Zero Net Energy Home Project in Maryland: First Year Progress Report

BY BEN SCHLESINGER

Introduction

This article presents a progress report on a project aimed at demonstrating to the energy policy and real estate/construction communities whether building a zero-net energy ("ZNE") house in the U.S. Mid-Atlantic coastal region can be economically feasible using existing technology. The premise is that the house uses state-of-the-art renewable energy technology that is readily available to most builders. The ZNE components are largely out of sight and automated, and don't require any training or a Ph.D. in engineering to operate.

The discussion covers the following:

- Rationale and assumptions
- Equipment selections
- Results: First-year electricity flows
- Rough-cut economics
- Deploying the batteries
- Concluding thoughts

No local natural gas distribution is available at the site, hence the ZNE option. Propane is distributed in the house for "esthetics" like fireplaces and cooktops.

Rationale: 'By-the-way' carbon neutrality

The 5,140 s.f. house replaced a pre-existing house located on waterfront property in historic St Michaels on Maryland's Eastern Shore of Chesapeake Bay. Construction took 12 months from 11/2017 to 11/2018. Leading regional homebuilder Paquin Design/ Build was contracted because of their bid, experience, timeliness and quality, as well as enthusiasam for the ZNE program. Architect Charles Paul Goebel of Easton, MD and interior designer Erin Paige Pitts of Annapolis, both also leaders in the region, were chosen because they could best design the appearance, flow and fit of the new house with its extensive water frontage. Hence, the home is optimized for beauty, comfort, ease of operation, style, resort living – not really for carbon or energy. Figure 1 shows some views of the new house.

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See footnotes at end of text.

Figure 1 View of House and Bay Front

Subject to the foregoing, the question addressed is, simply, what about energy? Can a house like this be built with normal real estate criteria and still be ZNE and/or carbon net-neutral?

Equipment selections: best available technology

In light of the foregoing design and construction priorities, the ZNE strategy was to equip the house with the best major energy system components available in the industry when the house was built in 2018:

• "Macro" insulation. The siding is built with 2' x 6' studs in order to allow for 2" closed cell blown-in insulation and 4" fiberglass batting. Likewise, the house embodies a "house within a house" philosophy, i.e., insulated empty spaces sepa-

Figure 2 Geothermal drilling underway on property

rating the upper floors from the roof. Lighting is mostly LED, but kitchen and other appliances were chosen for design and quality, not energy.

- Geothermal energy. Eight 220′ depth geothermal wells were drilled in the front yard in a process that was completed in less than half the scheduled time. It's worth noting why: drilling tech and know-how from hundreds of thousands of gas wells in the region have spilled over to make geothermal drilling more efficient, thus advancing green energy. It took about nine

Figure 3 Solar PV array atop the house

months for the lawn to recover, however, and large sections of the front yard now comprise a "Miss Utility" field with shallow buried glycol feed lines from the field to the house.
- Energy Star leading geothermal heat pumps. Two 4-ton ClimateMaster 45 SEER ground-source heat pumps provide all heat, air conditioning and hot water for the house. Developed at Oak Ridge National Lab, their industry-leading efficiency is achieved by variable speed glycol loops, variable air flows through nine sub-zones, and other improvements and advances. Unlike typical outdoor air-source heat pumps, these are quiet enough to be located inside the house.
- Rooftop solar photovoltaic (PV) energy. As originally conceived, the plan was to install a Tesla solar roof, but this product wasn't available in time for construction. So instead, fifty 360-watt SunPower PV panels are installed, totaling 18 KW of electricity production capacity. Local contractor Sunrise Solar of Chestertown, MD, mounted them tightly on two large, nearly flat sections

