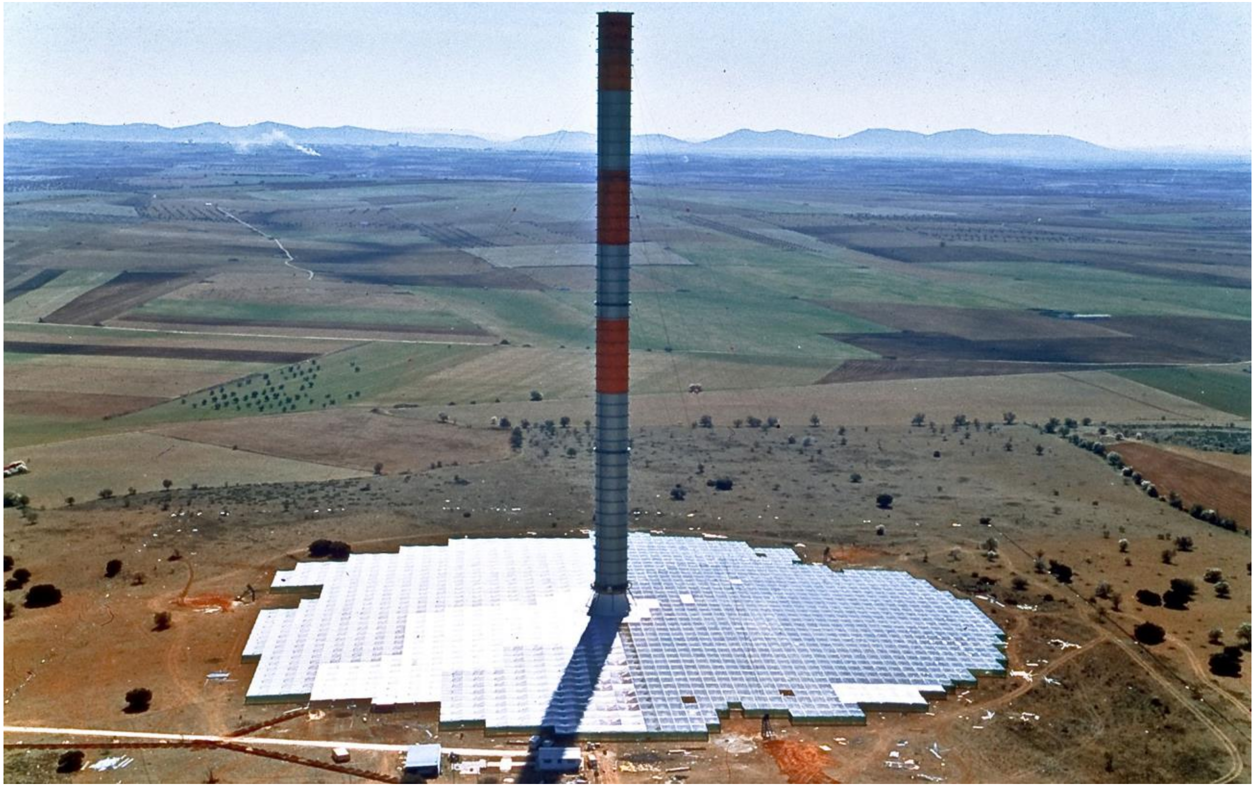


Figure 1. Solar Updraft Tower in Manzanares, Spain (GROSE)

Technology of the Solar Updraft Tower

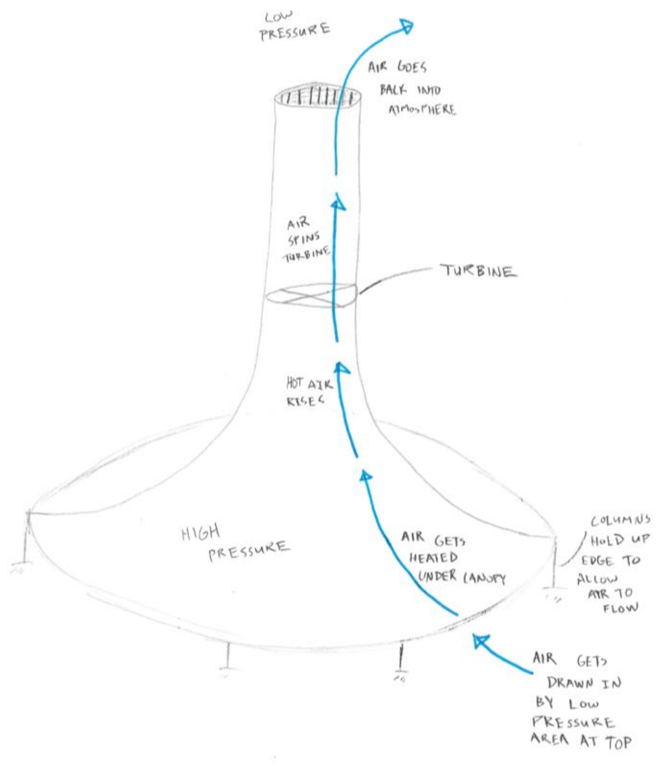


Figure 2. Solar Updraft Tower

What is a solar updraft tower and how does it work? A solar updraft is a renewable energy generator that produces electricity through a heat differential in the air. The updraft tower traps air heated by the ground underneath the glass or plexiglass canopy area at the base. The heated air tries to expand but the canopy traps in increasing the pressure. The air forces its way upward and out of the top of the tower to an area of less pressure, spinning the turbine and generating electricity as it passes through. This process can be seen in *Figure 2.* This process can continue even after the sun goes down, albeit with reduced efficiency, because the ground is still warmer than the air at the top of the tower. This nighttime efficiency can be increased by using pods of water to better store the thermal energy from the sun through the night.

Rethinking the Concept

One idea of a modification was to utilize water vapor instead of air. We thought water vapor would be better at propelling the turbine harder and faster. Since water vapor is denser than the other molecules of air, this added mass increases the force that spins the turbine. In turn, the faster spinning turbine would produce more electricity. We proposed a small modification to the original solar updraft tower (*Figure 2*), in that there would be a pond of water underneath the canopy base to collect the solar energy. The water from the base pool would then evaporate and rise to spin the turbine using the same principle as before of a heat differential. One draw back from this idea is that there would need to be a constant supply of water, but this could be countered by placing the structure above a reservoir or maybe even over a wastewater treatment plant's treatment ponds.

