Assessing the Viability of Onsite Non-Battery Power Storage for Sustainable Design

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1.0 Introduction

Photovoltaic energy generation is a primary strategy in sustainable design, however storing the electricity for use during non-producing times poses an added challenge. Currently batteries are the most popular solution to this problem, however their cost, and the negative environmental impact of their lifecycle, are significant drawbacks. Storing electrical energy as hydropower (or other forms of gravitational potential energy), compressed air, thermal energy, or as hydrogen gas, are all technologically available alternatives to chemical batteries. Although some of these methods have been applied for centralized energy storage at grid scale, this has not translated to smaller scale implementation. Determining if any of these systems could be a competitive alternative to batteries for onsite power storage, both economically and environmentally, can increase opportunities for sustainability. It is the hope that if any of these alternative methods proves viable, further research could be conducted in creating prototypical systems to asses efficiency, cost, and lifecycle impact in situ. Subsequent refinement of system parts could be achieved by modifying components for the specific application of energy storage improving performative criteria for cost, efficiency and impact.

2.0 Background and Significance

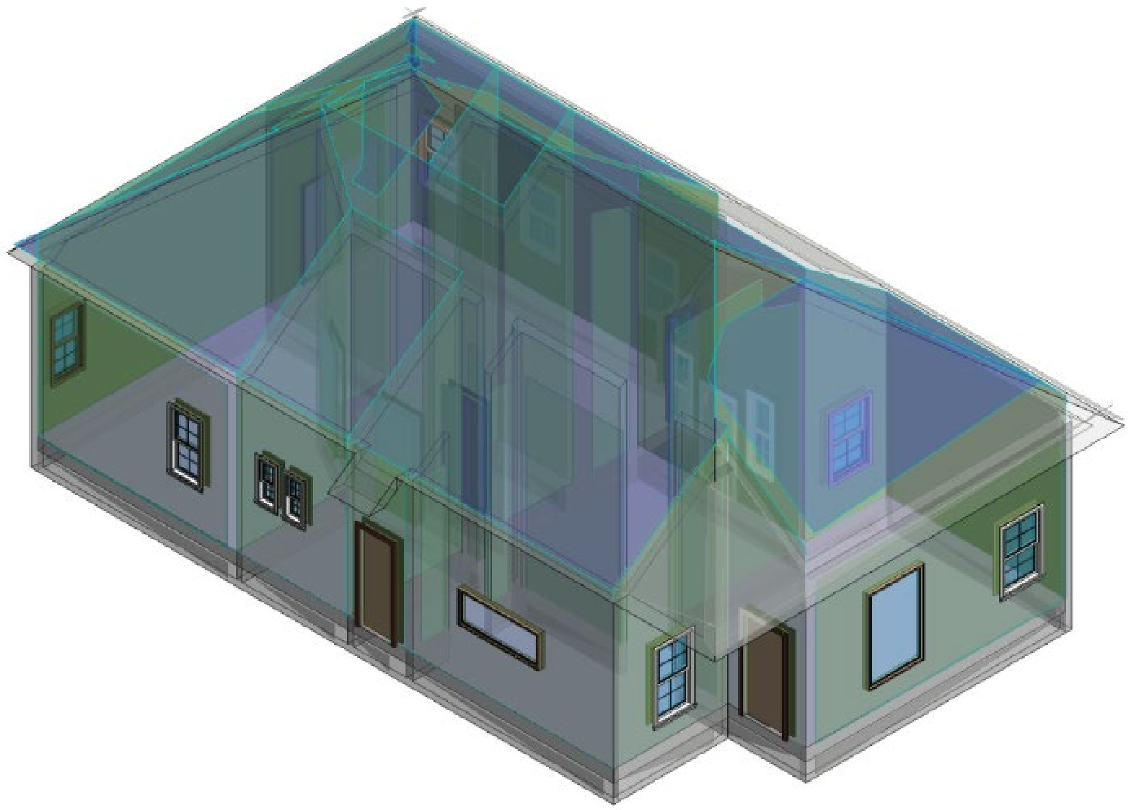
Storing energy from photovoltaics for non-producing periods is a pressing challenge for sustainable energy production and use. Currently this problem is solved through batteries or gird-interconnection. In addition to being a cost-limiting component for on-site solar, batteries area challenge for the implication for solar because of their relatively short life-cycle. After multiple charging cycles current Li Ion based batters diminish in efficiency. These batteries (as well as Lead Acid, NiCad and other configurations for chemical based electrical storage) all have significant life cycle impacts. Because of their lifespan, batteries must be recycled or disposed. In addition, the mining of researches such as Lithium for batteries from across the globe creates multiple ecological hazards. Finally, the production and disposal of batteries with these toxic metals as well as strong acids creates many hazards for human health during the production and disposal phase of batteries' lives (Kan, 2013), (Notter, 2010).

