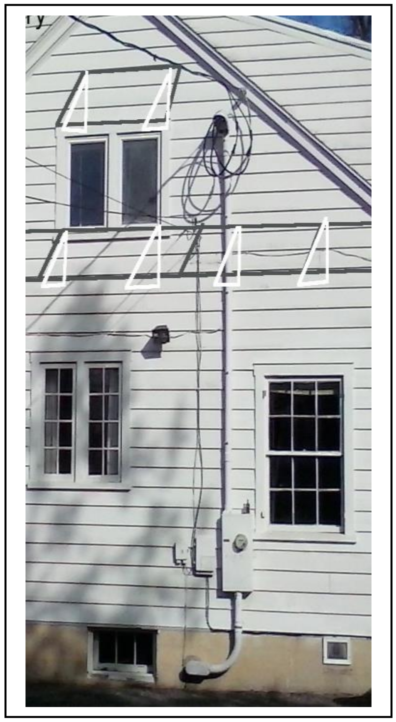
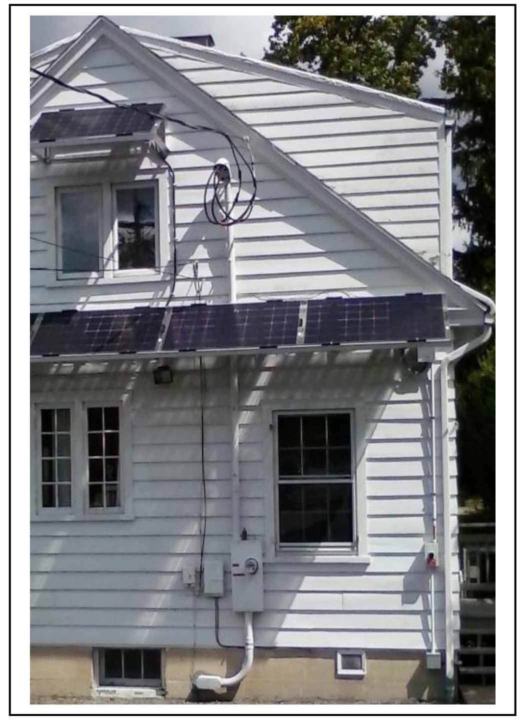
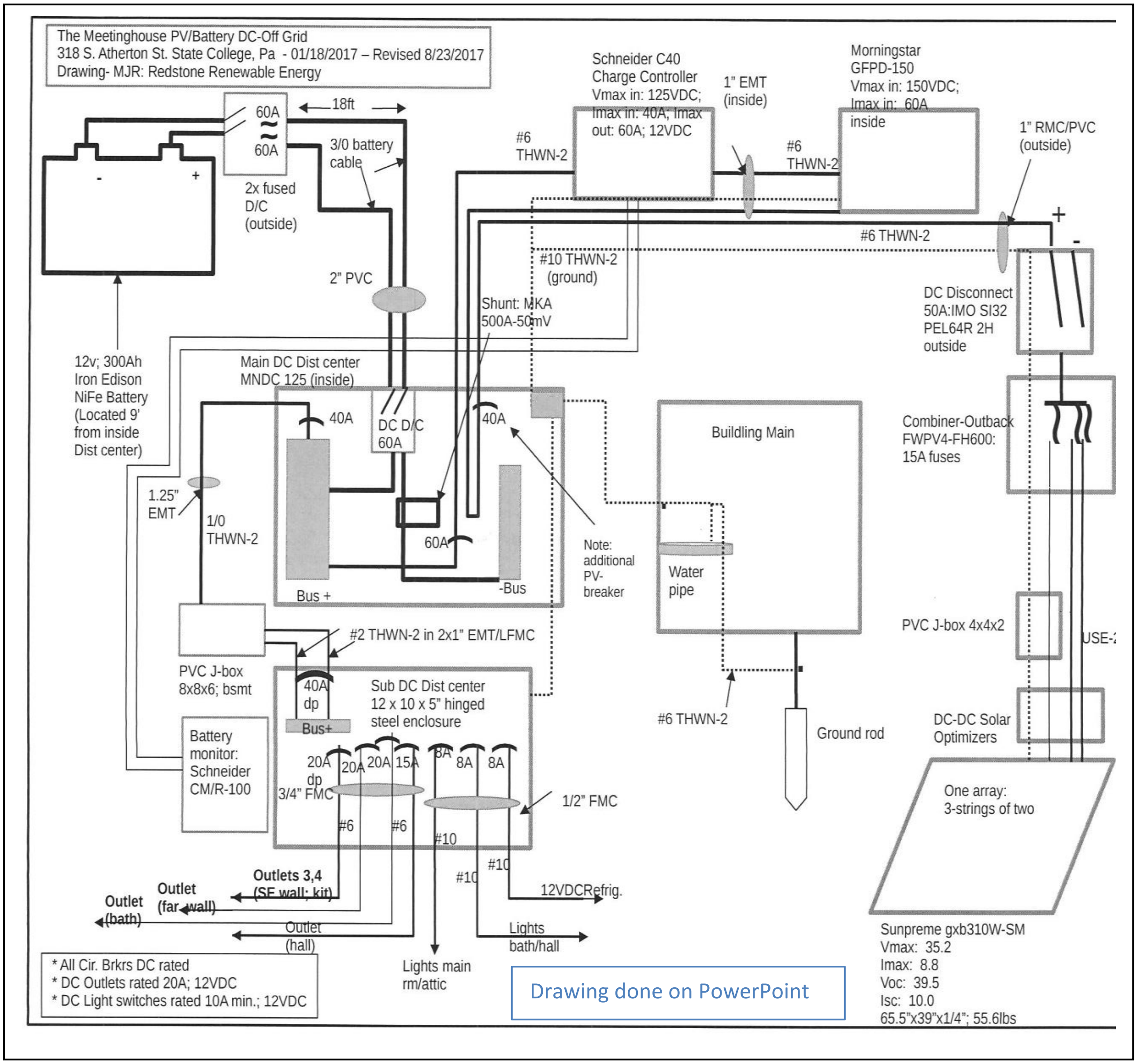