Solar Cycle Tower

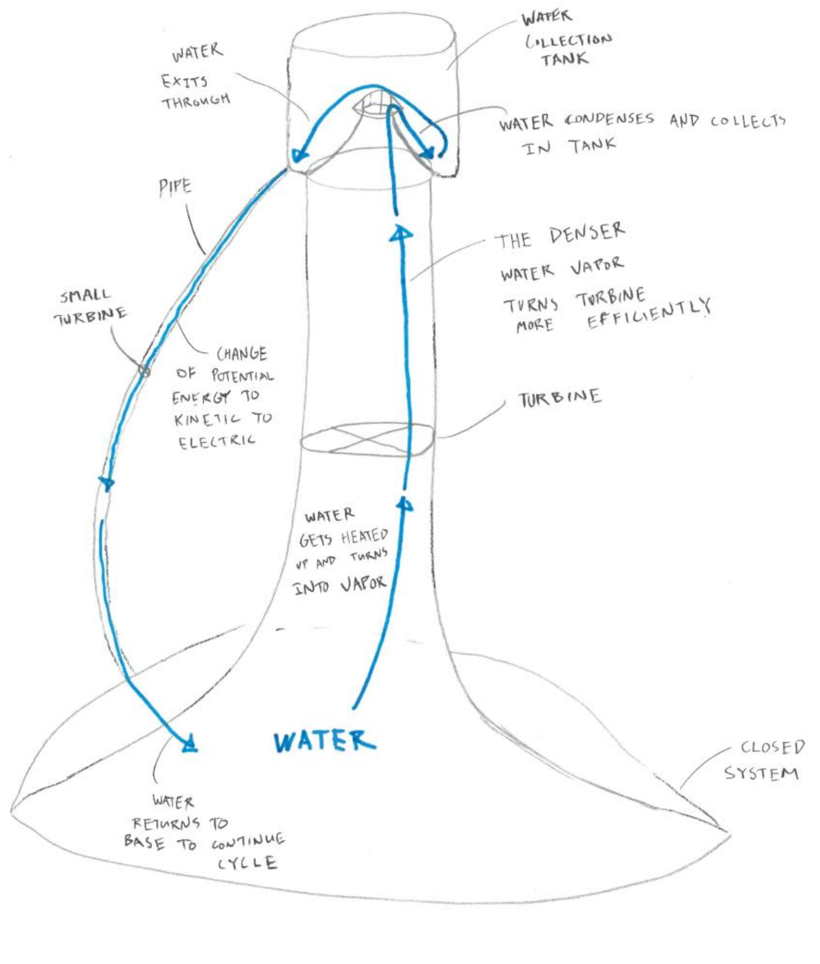


Figure 3. Solar Cycle Tower

The issue of constantly needing water got us thinking if it would be better to close the system from the environment (see *Figure 3*). Being a closed system would eliminate the resupply of water back into the tower, and the system can be placed in any environment, especially those areas of low rainfall. Thus, we created a new design we called the solar cycle tower based on the recycling of water, use of solar heat and shape of the system. With this setup, the water at the base of the tower would be heated up by sun rays causing the water to evaporate. This newly formed water vapor would rise up through the turbine generating electricity. After passing through the turbine, the water vapor would be collected in a tank at the top of the tower. This tank would condense the water vapor through a difference in temperatures of the vapor and walls of the tank. We imagined that the tank would be painted white and insulated to resist absorbing solar heat keeping the tank as cool as possible. We also proposed that we capitalize on the gravitational force of the water since the water was already up so high. So, a second turbine would be present for the condensed water flowing down to producing even more electricity. This water cycle combination would possibly almost double the power output compared to the previous solar tower. As a side thought, we believe that we could store some water in the tank to act as a tuned mass damper to help counteract seismic forces.

Interdisciplinary Collaboration

At this point in the project, we sought out the help of a third year Mechanical Engineering student studying at UC Davis named Garrett Robertson. We contacted him to act as a consultant on this project because we wanted someone with more expertise in this area. It was a very good thing that we did consult with him too. He pointed out a major problem with using water vapor. For turbines to be efficient and not corrode the turbine blades, the steam needs to be superheated, which would not really be possible using sunshine alone for energy input. There would need to be some supplemental power or material to heat the water to adequate temperature, thus this requirement would take away from the additional efficiency of using water in the first place. We did contemplate with the idea of using an alternative fluid that possessed a low boiling point than water, so we could ensure the system’s reliance on only sun rays. However, Garrett pointed out that there is minimal information on the material properties of these vapors. Therefore, we would have had to conduct these experimental function tests ourselves, which is out of the scope of our project and experience and would take considerable time, guidance, and funding we do not have at our disposal. So, we had to go back to the drawing board on our research.

Hydroelectric Gravity Battery

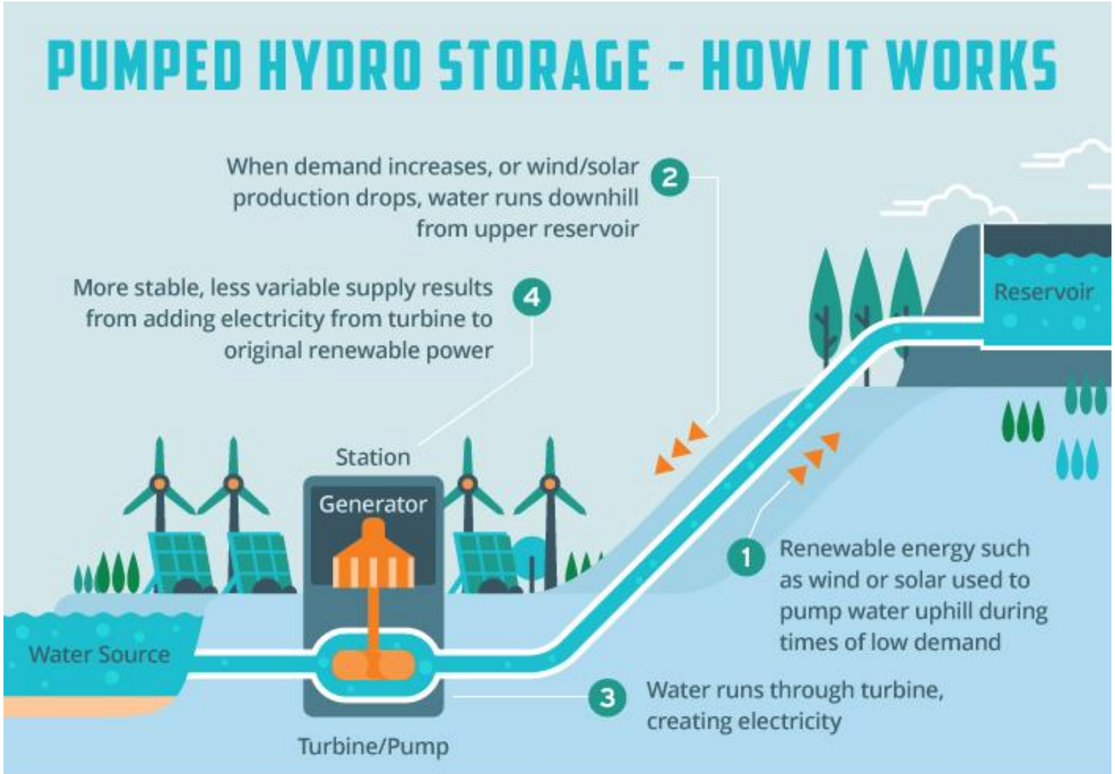


Figure 4. Pumped Hydroelectric Storage, Reservoir Example (Gilmore)

Pumped storage hydropower is another form of renewable energy that we came across through the course of our research. Pumped storage hydropower is a way to store excess energy produced during the day for use during peak electricity demand times, reducing the losses on the power grid. As can be seen in *Figure 4*, this is conventionally done on hilly or mountainous terrain with upper and lower water storage. The water can be pumped up when there is excess green energy or by a power station during low demand times. The water is then released at high demand times to reduce strain on the power grid. Pumped hydroelectric storage uses a difference in height between the two tanks (called head) to generate the pressure necessary to turn the turbine. Instead of using lithium battery storage plant with toxic chemicals, the water stores the surplus energy in the form of potential energy once it is raised in elevation. In essence, this method is a clean gravity battery.