Alternately though interconnection, Individual users share surplus power with the main grid. They then draw form the grid during non-producing hours. Currently many power grids, including Los Angeles PG&E, draw heavily from fossil fuels. The large-scale production of sustainables at wind and solar farms is also confronted by similar issues of temporal variability. Surplus energy from these systems must also be stored on a massive scale. Some of these mass storage systems rely on Pumped-Hydro-Energy Storage or Compressed Air Energy Storage (CAES) to sequester power for later use (Xing, 2015). However, the long-range transportation of power through high voltage lines results in large losses of efficiency and poses numerous hazards, having caused numerous deadly wildfires in California.

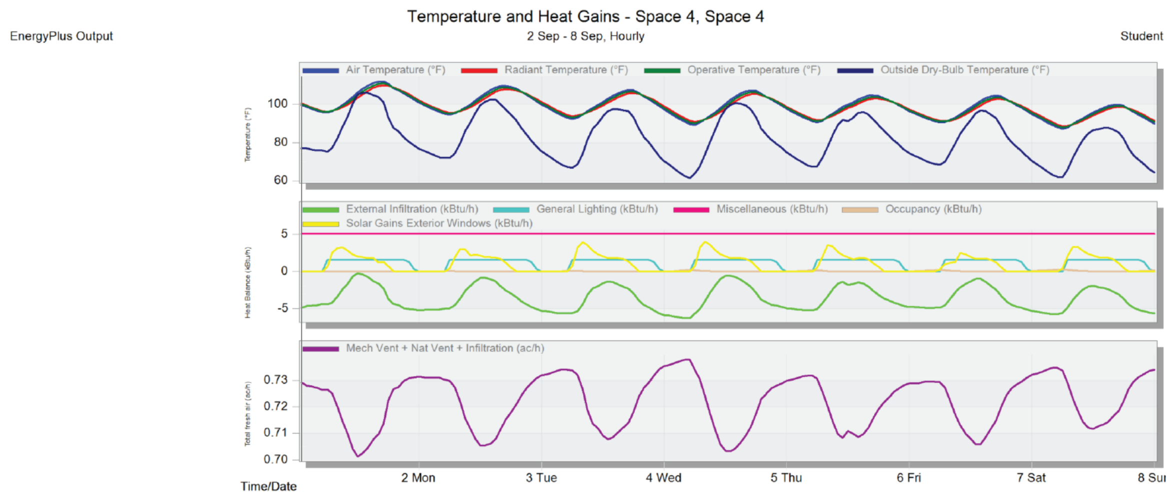
Evaluating the translation of these available technologies to an onsite system offers many advantages, and potentially can be done with a reconfiguration of off-the-shelf components. Calculating the efficacy of these alternative configurations can evaluate whether any of these systems is a viable alternative for battery storage for photovoltaics.

3.0 Methodologies

To assess the viability of non-battery systems, both selecting a baseline for companions, and determining an energy volume for daily demand are essential. The Tesla Power Wall is one of the leading propriety battery systems on the market, relying on the battery manufacturing for electric cars to create a consumer energy storage system for Photovoltaics (Tesla also creates proprietary PV systems). As a result, the Power Wall battery was selected as the market baseline for battery storage. The Tesla Power Wall Unit costs $6600 and their proprietary installation can range form $2000-6000. Each unit has a total capacity for 13.5Kwh with a Peak Capacity of 7kw and Continuous Capacity at 5kw. The system is reported to be 92% Efficient (Tesla, 2020).