THE MEETINGHOUSE ON ATHERTON PV/BATTERY – STATE COLLEGE, PENNSYLVANIA

When opportunity, in the form of a modest inheritance, met preparedness via my own savings, were both coupled with my growing desire to promote the use of renewable energy in my community, an off-grid system for a residential apartment on the second floor of an historic church building was born.

I put all my introductory training from the Solar Living Institute, advanced hybrid system and storage coursework from SEI, and my experience in building over eighty grid-tied systems to date to the test when the idea to hard-wire the 300sf apartment for 12VDC, powering it by state of the art DC-optimizer-equipped frameless bi-facial modules, backed by a lifetime-warranted nickel-iron battery bank, routed through a MidNite Solar DC power center, and installation of side-by-side AC and DC electrical fixtures was presented to the property owners, Sharon and Joe Schafer and David and Jen Lemmon. The landlords, who are pro-actively involved with community initiatives such as permaculture, local sustainable farming, and running a community garden, thankfully embraced this endeavor. 100% of the material and labor were donated for their use where at least half of the apparatus (modules, wiring, and related components) would permanently remain on the premises. It was understood that both parties could promote the project into the eyes and ears of the community: The Meetinghouse on Atherton (formal name for the building site) to the lessee's which included The Friends & Farmers Food Cooperative, Taproot Kitchen (food caterers comprised of special needs folks and their parents), and Nittany Valley Church; and me by having an open-to-the-public showcase system as an advertising tool to promote what my newly formed business: Redstone Renewable Energy, LLC, could offer.

Although other than our area's zoning department, no building /electrical permit was required (due to the PV system being classified as a "temporary appurtenance" which would have neither inverter nor grid-tie) I paid for one anyways. I feel it is always a good idea to inform the area's CODE Enforcement officers what I am up to. It helps keep the renewable energy topic hot, serves as an educational tool, and allows the system designs to become an accessible public record. It also affords a chance for more eyes to scan my designs towards a better chance of spotting any red flags.