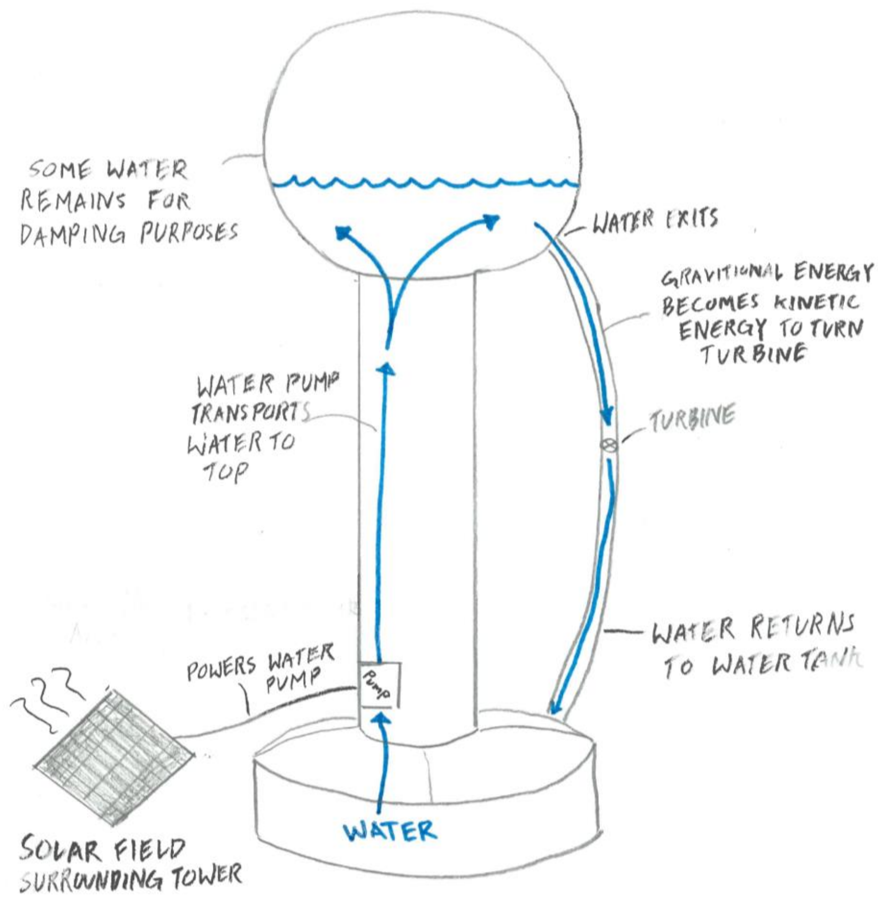


Figure 5. Hydroelectric Battery

We adapted the idea of pumped hydroelectric storage from the usual reservoir setup to instead be a tower, seen in *Figure 5*, that would act as our change in elevation, allowing places with a more level landscape to construct these towers as to not rely on the landscape to make a pumped storage hydropower plant feasible. These towers would require an energy input to power a water pump, which we thought could be a solar field built around the tower. One thing to consider though with pumping water up is the efficiency of the pump. Garrett pointed out that we would have approximately an 85% efficiency. Meaning that we would lose 15% of the energy that we were trying to store. We also would need many of these towers to store enough energy for a large population of people.

Terraforming Habitation

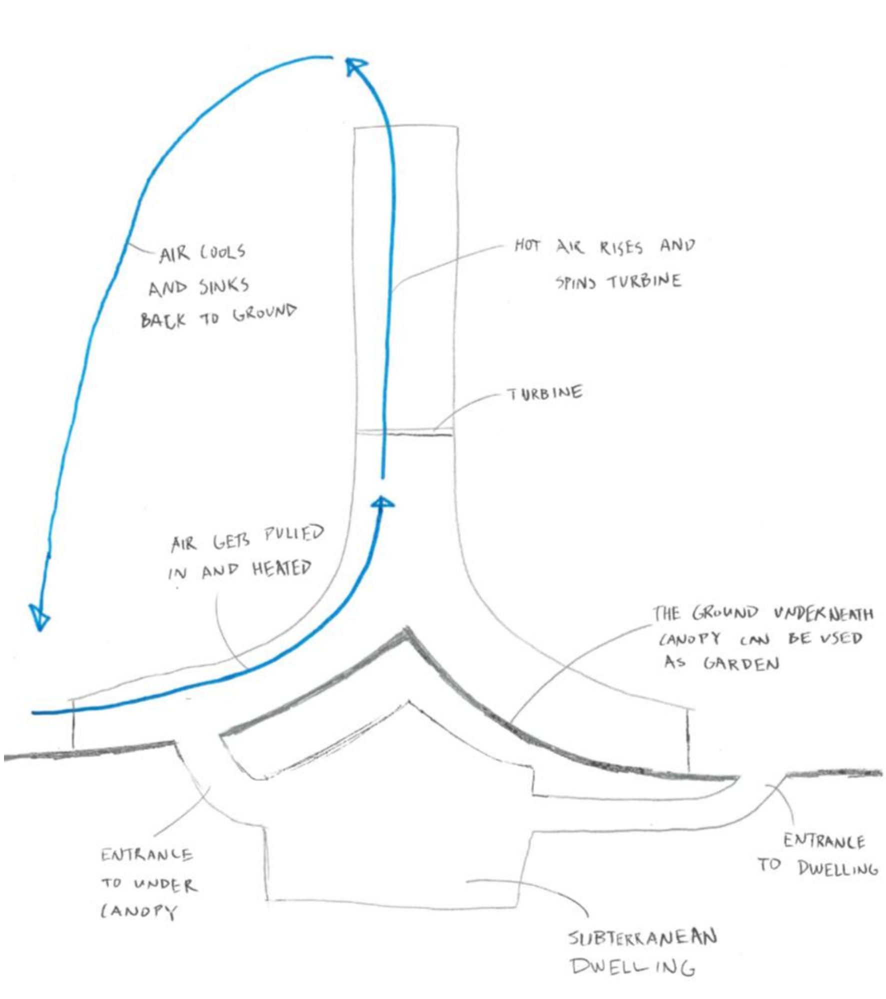


Figure 6. Terraforming Habitation

Another avenue we were researching that was based more off the solar updraft tower was terraforming. One interesting and unintended side effect of having a solar updraft tower over an area of soil is that the base canopy traps water vapor in the air under it and then forces it to condense. This increases the humidity dramatically changes the atmosphere of the original area by putting water back into the topsoil, which can make the land area underneath more fertile for plant life to flourish. In essence, the solar updraft tower canopy can transform the climate of an arid landscape into a more habitable one (which is the essence of terraforming). Obviously, this could be used to reclaim land that was previously too dry to grow plants. We again proposed, a modification to the solar updraft tower. This time it was to include a dwelling underneath the base structure to act as a home for people who could farm the land being terraformed under the canopy of the solar updraft tower (see *Figure 7* for more detail). We believed that we could optimize the land by providing three different uses: energy generation, crop cultivation and habitable space. This system would be ideal for parts of the world like the Sahara, where there is a need for building developments. It can also contribute to the African Union efforts to make the "Great Green Wall", which is an initiative to change the present desert landscape into farmable land (Monks).