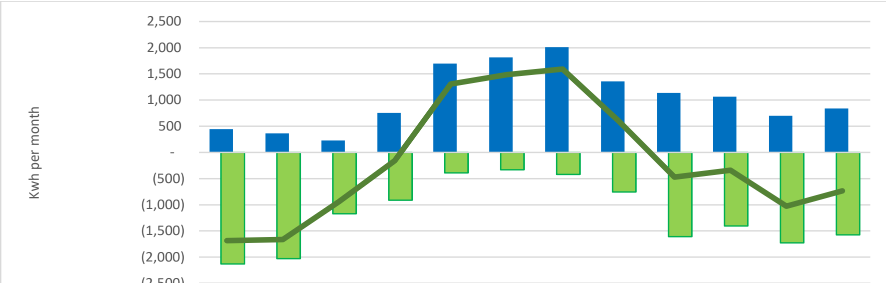
Figure 4 Tesla PowerWalls in garage

of roof (see Figure 3) to keep them out of sight from ground level. This orientation is suboptimal because they're not tilted perfectly, but they're nonetheless highly productive.
- Tesla PowerWalls. Three 13.5 kwh lithium-ion battery packs are installed in the garage (see Figure 4), totaling 40.5 kwh of storage, minus various inefficiencies. So far, these have been used mostly to provide stand-by electricity during power outages; indeed, they operated seamlessly during six brief outages in the first year. As long as the sun shines, the batteries' stand-by generation could continue indefinitely. More aggressive deployment of the batteries is planned for the second year, as discussed below.

Results: First-year electricity flows

In the first 12 months after ZNE systems were installed, the house was net negative energy, i.e., a total of 2,033 kwh of electricity was returned to the grid and all household demand was met. This included all electricity for heating, air conditioning, hot water, lighting, appliances, security and even charging the author's electric vehicles for about 3,000 miles worth of travel. In addition (not shown), about 20 gallons of propane were consumed for cooktops and fireplaces.

Figure 5 shows monthly energy flows between the house and the grid. Seasonal variations dominate the picture – the house was a net energy producer until December 2018, then became a net consumer through March 2019, and then was a net producer again through July 2019. Three main reasons explain this seasonality: a) geothermal heat pumps are more efficient on their cooling cycle than for heating, b) winter solar PV production is hobbled by the low angle of the sun, and c) energy demand for lighting is greater on short winter days. Note that the first year in this analysis included the final four months of construction, but builders used HVAC, plug-in construction equipment, some lighting, etc. Still, Figure 5 shows somewhat higher demand during comparable months in 2019, thus portending tighter second-year ZNE results.



	Aug-18*	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19
Billed Usage	446	364	230	756	1,697	1,816	2,011	1,359	1,135	1,064	700	840
Billed Generation	(2,131)	(2,027)	(1,171)	(912)	(389)	(331)	(419)	(755)	(1,608)	(1,405)	(1,727)	(1,576)
Net	(1,685)	(1,663)	(941)	(156)	1,308	1,485	1,592	604	(473)	(341)	(1,027)	(736)

Figure 5 Summary of first-year energy production and demand
Source: BSA 2019, from Choptank Electric Cooperative, 2018-2019. Months refer to the preceding sixth day through the fifth day of the month shown. Asterisk denotes the full month consisting of July 12, 2018 through August 5, 2018 plus July 6, 2019 through July 11, 2019.

Unfortunately, there is no submetering in the house, thus no way to track demand from individual sources, appliances, etc. This suggests a project for future years.

Rough-cut economics

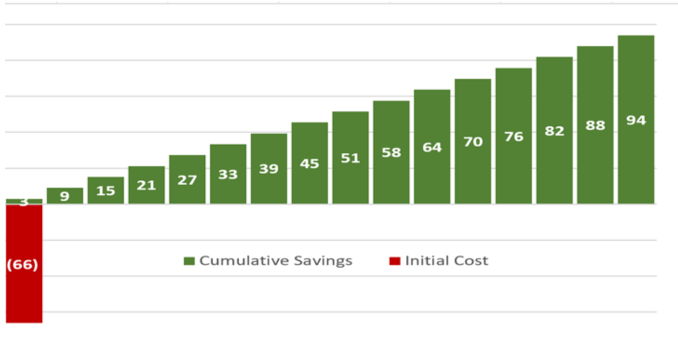


Figure 6 Rough-cut ZNE economics based on first year
Source: BSA 2019, from Choptank Electric Cooperative monthly bills in St. Michaels, and Pepco and Washington Gas bills in Bethesda, and initial capital expenditures (see text).

Figure 6 compares initial geothermal and solar energy costs with expected cumulative benefits, i.e., savings relative to 2017-2018 energy bills in the author's previous home in Bethesda, MD, with similar climate, demand patterns and size. On this basis, the ZNE components of the new house produce about a 10-year payback. Initial costs include 30% Federal investment tax credit (ITC) taken on geothermal and solar system costs and $4,000 in Maryland grants. The total cost for electricity in the first year was $98, which includes bills paid and payments received from Choptank Electric Cooperative, plus sales of solar renewable energy credits (SRECs, marketed by Sol Systems). In addition to electricity, about $30 was spent on propane in the first year.