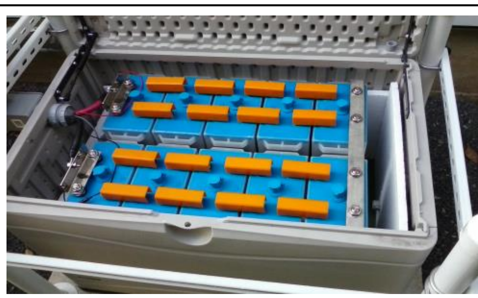
With my approved designs in hand, I began to implement a pre-planned four-month construction schedule that ended up being close to seven by the time it was commissioned.

First off with any power producing endeavor would be to perform a load analysis, which from the table below, came out to a projected 555Wh/day. Being that there were not any heating/cooling loads and no other noteworthy variances, no seasonal adjustments were necessary.

Load	Qty	x	Watts	x	Hrs./Day	x	Days/Wk.	÷ 7 =	Avg.Daily Wh
Refrigerator	1		80		5.5		7		440
Lights:Main	6		3.5		4		7		84
Lights:Hall	4		3.5		1		7		14
Lights:Bath	2		3.5		2		7		14
Cell Phone	1		4.5		0.25		7		1
C. Controller	1		3-15mA		24		7		2
Total Power			95W				Total Energy		555Wh/d

In order to stretch the effectiveness of my design, I implemented some passive measures towards mitigating my heating and cooling loads in lieu of active energy supplementation. These were simple yet effective: replace all cracked window panes, restore triple-track storm window frames and blinds making sure that all my old-style wooden sash windows had no less than three barriers of protection, adding 2-inch thick isocyanate foam board and packing Styrofoam to the back sides of my attic hatchway and crawl space doors, and finding cavities in the attic that could use supplementation from the two bales of ROXUL brand mineral wool that I purchased locally. With its integrative design, besides beautifying the outer wall, the 33° angled solar module awnings were mounted above the southern-most windows which would cut down on unnecessary summertime heat gain while allowing full ingress of wintertime sun.

Battery bank design. Because weather, here, in State College can blanket us with seven or more consecutive days with desultory non-stop overcast skies and desirous to design a system worth its mettle, my minimum parameters involved having 6-days of autonomy. According to the table below, the 300Ah NiFe's (see sidebar) turned out to be a perfect fit. The capacity of a bank of (10) at its fully charged state registers 14.1V at rest which would yield me 3,380Wh of energy assuming 80% D.O.D. Dividing our system capacity (3300Wh) into our bank's deliverable capacity and multiplying the result against the days of autonomy gives a real feel of 6.1 days. Sweet!



NiFe battery bank: ten 12V, 300Ah batteries in series. Battery temperature sensor cable and GFPD sensor wire shown. Small vent in lid (upper right), two more in side walls ~16" from ground level.

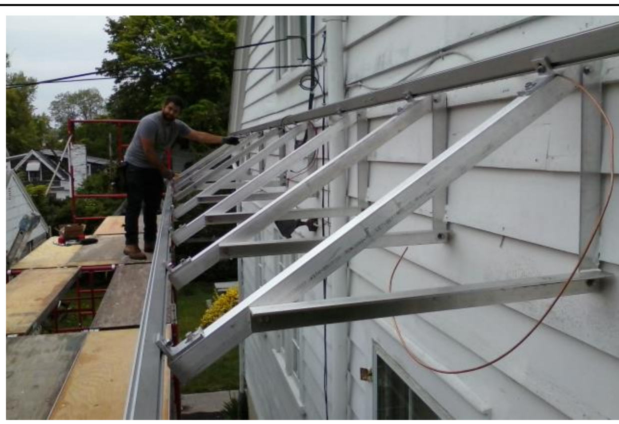
Average daily load (Wh/day)	÷	Inverter eff.	x	Batt T mult.	x	Days of Auton. Desired	=	Total system req. (Wh)
555		1		1		6		3330

Single Battery Capac. (Wh)*	x	Dis-charge Limit	=	Adjust. Capac. (Wh)
423		0.80		338

Total system capac. (Wh)	÷	Adjust. Capac. (Wh)	=	# Batt.'s	Batt. Bank capac. (10) batt.'s (Wh)
3330		338		9.8	3380

With a primary desire to order my NiFe's from Encell Technology, Inc. (Alachua, Florida) – the only USA company that manufactures them - I chose their largest production model which was 300Ah. But here is where my luck ran out. After speaking with Chris Maier, CFO, he informed me that their facility would be closed for a while as they are in the process of changing their positive electrode (nickel) supplier. Rather than wait, I ultimately ordered the bank from Colorado-based Iron Edison Co.