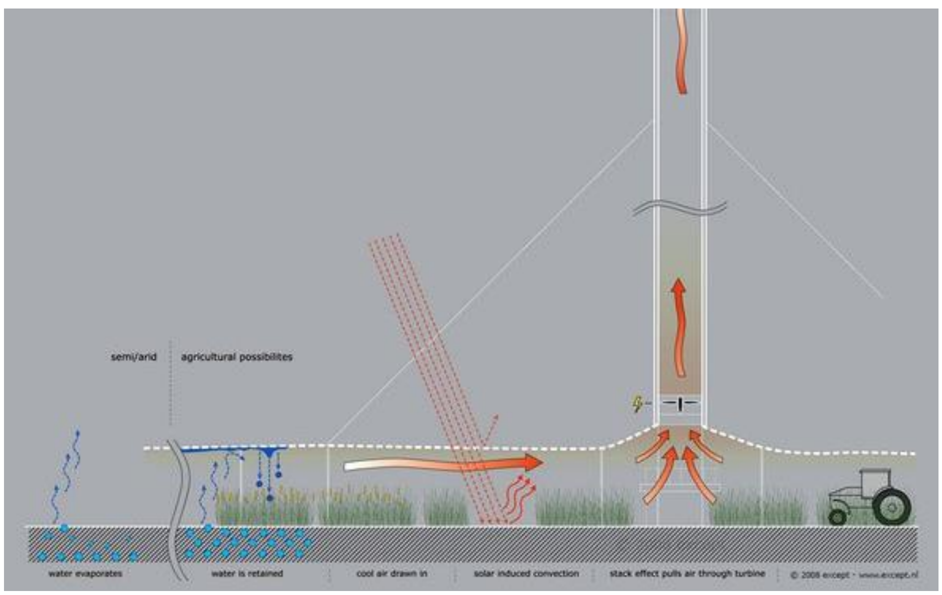
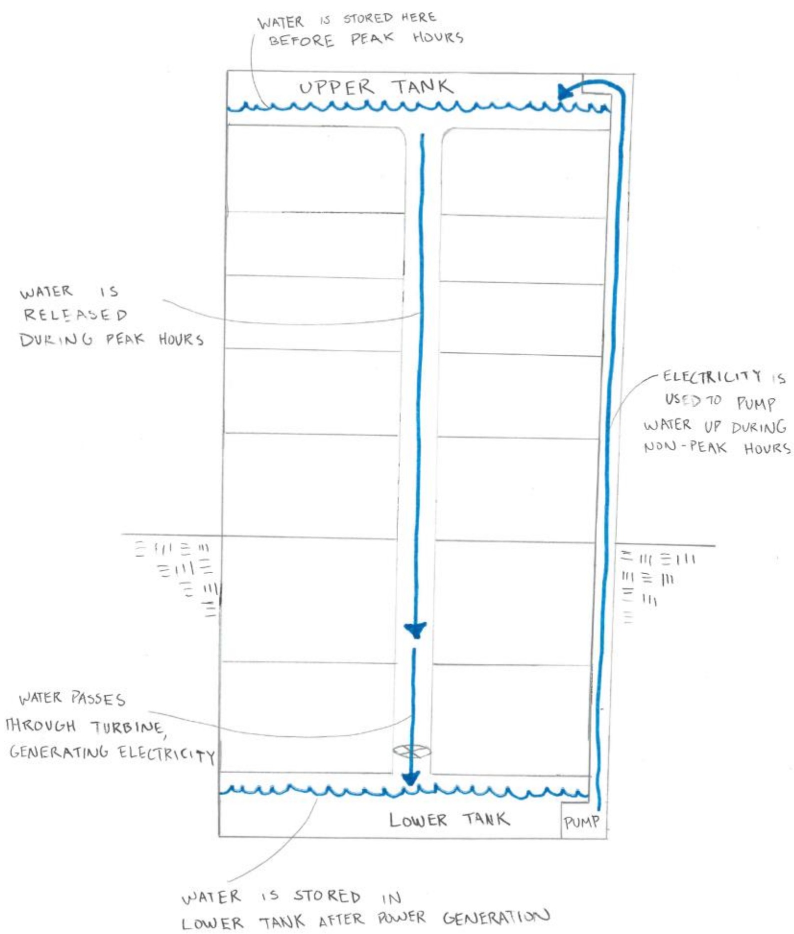


Figure 7. Cross Section of Terraforming in Action (Bosschaert)

Some problems we considered were the habitability of the subterranean structure and the price of the structure. In order to keep the inhabitants happy and healthy, we would need to bring in natural light. By having skylights in the ground we would be decreasing the efficiency of the solar updraft tower. The price of the solar updraft tower alone is very high and if added to the cost of making the subterranean dwelling, the people we were hoping to benefit most from this would have a lot of trouble finding funding.

Integrated Hydroelectric Battery



[Dimensions: 250 feet by 280 feet (total: 70,000 square feet) and 8 stories at 15 feet (120 feet high)]

Figure 8. Integrated Hydroelectric Battery

Returning to our roots as architectural engineering students, we circled back to a building. We wanted to combine what we had learned from the terraforming habitation and combine it with the stored hydroelectric battery. We liked the idea of the integration of renewables into everyday life and believed stored hydroelectric battery was promising system. What we came up with is called the integrated hydroelectric battery based on the use of water to generate electricity, storing energy from another power source and this hydroelectric storage system being present within a building. The integrated hydroelectric battery is supported by an openly configurable structure and harnesses the gravitational energy of water as a supplementary source of electric energy (see *Figure 8*). The floor plan of the building portion of the integrated hydroelectric battery is open to most any occupancy that the owner or architect wants to tailor to satisfy the end consumers, whether the occupancy be affordable housing or vertical farming to name a few options. The integrated hydroelectric battery consists of five key parts: the lower tank, upper tank, pump, turbine and the structure supporting them all. The lower tank is located at the same level of the building's foundation and is the starting point in the water's cycle. Water travels up the height of the building by way of the pump, which is powered by excess renewable energy or by the power grid during the time of off peak demand. Once the water reaches the top of the structure, the upper tank holds it until a sufficient amount of water is present for power generation. Water is then released from the upper tank spinning a turbine producing electricity when the energy source is idle or during the peak demand time of the day. After that, the water returns to the lower tank, where it is stored and waits for the next power cycle to begin the next day.

When we mentioned off-peak and peak demand, we are referring to the Time Of Use (TOU) plan that is offered by electric utility companies like Pacific Gas & Electric and Southern California Edison. TOU plans are electricity rate plans that have different pricing throughout the day based on the overall power demand. This will be explained in detail in the Energy Cost Analysis section. For our project, we modeled the integrated hydroelectric battery to work with the prime version of time of use plan (TOU-D-PRIME) as a cost saving measure. What is meant by cost saving measure is that the system would only power the building during peak demand times from the power grid when energy is most expensive, and not during the entire night when many renewable energies lose the ability to produce electricity. We decided to have the integrated hydroelectric battery act like this because there would need to be a very large green energy area to power the building and the pumps, and we were worried about the weight of the water being too great if we stored enough for 12 hours. Reason being is the amount of the water is proportional to the energy produced by the battery and the large weight of the water would threaten the stability and yield strength of structure supporting the top water tank. We proposed and analyzed a structure that could have solar on the roof, but we decided against pursuing this combination of the integrated hydroelectric battery and solar panels because we wanted to prove our energy storage system works on its own. However in the future, our system can be combined with any power generating sources like solar panels or wind turbines.