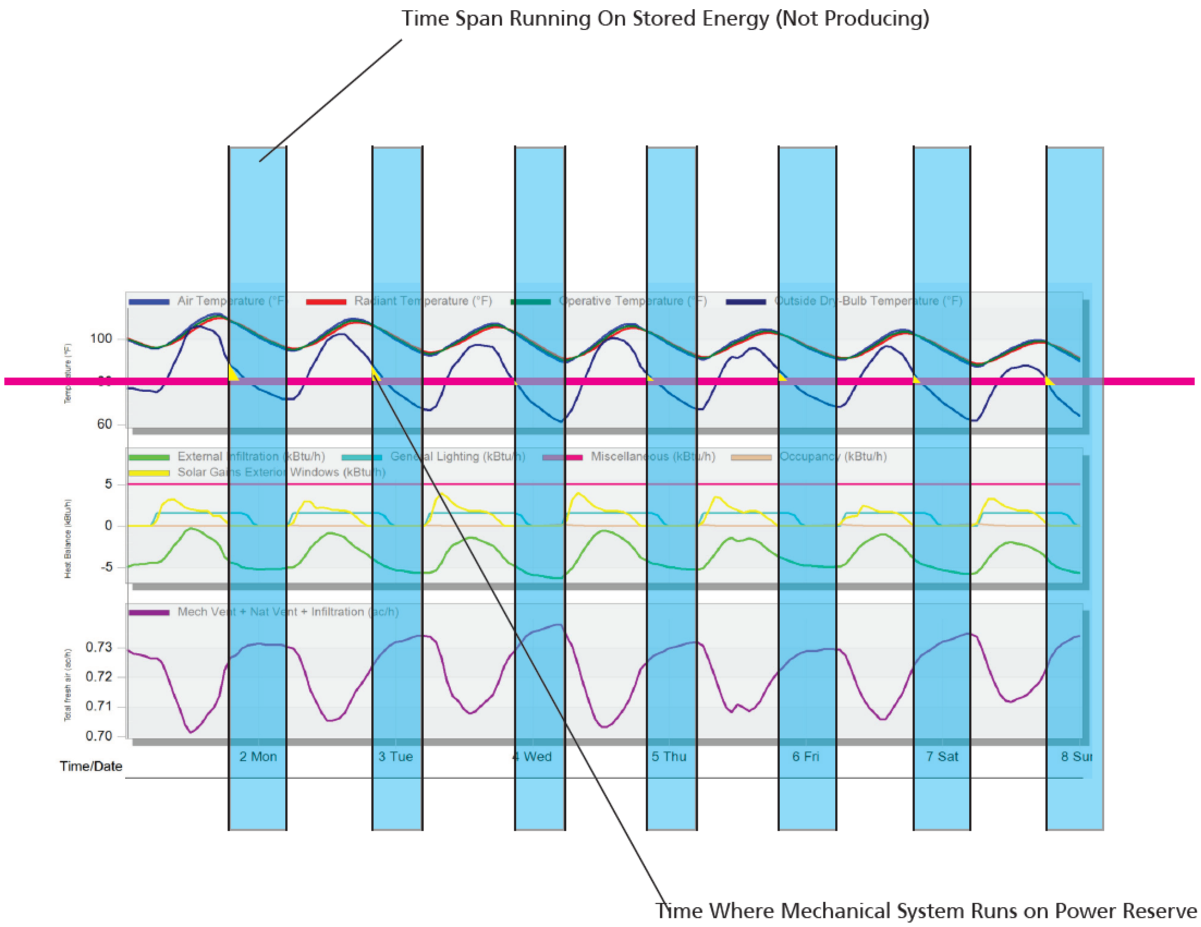
1200sqft Single Family Residence Model for Simulation (Revit, 2020, Desing-0Builder, 2020)



Air Temperature (°F)	111.11	94.67	105.06	101.26	92.48	106.99	95.12	96.48	103.20	87.21
Radiant Temperature (°F)	108.64	95.52	105.42	99.49	94.28	105.48	94.02	97.41	100.90	88.53
Operative Temperature (°F)	109.87	95.09	105.24	100.37	93.38	106.24	94.57	96.95	102.05	87.87
Outside Dry-Bulb Temperature (°F)	104.82	71.96	84.21	93.80	64.43	92.96	83.97	74.43	96.35	61.88
External Infiltration (kBtu/h)	-1.29	-4.93	-4.42	-1.56	-6.17	-2.93	-2.37	-4.76	-1.42	-5.61
General Lighting (kBtu/h)	1.59	1.59	1.59	1.59	0.00	1.59	1.59	0.00	1.59	0.00
Miscellaneous (kBtu/h)	5.04	5.04	5.04	5.04	5.04	5.04	5.04	5.04	5.04	5.04
Occupancy (kBtu/h)	0.00	0.04	0.00	0.00	0.11	0.00	0.02	0.00	0.00	0.28
Solar Gains Exterior Windows (kBtu/h)	1.80	0.39	0.00	2.00	0.00	0.67	3.34	0.00	1.72	0.40
Mech Vent + Nat Vent + Infiltration (ac/h)	0.71	0.73	0.73	0.71	0.74	0.72	0.71	0.73	0.71	0.73