<u>Array sizing.</u> At first glance, based on my daily loads, it appears that I would only need two modules: 555Wh/d ÷ 2.0 sun-h/d (Dec. = worst month) ÷ 0.80 (Batt. eff.) ÷ 0.9962 (c.controller eff.) ÷ 0.65 (PV system eff.)* = 536W (required PV capacity) ÷ 310W (module size) = 2 modules (rounded up).



Intern construction partner Jack van Hekken, Senior Environmental Engineering, Penn state University

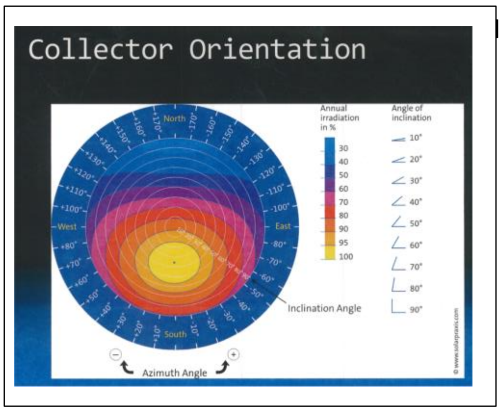
But I need to take into account the energy required to fully charge my battery bank from an 80% DOD within two days (nominally less than a week), again, considering this fickle State College weather. It would take over seven days for a 620W array to satisfy my loads while completely re-charging my bank. No way! Adding together 1,100Wh (the first part for my daily loads over two days) to 3,380Wh (the second part which is the energy required to re-charge my battery bank) gives me a 4,480Wh target.

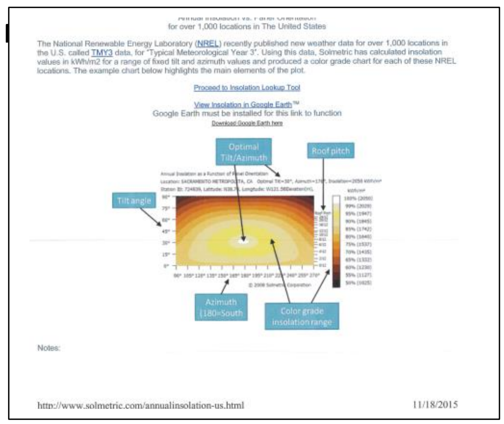
If one module gives me 644Wh over a two-day period (310W x 2 sun-h/d x 0.65 (PV system eff. – see side bar) X 0.80 (battery charge eff.)), I would need 7.1 of them (4,480Wh ÷ 644Wh) to hit my 2-day goal. Since I only have room for 6-modules, I had to settle for a 2.3-day battery bank re-charge + load handling period.

Another thing I needed to keep in mind was to cross-check my sizing to see if there was enough PV capacity to handle my daily load and re-charge my bank from their D.O.D. in less than one typical spring or fall day (H.P. 174.46 *Off-Grid Vacation Cabins* by Dan Fink). An average spring/fall day would yields me 5.2 sun-hours meaning I will have my re-charge in 0.98 days:

$$(3{,}935Wh\ (555Wh\ daily\ load + 3{,}380\ bank\ recharge)) \div \left(\frac{4{,}023Wh}{day}(1{,}860W\ sys.cap. \times 5.2sun.h/day \times 0.65PV\ eff. \times 0.80batt.eff.)\right).$$