Our model for the integrated hydroelectric battery building that we started out with was a 6 story mixed-use building with 2 levels of underground parking that would be constructed with steel framing. The conceptual structure had a footprint of 70,000 square feet. We estimated that the integrated hydroelectric battery would cost an extra 15-20% of the construction cost on top of the original construction cost. The high expense is due to it being a new experimental design and heavy water loading. Exact dollar values were difficult to estimate because of the myriad of variables like land cost, labor, equipment, government and city fees, etc. Yet, our concept can be created with widely available materials due to the simplicity. Constructability of the integrated hydroelectric battery is possible and the massive water load of the prototype would be accounted for in the design process. The gravity load of the water was about 1.5 ksf *(Figure 15)*, which would require larger columns and deeper beams than usually prescribed by structural engineers, but would take approximately 34 years to have paid for itself { ($150/SF * (70000 SF *6) * .15))/ $273,915/year) =45.9 years} . (In this estimation we took the average price per square foot multiplied by the square footage of our building times the number of floors, then divided by savings per year from Figure12) In later thoughts of the design, we pictured that the upper tank could be supported by a space frame to save on weight and have longer span lengths than regular wide flange beams. Also, the upper tank of our structure could be utilized as a sloshed tuned damper if a sufficient level of water remained in the tank and servo fins were installed inside the tank to delay the movement of water during a seismic event, acting as a tuned sloshing damper. This type of water damper was proposed and implemented in the One Rincon condo tower in San Francisco, California (Nolte). We also realized that the weight of water can be decreased if we proportionally increased the overall height of the system allowing the water to have more force in propelling the turbine. This would mean a taller building with a smaller square footage would be more efficient at using the integrated hydroelectric battery because it uses less water and created more electricity due to the greater height difference. We had several avenues to explore, but for the sake of this study, we were interested in investigating if the integrated hydroelectric battery would do what it was intended to accomplish, which was to save money on electricity.

Energy Cost Analysis

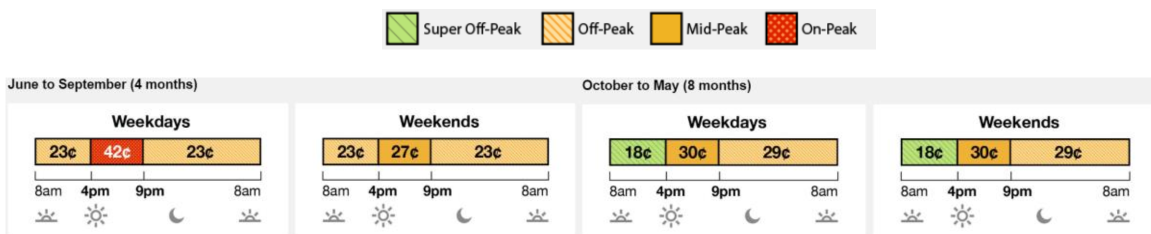


Figure 9. TOU-4-9PM Pricing (“Time-Of-Use Residential Rate Plans”)

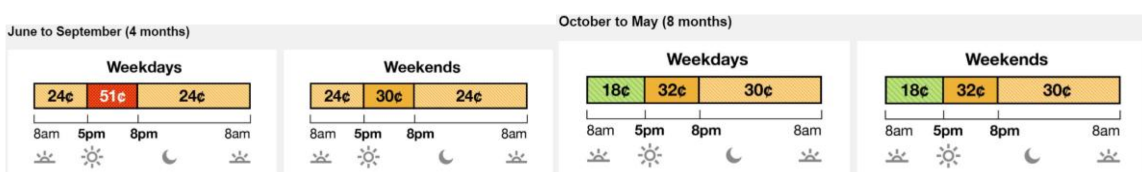


Figure 10. TOU-4-8PM Pricing (“Time-Of-Use Residential Rate Plans”)

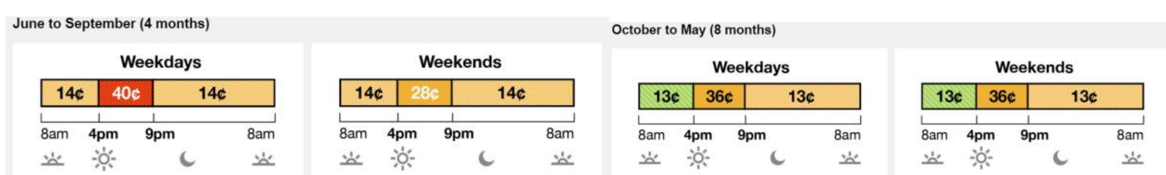


Figure 11. TOU-D-PRIME Pricing (“Time-Of-Use Residential Rate Plans”)

For electric rate pricing, we decided to look at Southern California Edison plans, in order to keep different energy companies different pricings from being a factor in our energy cost evaluation. Southern California Edison provides four different plans: TOU-D-4-9PM, TOU-D-5-8PM, TOU-D-PRIME, and their Tiered Plan. All the TOU plans have times of the day where there is a peak, for demand as well as price. They also have periods of the day where there is off-peak demand and pricing. Our integrated hydroelectric battery system is designed to pump water up during these off-peak times, therefore avoiding the substantial price increase that comes with using electricity during peak times. Each TOU plan has its own pricing for both summer and winter, and can even have a different peak length, as can be seen in *Figure 9-Figure 11*. We also looked at the older Tiered plan which is just a set price based off of kW usage, but this plan would not benefit from our system because we are using about 15% more energy than the TOU-D-PRIME plan since the pump is not 100% efficient.