Another comparison could be drawn with energy bills in the previous house on the property. During the six months in the author's ownership from April to October 2017, the house used 14,082 kwh of electricity, costing $1,892 – and this period almost entirely avoided winter heating bills. Thus, the new house produced at least a 95% energy cost savings.

The Tesla battery packs on-site were excluded from this analysis because they were installed about halfway through the first year and, again, were used as an emergency stand-by.

These results may or may not be replicable in other regions. Weather data in Figure 7 show St. Michaels is more conducive to ZNE than some places (less snow to block out solar energy than the U.S. average) and worse than others (less sunshine to produce solar energy than Southern California)..

Finally, there's a seemingly endless array of carbon-related choices that this project has not yet addressed but will likely take up in the near future. Three examples:

- The author's EV charging took place partly at home in St. Michaels using solar energy and partly at other locations within PJM's grid, which relies on coal, nuclear, natural gas and some re-newable generation fuels. It is unclear whether

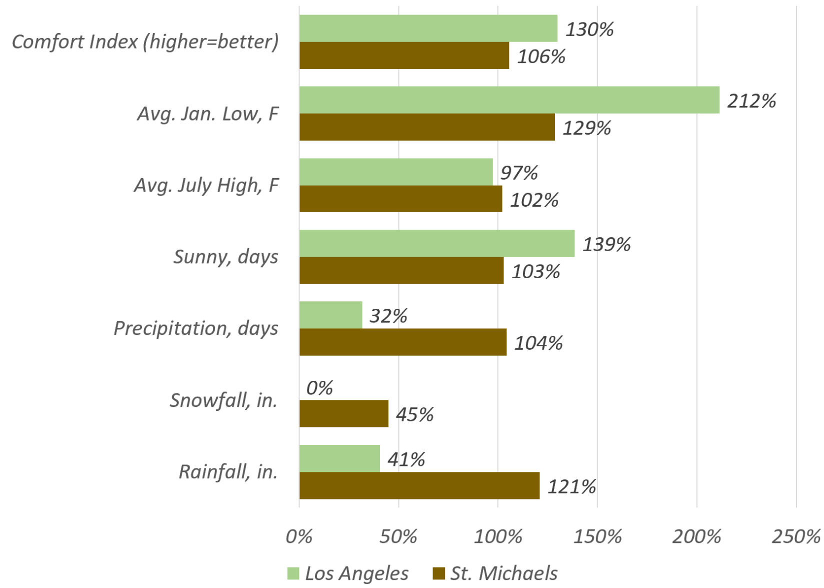


Figure 7 St. Michaels and Southern California weather versus U.S. averages

Source: BSA 2019, from www.bestplaces.net.

electricity used for EV charging at home ought to be part of a separate equation or not, thus future updates will seek to segment EV demand for separate economic analysis.

- The house's two-acre lawn is maintained by a team using gasoline-powered mowers. The author is considering lower-carbon alternatives, such as Ryobi's new 42 in. lithium-ion battery-powered riding mower that could be charged at the house like an EV.
- Waterborne commerce has been fundamental to the long history of St. Michaels, where fishing and commercial fleets were manufactured, and warships too, which attracted fierce British naval attention in the War of 1812. Boating remains popular here and the author is considering a pleasure craft with a lower carbon twist: a Yanmar 200 hp turbodiesel outboard using biodiesel available from local agricultural industries. No decision yet.

Deploying the Batteries

One of the main reasons for building or retrofitting houses to a ZNE standard[1] is to reduce emissions of greenhouse gases, especially carbon dioxide. A basic green energy/economic question is how best to deploy 40.5 kwh of stored electricity on-site to maximize carbon offsets, a concern that's been raised in literature (for example, see Hittinger and Azevedo, 2015[2] and Hittinger and Lueken, 2015[3]). The nascent PJM "duck curve" effect shown in Figure 8 suggests the answer might lie in careful timing: discharge batteries in the evening to maximize offset of on-grid hydrocarbon fuels.