*A shading analysis resulting from my Solar Pathfinder measurements came out to 75.7% (a 24.3% derate). My tilt angle and azimuth derating gathered from an average of the two NREL charts shown below, was 93% (a 7% de-rate). Multiplying these together gives me a 70.4% overall shading + orientation de-rate. I subtracted 1% (soiling); 1% (mismatch); 1% wire loss; and a 2.4% components loss (disconnects, circuit breakers, fuses, GFPD) to arrive at a 65% PV system efficiency.




for over 1,000 locations in The United States

The National Renewable Energy Laboratory (NREL) recently published new weather data for over 1,000 locations in the U.S. called TMY3 data, for "Typical Meteorological Year 3". Using this data, Solmetric has calculated insolation values in kWh/m2 for a range of fixed tilt and azimuth values and produced a color grade chart for each of these NREL locations. The example chart below highlights the main elements of the plot.

Proceed to Insolation Lookup Tool

View Insolation in Google Earth™
Google Earth must be installed for this link to function
Download Google Earth here

Notes:

http://www.solmetric.com/annualinsolation-us.html 11/18/2015

<u>B.O.S.</u> After determining my loads' energy requirement, battery bank size, and PV capacity, it was a matter of tracking down the balance of system components to seamlessly integrate the support infrastructure for a 12VDC system into the 90-year old building. For the charge controller, I chose the Schneider Electric C40 because it has a relatively high PV input voltage for a PWM (125V), and a feature allowing an internal resister to be clipped so that my NiFe's can be charged at their happiest level-17.0V.

My control center was centered around a MidNite Solar 125 MNDC-PLUS DC power distribution center because of its user friendly lay-out: plenty of knock-outs up to 2" in diameter, multiple shunt mounting pads, three different places to place panel mount and/or DIN rail CB's, and a couple of insulated busbars.

MNDC: Just getting started with my apartment circuit

After: showing the
MORNINGSTAR GFPD
and C40 charge controller
(w/out cover) →

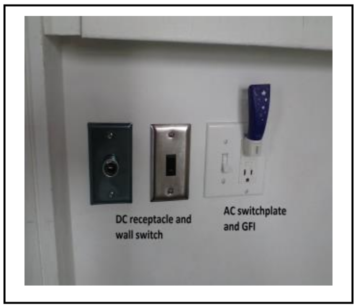
Appliances

Refrigeration. After some research, I decided to go with a SunStar 12/24VDC refrigerator because after a good match between quality and price (and as is the case with Outback inverters), the SunStars have chip cards and parts that are field serviceable. This model is rated at 500Wh/d with a 40-80W power draw. I wired it with its own circuit and used an 8A breaker for the OCPD.

9.5cf Sunstar next
to the side-by-side
12VDC and 120VAC
receptacles:

Bathroom DC-AC
side-by-side lighting

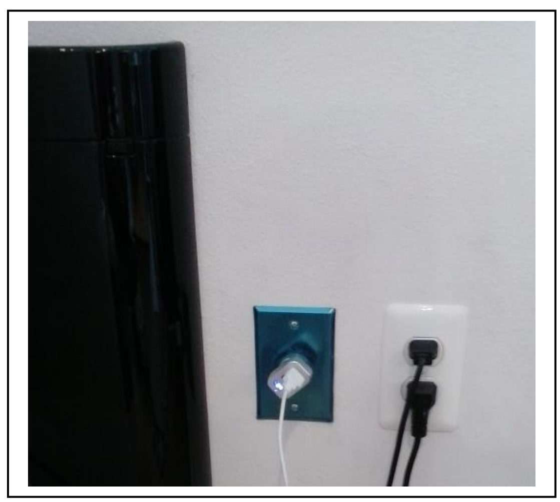
Lighting. I made local store-bought purchases for both spot-light style and recessed fixtures – all utilizing GU-10 bases sockets. What converted these AC fixtures to DC were three things:



1. DC-rated bulbs;
2. Heavy gauge branch wiring (I used #10 AWG stranded for an 8Amp DC circuit);
3. High DC-Amp rated switches – very important in reducing the chances of arcing when the current flow is interrupted. AC, because of its sinusoidal nature, is self-extinguishing when power is cut so their internal switching mechanism can have a lighter design, not generally suitable for handling DC power which comes at you like a freight train!