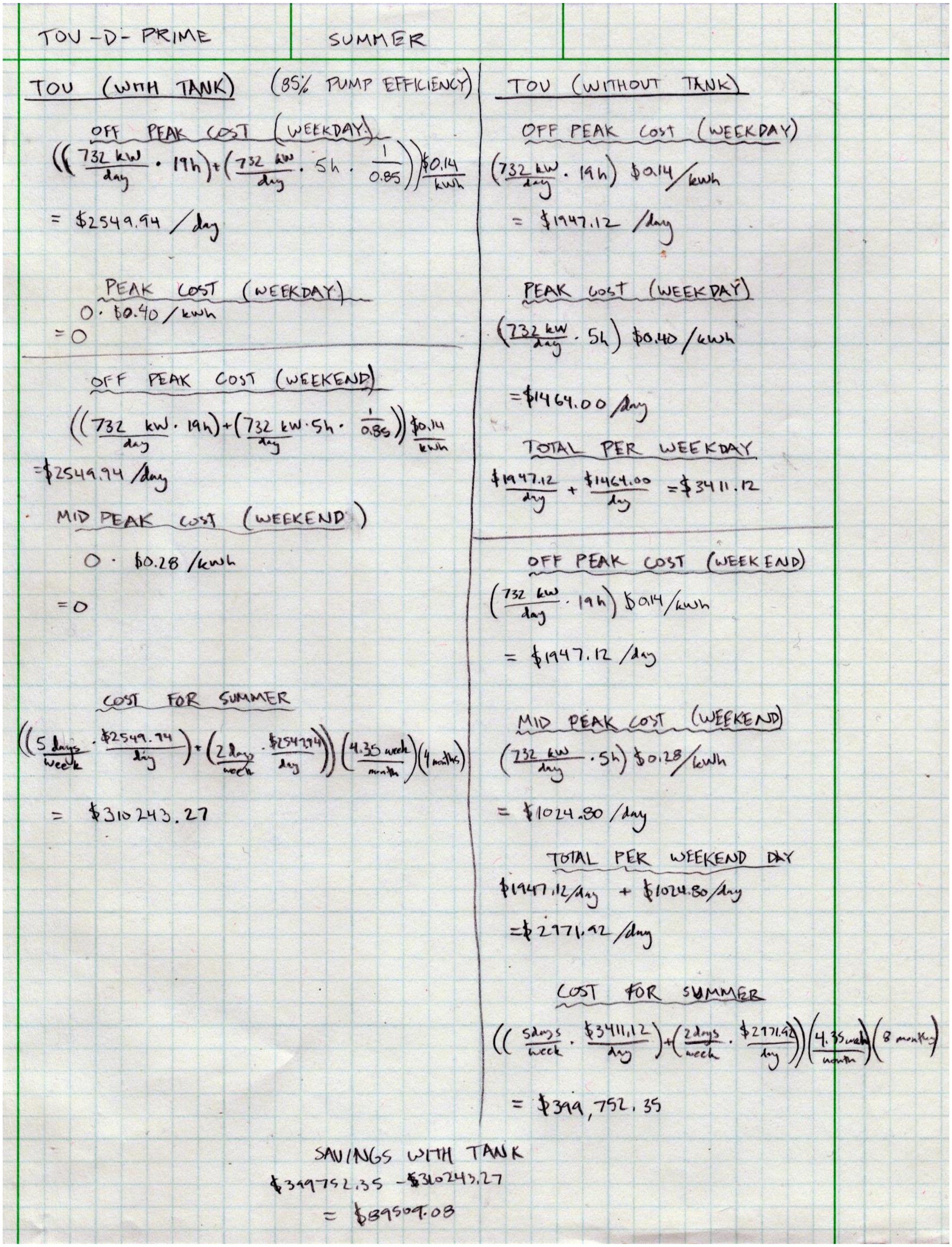
The TOU-D-PRIME plan is for customers that have some form of energy storage that can shift their usage to lower demand times. This plan is the ideal plan for our system, and we found TOU-D-PRIME to be the most cost effective for our building when compared to the other TOU plans as well as the Tiered plan, saving upwards of $270,000 a year when compared to the same and other TOU plans without the integrated hydroelectric battery.

BUILDING USAGE			**TOTAL COST WITH T.**	**$**	**886,409.33**
732	KW/DAY				
PUMP EFFICIENCY			**TOTAL SAVINGS PEF**	**$**	**273,915.75**
0.85					

SUMMER					
TOU 1 (WITH TANK)			TOU 1(WITHOUT TANK)		
WEEKDAYS			WEEKDAYS		
5	HOURS OF FLOW		0	HOURS OF FLOW	
TIME OF DAY	# OF HOURS	PRICE	TIME OF DAY	# OF HOURS	PRICE
OFF PEAK (9PM-4PM)	19	$ 0.14	OFF PEAK (9PM-4PM)	19	$ 0.14
COST			COST		
$ 2,549.94			$ 1,947.12		
PEAK (4PM-9PM)	5	$ 0.40	PEAK (4PM-9PM)	5	$ 0.40
COST			COST		
$ -			$ 1,464.00		
TOTAL PER WEEKDAY	$	2,549.94	TOTAL PER WEEKDAY	$	3,411.12
WEEKENDS			WEEKENDS		
5	HOURS OF FLOW		0	HOURS OF FLOW	
TIME OF DAY	# OF HOURS	PRICE	TIME OF DAY	# OF HOURS	PRICE
OFF PEAK (9PM-4PM)	19	$ 0.14	OFF PEAK (9PM-4PM)	19	$ 0.14
COST			COST		
$ 2,549.94			$ 1,947.12		
MID PEAK (4PM-9PM)	5	$ 0.28	MID PEAK (4PM-9PM)	5	$ 0.28
COST			COST		
$ -			$ 1,024.80		
TOTAL PER WEEKEND DA	$	2,549.94	TOTAL PER WEEKEND D.	$	2,971.92
SUMMER		4 MONTHS	SUMMER		4 MONTHS
TOTAL PER 4 MONTHS	$	310,243.27	TOTAL PER 4 MONTHS	$	399,752.35
			TOTAL SAVINGS (SU	**$**	**89,509.08**

WINTER					
TOU 1 (WITH TANK)			TOU 1(WITHOUT TANK)		
WEEKDAYS			WEEKDAYS		
5	HOURS OF FLOW		0	HOURS OF FLOW	
TIME OF DAY	# OF HOURS	PRICE	TIME OF DAY	# OF HOURS	PRICE
SUPER OFF PEAK (8AM-4F	8	0.13	SUPER OFF PEAK (8AM-4PM)	8	0.13
COST			COST		
$ 1,321.04			$ 761.28		
MID PEAK (4PM-9PM)	5	0.36	MID PEAK (4PM-9PM)	5	0.36
COST			COST		
$ -			$ 1,317.60		
OFF PEAK (9PM-8AM)	11	0.13	OFF PEAK (9PM-8AM)	11	0.13
COST			COST		
$ 1,046.76			$ 1,046.76		
TOTAL PER WEEKDAY	$	2,367.80	TOTAL PER WEEKDAY	$	3,125.64
WEEKENDS			WEEKENDS		
5	HOURS OF FLOW		0	HOURS OF FLOW	
TIME OF DAY	# OF HOURS	PRICE	TIME OF DAY	# OF HOURS	PRICE
SUPER OFF PEAK (8AM-4F	8	0.13	SUPER OFF PEAK (8AM-4PM)	8	0.13
COST			COST		
$ 1,321.04			$ 761.28		
MID PEAK (4PM-9PM)	5	0.36	MID PEAK (4PM-9PM)	5	0.36
COST			COST		
$ -			$ 1,317.60		
OFF PEAK (9PM-8AM)	11	0.13	OFF PEAK (9PM-8AM)	11	0.13
COST			COST		
$ 1,046.76			$ 1,046.76		
TOTAL PER WEEKEND DAY	$	2,367.80	TOTAL PER WEEKEND DAY	$	3,125.64
WINTER		8 MONTHS	WINTER		8 MONTHS
TOTAL PER 8 MONTHS	$	576,166.06	TOTAL PER 8 MONTHS	$	760,572.73
			TOTAL SAVINGS (WINTER)	**$**	**184,406.67**

Figure 12. TOU-D-PRIME Cost Analysis of Proposed Building



TOU-D-PRIME SUMMER

TOU (WITH TANK) (85% PUMP EFFICIENCY)

OFF PEAK COST (WEEKDAY)

$$\left(\left(\frac{732\ kW}{day}\cdot 19h\right)+\left(\frac{732\ kW}{day}\cdot 5h\cdot\frac{1}{0.85}\right)\right)\frac{\$0.14}{kWh}$$

$= \$2549.94\ /day$

PEAK COST (WEEKDAY)