Peak Cooling Loads (Design-Builder, 2020_

To create a baseline for daily demand Autodesk Revit was used to model an typical Los Angeles Single-Family Residence of 1200sqft. As the conversion to a home for photovoltaic selects for a energy-conscious user the baseline model assume that some remodeling was also done at the time of installation to bring the building envelope up to current CA Title 24 standards for energy efficiency, and would also have efficient mechanical conditioning systems. This information was integrated in design builder to simulate energy demand during non-producing hours during the week of peak cooling demand in Los Angeles (The Week of September 2nd). Effective this energy efficient home with a heat-pump based mechanical system, current LED lights, and Energy-Star appliances and an overall r-22 envelope with a cool-roof uses about 30Kwh/Sqft annually.



Modified Chart from Design-Builder Highlining Non-Producing Demands During Peak Cooling Week in Los Angeles, CA (2020)

For non-producing hours Design-Builder yielded a Lighting Demand of 300w, Appliance/Computer demand of 1kw, and a Mechanical demand of 4kw. The peak Load is 6kw with a 2hr mechanical Load of 8kw, and 10hr non-mechanical load of 13kw. The non-peak load is 1.5kw. All of these figures are scaled by a safety factor of 1.4 to yield an ideal Daily Storage Demand of 18.2Kwh. additionally, this system should be able to handle a peak load of 8.4kw, and a continuous load of 2.1Kw.

With this baseline information for comparison, research was performed to determine available off-the-shelf configurations for alternative energy storage to meet the daily non-producing demand as well as peak and continuous loads associated. The costs and sizes of these systems were calculated to assess the viability of these technologies for residential on-site storage. These are then compared to the cost of a battery system (Tesla Power Wall) to meet this demand which would be $15,000-$24,000, as two units would be required to meet demand.

4.0 Results

System	Tesla Powerwall	PowerSprout Turgo	PowerSprout Pelton	200 Bar CAES	Fuel Cell	Hyrdogen Combustion
Notes:	Standard Battery Storage System	Low Presssure Hydro-Generator	Low Flow Hydro-Generator	High Pressure CAES	Standard Fuel Cell	Hyrdogen Electrologisis and Combustion Engine Generation
Efficiency	92%	75%	75%	75%	85%	40%
Life-Cycle Impact	High	Low	Low	Low	High	Low
Needed Volume	N/A	120,000 Gal Water	10,000 gal Water	3m3 Compressed Air	550L Hydrogen	1800L Hydrogen
Potential For Retrofit or Use with Existing Systems	No	Yes	Yes	No	No	Yes
Potential For Furhter System Integration	No	Yes	Yes	Yes	No	No
Cost:	$15,000-24,000	$80,000	$11,000 (With Added Air Pressure	$30,000 (With Scuba Cylinders as Storage)	$35,000-$100,000	
Viability	**Yes**	**No**	**Yes**	**No**	**No**	**Maybe**

Table showing summary of results from calculations of available power storage systems. Only a hybrid pumped-hyrdo system with compressed air, and hydrogen combustion offer potential alternatives to battery storage based on performance metrics. All other systems were financially untenable, too large for onsite implementation, or both. Full discussion of each system elaborated in next section.

5.0 Discussion

Pumped Hydro-Storage:

Numerous low-cost hydro-generators exist on the market ranging from under $300 to $3000. These pumps are designed to operate at a range of flow rates/pressure (the two are inversely proportional). Because pumped-hydro storage is 75% efficient, the system would need to be oversized to produce 25kwh to meet daily demand. Calculations based water storage on a 10,000 gallon rain cistern. These are available for $5000-8000, however if rainwater collection is already implemented onsite, theoretically the system could be integrated with the existing system. The 10,000gallon tank is also the size of water pressure tanks found on top of most New York City buildings.

Version	Head (m)	Flow (l/s)
PowerSpout PLT (Pelton)	3 – 130	0.1 – 10
PowerSpout TRG (Turgo)	2 – 30	8 – 16
PowerSpout LH (Low Head)	1 – 5	25 – 56

PowerSprout Brand generators were the ultimately selected for calculations as the brand offers three models to perform at a variety of pressures/flows. Their Turgo generator ($1,599/1.3kw) operates at a flow rate of 10l/s or 600lp at 3m of head. Although this amount of gravitational pressure could be reasonably achieved onsite though rooftop storage of a mild grade, the 10,000 gallon tank could only provide 1.5kwhw. As a result, to operate at this pressure 120,000 gallons of water would need to be stored, the equivalent of three 20x40' swimming pools. As the cost of this system would far exceed $80,000, this system is not feasible.