<u>Power outlets.</u> It took me a while, but I was finally able to track down 12V cigarette style DC receptacles (Prime Products brand) to my liking – sturdily constructed ones stocked at my nearby RV parts dealership. The Prime Products brand receptacles are rated 20A at 12VDC and are all metal construction with heavy duty positive wire bolt-on posts and a welded metal male terminal tongue with a pre-drilled center hole for the negative. (The only downside was having to take apart the unit in order to cut off the two positive metal flanges which were positioned too close to the receptacle's negative walls.) Due to voltage drop considerations, it was a bit of a challenge to directly convert my 6 AWG stranded wire in the switch box since the industry only supplies female terminal connectors down to #10 AWG. My solution was to crimp the negative wires with #6 eye lugs, and tap the male terminal tongue's pre-drilled hole to fit a hairs' breadth larger MC4 metric screw. I tightened the connections with matching stainless steel nuts and lock washers then wrapped it with rubberized 3M 130C linerless rubber splicing tape with a final wind using Super 88 brand 3M heavy duty electrical tape.

I have five DC receptacles hard-wired into the walls of my 300sf living space, 1-each for my bathroom, hall, and kitchen areas, and (2) for the main room. Over time, I plan on getting a blender, crockpot, vacuum cleaner, sound system, and at least two different sized portable DC space heaters – all 12VDC. For the present, I am happily keeping my cell phone fully charged via a USB adapter.



12VDC receptacle with triple USB ports ranging from 1-2.4Amps; 120VAC 20A rated dual receptacle; left: a wall-mounted 120VAC plug-in style eheat/envi unit

System challenges.

Since locating a battery box inside the utility room of the building's basement was not an option due to area constraints, and a metal door that opened inward instead of the required outward/egress (NEC 480.9), and the room's copious use of aluminum clad wiring (hydrogen off-gassing from batteries and FMC cabling provide for a corrosive mixture!) I chose outdoor storage. Without wishing to spend large amounts of money on pre-fabricated cabinetry, I acted on a tip from my Iron Edison rep. and purchased a plastic deck box at a local hardware center. Because the plastic frame could not support the 500lbs of batteries, when pouring the steel-reinforced 4-inch thick concrete pad, I embedded (4) 1-inch threaded RIGID nipples as risers. After drilling a mirrored set of perforations in the bottom of the bin, I lined it with leftover Styrofoam packaging, screwed floor flanges upside down over the nipples, then bolted 2" x 10" lumber to the flanges, covered them with an extra layer of Styrofoam, and then screwed ¾" shelving wood to the 2 x 10's, after coating all the wood with Australian Timber Oil. Using PVC conduit and stainless steel wire mesh, I added two ¾" side vents and one upper vent on the higher-sloped backside of the lid. There are plenty of non-gasketed seams between the box sides and lid. Considering these together with the cross venting, I anticipated no need for forced hydrogen extraction. Since the box is mounted on the ground, I added corner posts for protection – 2" RIGID conduit flanged and bolted to the pad did the job.

Because my battery bank is located more than 5-feet away from the service panel, and because the conduit passes through an outside wall, I added fuses and a disconnect whose line terminals are oriented toward the battery side. A second means of disconnection was placed on the inside of the building (as per NEC 690.71(H)). I installed the outside disconnect and fuses into a custom fitted NEMA 3R metal J-box with two ANL type fuses and blocks (1-each for both the positive and negative leads) and a set of 50Amp continuous rated battery "kill" switches.

<u>Voltage drop considerations.</u>

<u>Battery bank to control center.</u> The goal that I try to achieve is a <1% voltage drop. The following voltage drop equation is supplied in UGLY'S ELECTRICAL REFERENCES:

$$(2 \times K \ \times distance\ in\ feet\ one\ way \times max. Amperage) \div wire\ size\ circular\ mills$$

$$(2 \times 12.9 \times 18ft \times 60A) \div 167{,}800cm = 0.166V \div 12VDC = 0.0138 = \mathbf{1.38\%\ Vd}$$

$$K = 12.9\ (resistance\ in\ ohms\ of\ one\ circular\ mil\ foot\ of\ copper\ conductor)$$

c*m* value used in equation is for 3/0 conductor size

I would have had to use 250kcmil conductor (cm = 250,000) in order to keep the voltage drop below 1%. This was too large a wire to work with in my confined spaces, so I bit the bullet and chose 3/0 (supplied by The Pacer Group Sarasota, Florida), which I felt got me close enough.