$0\cdot \$0.40\ /kWh$

$=0$

OFF PEAK COST (WEEKEND)

$$\left(\left(\frac{732\ kW}{day}\cdot 19h\right)+\left(\frac{732\ kW}{day}\cdot 5h\cdot\frac{1}{0.85}\right)\right)\frac{\$0.14}{kWh}$$

$= \$2549.94\ /day$

MID PEAK COST (WEEKEND)

$0\cdot \$0.28\ /kWh$

$=0$

COST FOR SUMMER

$$\left(\left(\frac{5\ days}{week}\cdot\frac{\$2549.94}{day}\right)+\left(\frac{2\ days}{week}\cdot\frac{\$2549.94}{day}\right)\right)\left(\frac{4.35\ week}{month}\right)(4\ months)$$

$= \$310243.27$

TOU (WITHOUT TANK)

OFF PEAK COST (WEEKDAY)

$$\left(\frac{732\ kW}{day}\cdot 19h\right)\$0.14/kWh$$

$= \$1947.12\ /day$

PEAK COST (WEEKDAY)

$$\left(\frac{732\ kW}{day}\cdot 5h\right)\$0.40\ /kWh$$

$= \$1464.00\ /day$

TOTAL PER WEEKDAY

$$\frac{\$1947.12}{day}+\frac{\$1464.00}{day}=\$3411.12$$

OFF PEAK COST (WEEKEND)

$$\left(\frac{732\ kW}{day}\cdot 19h\right)\$0.14/kWh$$

$= \$1947.12\ /day$

MID PEAK COST (WEEKEND)

$$\left(\frac{732\ kW}{day}\cdot 5h\right)\$0.28/kWh$$

$= \$1024.80\ /day$

TOTAL PER WEEKEND DAY

$\$1947.12/day + \$1024.80/day$

$= \$2971.92\ /day$

COST FOR SUMMER

$$\left(\left(\frac{5\ days}{week}\cdot\frac{\$3411.12}{day}\right)+\left(\frac{2\ days}{week}\cdot\frac{\$2971.92}{day}\right)\right)\left(\frac{4.35\ week}{month}\right)(8\ months)$$

$= \$399,752.35$

SAVINGS WITH TANK

$\$399752.35 - \$310243.27$

$= \$89509.08$

Figure 13. TOU-D-PRIME Cost Analysis of Proposed Building-Hand Proof

This explanation Figure 13 is to show how we set up our Excel sheets to get cost values and then compare them.

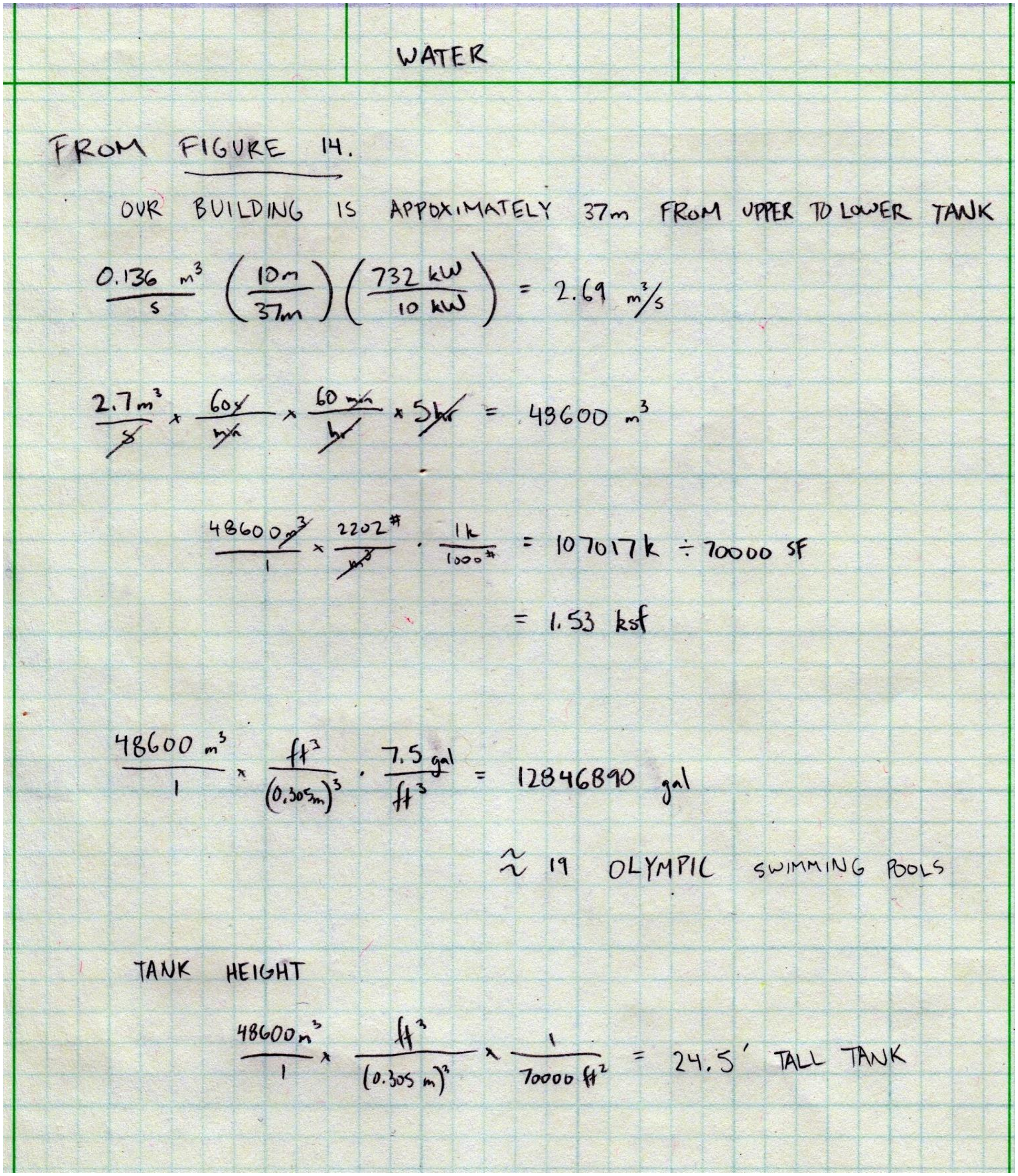
1. *Starting with the TOU (WITH TANK) side (the left column OFF PEAK COST (WEEKDAY)) we took our building's kW usage multiplier by the number of hours of non-peak usage {732kW/day *19 hours}. We added that to the extra cost during this time to power the pump that would get the water up to the height necessary to generate electricity for the peak demand time of 5 hours. To get the energy needed to pump for 5 hours week took the power usage, multiplied it by the hours of use , as well as 1 over the pump efficiency to increase the power usage to account for the losses in the system.*
2. *For PEAK COST (WEEKDAY), there are no hours during peak demand which our building is using energy so the hours are zero and therefore the cost from this part of the day is zero.*
3. *We repeated this same process of 1 and 2 for WEEKENDS.*
4. *To total up the cost for the summer we took the price/day for WEEKDAYS and WEEKENDS and multiplied them by the number of days per week each of these are (5 days/week for WEEKDAYS and 2days/week for WEEKENDS). Then we multiplied by the average number of weeks per month (4.35weeks/month) and the number of months that are considered the Summer by Southern California Electric (4 months).*
5. *The TOU (WITHOUT TANK) is simpler, we just took the same process from 1 and took out the part with the pump efficiency and redistributed the hours that the pump would have covered to the peak pricing.*
6. *Following step 4 again, we got a total for the summer cost and then took that number and found the difference between the two ($89509.08).*

	Maximum Power Output (kW)				
	5	10	25	50	100
Head (m)	Flow required (m^3/sec)				
2	0.340	0.680	1.699	3.398	6.796
5	0.136	0.272	0.680	1.359	2.718
10	0.068	0.136	0.340	0.680	1.359
50	0.014	0.027	0.070	0.136	0.272
100	0.006	0.014	0.034	0.068	0.136

Minimum flow rates required for a range of (gross) heads.