PowerSprout's Pelton ($1,599/1.3kw) generator operates at 360lph or 105Kwh for a 10,000 gallon tank however this pump requires 130m of head or 180psi of pressure. If the cistern is capable of withstanding this pressure, combining this system with pumped air-pressure compressor often used in wells, may offer a viably hybrid, as the low volume requires could bring down costs to $11,000. Further cost reduction can be achieved if the system takes advantage of an existing rainwater storage system that can meet pressure demands. Additionally, the use of the water volume either as thermal mass, or circulated through a hydronic conditioning system may offer further efficiencies (PowerSprout, 2020).

Compressed Air Energy Storage:

There are a variety of CAES systems in large scale implementation. The most relevant would be an advanced adiabatic, that recuperates some of the energy that is lost as heat. As these systems are 75% efficient the on-site storage capacity would have to be scaled to accommodate 25 kwh to meet demand. The advanced adiabatic systems range from producing 2kwh/m3 at 70bar pressure to 6kwh/m3 at 200bar. Although fining a pump to storage energy at this pressure is not challenging, and they can be found on Amazon for as low as $350, storing such high pressure gas is a challenge, as large tanks such as typical residential propane tanks are rates to 330 psi or 20 bar for 500gal or close to 2m3 of storage capacity. Thus, the most promising off-the-shelf storage vessel would be a scuba tank or other gas tanks which can be procured new for under $180 for the standard 18l size and can accommodate pressure of over 300 bar. At 200bar 3m3 would be necessary to store the appropriate volume of energy or close to 170 scuba tanks. This is both volumetrically challenging and would being the cost to easily over $30,000. Although hypothetically there are ways that CAES could be integrated with the refrigerant cycle of a heat pump or domestic hot water system to further improve efficiency, it does not seem like a viable onsite residential power storage system.

Hydrogen Storage:

Hydrogen can be stored through water electrolysis. This hydrogen can then be used as in a fuel cell or combusted. Because Hydrogen Combustion can create green house gasses, catalytic systems bust be included and its burn efficiency must be adjusted to be about 25% efficient requiring 72kwh surplus. Hydrogen fuel cells are 85% efficient requiring 22kwh or surplus from the photovoltaics. As fuel cells include both strong acids such a formic acid, and rare metals in their membrane, cathode and anode, they are not ideal form an environmental benchmark compared to batteries. Residential systems also range from $35,000-$100,000, but this system would only require 550l of hydrogen to meet demand. A combustion system would require 1800l of hydrogen storage.

As the mechanics for hydrogen combustion already exists at many sites with onsite diesel or propane power. The propane tanks can be adapted for hydrogen storage, and the typical 500gallon tank can accommodate the 1800l necessary to meet non-producing demands. Retrofitting propane combustion generator, or repurposing and retrofitting a diesel engine to serve as a generator are also possible, creating the opportunity to upcycle fossil-fuel hardware.

6.0 Conclusions

As affordable battery storage remains one of the main hurdles for the wide-spread adoptions of residential photo-voltaics, evaluating alternatives from and economic and sustainability standpoint is essential. From this preliminary research of available off-the-shelf systems batteries, despite their ecological disadvantages, outperform most alternatives. The only two possible systems include hydrogen combustion retrofits, and a hybrid pumped-hydro air pressure system. The former requires such significant over-production that the surplus photovoltaics necessary to meet the Daily Demand figure effectively negates any cost and carbon savings through retrofit. Hybrid pumped-hydro storage can potentially be a promising alternative to batteries, especially given the extant use of rainwater storage and the added capacity for efficiency by using the mass of water as thermal mass in design or using the water for passive solar heating or circulating it through a hydronic mechanical system.

7.0 Future Work

In order to further explore the viability of any of these alternatives to non-battery power storage, experimental testing must be performed with prototypical assemblies created with available off-the-shelf components or retrofitting existing systems. This data can validate the theoretical possibilities of implementing a non-battery system. It can also lead to improving system efficiency. Exploring and testing other hybrid configurations is also essential to improve efficiency for the system by synergistically reducing energy demand and improving building energy performance. Additionally, further life-cycle analyses of alternative systems is imperative to determine their embodiment in comparison with battery-based systems. This information can also lead to further optimization in alternative power-storage system design, and if adopted at scale by industry can lead to significant cost reductions in implementation.

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