Even more useful would be real-time information about PJM generation, e.g., marginal fuels on a 15-minute basis as Brown et al 2019[4] suggest. This could improve carbon offsets not only from the house but also from EVs, whether charged at home or not. The author plans to attempt this strategy in the second year.

Concluding thoughts

From an economic perspective, a 10-year payback period might be unacceptably long for some homeowners. But since most houses are mortgaged, including this one, it makes sense to suggest that lenders internalize borrowers' enhanced ability to make monthly mortgage payments if they have ZNE houses.[5]

Going forward, the 10-year payback for this kind of project is bound to decline because capital costs for all ZNE equipment, especially PV panels and batteries, are falling to competitive levels unforeseen only several years ago (for example, see NREL 2018[6] and Bloomberg 2019[7]). For example, a 50% reduction in the installed ZNE equipment costs, which appears likely as production increases (Bloomberg 2019), would reduce the pay-pack period by almost 30% even if the Federal 30% ITC is allowed to expire as scheduled. Even today, payback periods could fall through use of lower cost solar and geothermal equipment, i.e., less than the best available.

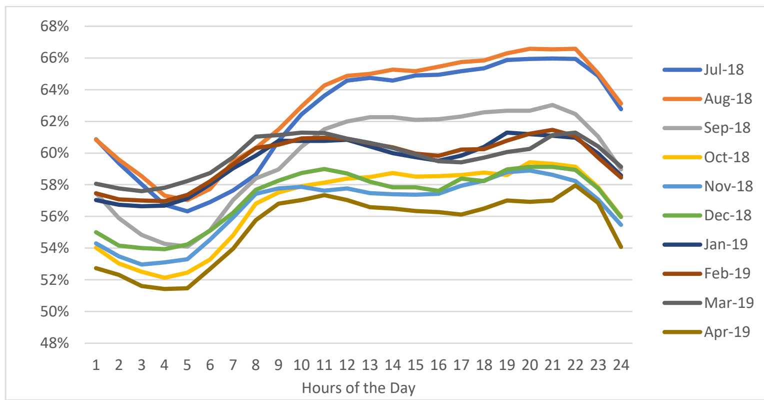


Figure 8 PJM Coal-Plus-Gas% throughout the Day, Average by Month in 2018

Source: BSA 2019, from PJM on-line hourly fuel use data.

Finally, ZNE homes like this, even with battery packs, will not obviate electric utilities because they'll need grid power on cold winter, on every rainy or cloudy day with poor solar, and every night if batteries are 100% dedicated to emergency back-up. But regarding natural gas, this house has no hook-up at all, which implies widespread ZNE could eventually put gas distributors at risk. Globally, natural gas use is increasing and hundreds of millions of buildings rely on gas utilities for heating and other vital energy demands, 60 million homes in the U.S. alone. Therefore, it is hoped that the gas industry will respond to the challenge and turn to lower carbon services and work toward decarbonizing altogether throughout the gas chain.

Figure 9 Historic skipjack passes by house

Footnotes

[1] Required as of 1/1/2020 under California Code of Regulations (Title 24, Part 6), see https://ww2.energy.ca.gov/title24/2019standards/documents/2018_Title_24_2019_Building_Standards_FAQ.pdf

[2] Hittinger, Eric S. and M. L. Azevedo, "Bulk Energy Storage Increases US Electricity System Emissions." Environmental Science and Technology 49. 5 (2015): 3203-3210.

[3] Hittinger, Eric and Roger Lueken, "Is Inexpensive Natural Gas Hindering the Grid Energy Storage Industry?" Energy Policy. 87 (2015): 140-152.

[4] Brown, Patrick, et al., "Optimized PV + Storage System Designs For Nodal Electricity Value" presented at 42nd IAEE International Conference, Montreal Canada (2019).

[5] For example, see https://www.energy.gov/energysaver/incentives-and-financing-energy-efficient-homes/financing-energy-efficient-homes

[6] National Renewable Energy Lab (NREL), "Costs Continue to Decline for Residential and Commercial Photovoltaics in 2018," December 2018, at https://www.nrel.gov/news/program/2018/costs-continue-to-decline-for-residential-and-commercial-photovoltaics-in-2018.html

[7] Bloomberg NEF, "Battery Pack Prices Fall As Market Ramps Up With Market Average At $156/kWh," December 3, 2019, at https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/