Figure 14. Water Flow Rates

This table shows the flow rate of water necessary given a height change (head) and a desired power output (kW). This chart shows that the water rates are linearly proportional, so one can find the flow rate of water for any head height and any desired power output. This process can be seen in figure 15.



WATER

FROM FIGURE 14.

OUR BUILDING IS APPOXIMATELY 37m FROM UPPER TO LOWER TANK

$$\frac{0.136\ m^3}{s}\left(\frac{10m}{37m}\right)\left(\frac{732\ kW}{10\ kW}\right) = 2.69\ m^3/s$$

$$\frac{2.7m^3}{s} \times \frac{60s}{min} \times \frac{60\ min}{hr} \times 5hr = 48600\ m^3$$

$$\frac{48600\ m^3}{1} \times \frac{2202\#}{m^3} \cdot \frac{1k}{1000\#} = 107017k \div 70000\ SF$$

$$= 1.53\ ksf$$

$$\frac{48600\ m^3}{1} \times \frac{ft^3}{(0.305m)^3} \cdot \frac{7.5\ gal}{ft^3} = 12846890\ gal$$

$\approx$ 19 OLYMPIC SWIMMING POOLS

TANK HEIGHT

$$\frac{48600m^3}{1} \times \frac{ft^3}{(0.305\ m)^3} \times \frac{1}{70000\ ft^2} = 24.5'$$ TALL TANK

Figure 15. Water Properties for Proposed Building

1. *Taking the 10 meter head/10kW output flow rate from Figure 14 (0.136m3/s) we converted that flow rate using our building height of 37 meters and our 732 kW demand as a ratio to 10m head/10kW output.*

2. *Using the new flow rate we converted it into a per hour flow rate by multiplying by seconds per minute and then minutes per hour. We then multiplied by the amount of time the tank would need to supply water to generate electricity during peak times which is 5 hours for the Prime plan in order to find the volume of water necessary..*
3. *Then we took that volume and multiplied by the density of water (2202#/m3), and then converted to kips from pounds to get the weight of the water necessary for 5 hours of energy generation. We then divided by the square footage of the building (70000 SF) to find the distributed load on the building in kips/square foot.*
4. *Taking the volume we calculated earlier, we converted it into cubic feet, and then into gallons of water. We then took those gallons and divided by 660253 gallons/per olympic swimming pool*

   *{12846890gal * ((1 olympic pool)/ 660253gallons)=19.4 olympic pools}*
5. *Again we took the volume of water necessary for 5 hours of energy generation, and again converted to cubic feet to then divide by the building's square footage of 70000 SF to determine the height of the tank in feet.*

Competition Comparison

Conducting due diligence, we did look into other energy storage devices. One of which was Tesla Powerwall. The Tesla Powerwall is a large lithium ion "battery that stores solar energy so you can use it on demand and self-power your home to reduce your reliance on grid electricity. In the event of a grid outage, Powerwall automatically provides backup power or easily integrates with solar to ensure your home is powered 24/7. With Powerwall, you are assured of energy security and a clean energy lifestyle" ("Tesla Powerwall"). Tesla is well known for its innovative products, but this one does have drawbacks as well. Unknown to most people, lithium ion batteries are a nonrecyclable material. Over the course of using and recharging the lithium ion batteries countless times, the lithium loses its electricity storage capacity. Once the lithium ion battery loses its ability to charge, it cannot be renewed and there is no alternative use for it as a disposal material currently. So, its final destination is landfills. Furthermore, Tesla warranties their Powerwall at only 10 years. We estimated that the integrated hydroelectric battery will withstand the life of the whole building, which is approximately 50 years. This saves on the cost of periodically replacing the battery and the integrated hydroelectric battery has a larger capacity of power generation than the Powerwall. Not to mention, the extraction and refinement of lithium that the Powerwall is comprised of is harmful for the environment. Lithium ion mining around world devastates the landscape around the world from Asia to South America. For example,

> In May 2016, hundreds of protestors threw dead fish onto the streets of Tagong, a town on the eastern edge of the Tibetan plateau. They had plucked them from the waters of the Liqi river, where a toxic chemical leak from the Ganzizhou Rongda Lithium mine had wreaked havoc with the local ecosystem.There are pictures of masses of dead fish on the surface of the stream. Some eyewitnesses reported seeing cow and yak carcasses floating downstream, dead from drinking contaminated water. It was the third such incident in the space of seven years in an area which has seen a sharp rise in mining activity, including operations run by BYD, the world' biggest supplier of lithium-ion batteries for smartphones and electric cars. After the second incident, in 2013, officials closed the mine, but when it reopened in April 2016, the fish started dying again. (Katwala)

It is clear that mining for lithium is very dangerous for the environment but also the way lithium is separated from other heavy metals is also very harmful. It takes

> approximately 500,000 gallons [of water] per tonne of lithium. In Chile's Salar de Atacama, mining activities consumed 65 per cent of the region's water. That is having a big impact on local farmers – who grow quinoa and herd llamas – in an area where some communities already have to get water driven in from elsewhere. There's also the potential – as occurred in Tibet – for toxic chemicals to leak from the evaporation pools into the water supply. (Katwala)

Figure 16. Evaporation Pool of Salar de Atacama, Chile (Katwala)*

From *Figure 16* above, you can see the vivid hues from the heavy metals and acid floating in the pools of contaminated water. If these evaporation pools leak out to the rest of the surroundings, it poisons virtual everything making it unusable for consumption and irrigation. Similar operations to these ones in China and Chiles are present in Argentina, Bolivia, Brazil, Zimbabwe, Australia and even in the U.S. Obviously, we want to reduce pollution like this. That is why the integrated hydroelectric battery is significantly less hazardous because we are not requiring rare materials and instead are using readily obtainable competents for all of the parts of the integrated hydroelectric battery. Overall, we believe our integrated hydroelectric battery has an edge over lithium ion battery when weighting all the large scale costs financially and environmentally.

Vision for the Future

We hope that our senior project will encourage others to push the boundaries of green energy possibilities further to make the world cleaner and less dependent on fossil fuels. By creating and analyzing these concepts, we wanted to bring awareness to renewable energy storage and show that more research and experimentation in this field is almost as important as green power generation if a completely green energy powered future will be reached. We hope greener communities will be created because of the energy cost savings of our integrated hydroelectric battery and eventually transition from merely a cost savings technique to a complete nighttime storage of green energy. The integrated hydroelectric battery and other energy storage systems will assist in increasing the effectiveness of renewables by way of providing constant energy to consumers. In the future, we envision that cities will be solely powered by renewable energy sources working in tandem with our energy storage system.

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