<u>Apartment subpanel feeder.</u> In order to minimize voltage drop in the 110' (my longest receptacle run) apartment subpanel branch coming up from the basement DC distribution panel, I ran 1/0 AWG, in 1 ¼" metallic LiquidTite (LMFC) to the basement's chase way opening. But because my chase way was less than 1 ¼" wide, the largest diameter conduit I could fit for the run up through the walls to my apartment, was 1" EMT (too tight for 1/0 wire). Solution? Parallel the last leg of my circuit with two side-by-side 1" EMT conduit runs, each containing #2AWG wire.

<u>Lighting circuits.</u> Even though there are only (16) 12VDC LED bulbs ranging from 3.5W – 10W (91 total W) spread over (2) separated circuits that comprise my entire lighting system, I still used, as a minimum, 10AWG wire, again to minimize voltage drop.

<u>Wire sizes used in system:</u>

- 3/0: battery box run'
- 1/0: #2 apartment subpanel run
- #6: receptacles
- #6: charge controller wiring
- #6 and #10: PV circuit
- #10: lighting and switches
- #10: refrigerator receptacle (250V x 20A style).

<u>Results.</u> After shutting down the PV/charge controller side of my system and letting my battery bank rest for an hour under zero load, I twice measured the voltage at the bank and compared it to my furthest wall receptacle, over 110ft away. Both times I came up with the same voltage down to the tenth of a volt (the extent of my meter's accuracy). Deducing that there could be a ~0.049V difference that my meter may not register, at a 14.6V measurement the maximum Vd would be 0.34%.

Home made switch plates. Finding no industry-supplied household type switch plates for the smaller odd-sized DC switches, I resorted to buying nickel-finished blank metal wall plates and used a fine-toothed coping saw blade to make hand-sawed cut outs. It was a tedious process and after one time-consuming mistake, found out that tolerances of 1/16" or greater didn't cut the mustard. I could have purchased the odd sized plastic plates specifically matched for the DC switches but I did not want my home to look like the inside of an RV.

System Features

Bi-Facial modules: I took advantage of a highly reflective white-washed building wall by choosing bi-facial modules, which allow photovoltaic production from both sides (Sunpreme Maxima GxB310W – featured in H.P.169.47 *PV Modules… Update & Trends*). The following module features were designed to squeeze every last drop of solar harvest from the tiny space available: bi-facial; frameless; built-in DC-DC optimizers; optimally angled awning-style mounting, heavy gauge wiring.

"Straight as a rail" - front-to-back tolerances for the frameless SunPreme mounting was only 1/4"

NiFe batteries. Need I say more? Its biggest attraction was the possibility of never having to buy another set of batteries again. Biggest concern: every ~10 years I will need to change out and add fresh electrolyte. According to the MSDS, it may contain cadmium and lithium hydroxide, which may or may not be allowed to be taken to area household hazardous waste drop-offs.

Ground fault protection. The MORNINGSTAR *150L Ground-Fault Protection Device* was the only listed equipment I could find that breaks both the positive and negative circuits in a faulting event – must-have equipment for an ungrounded system.

Ungrounded system. There is no bonding between the ground or any conductors - the negative terminal on the battery bank is even isolated. Since there is very little chance that a there could be any stray floating voltages in a ground fault event with this type of design, safety is enhanced. Of course this meant extra effort in breaking all fuses, circuit breakers, and disconnects for both the positive and negative circuits since both "+" and "-" circuits are ungrounded. I even went as far as double-breaking the PV circuits as well. The MORNINGSTAR equipment double-breaks the PV/Charge controller circuit.

AC Upgrade. During the DC wiring operation, I decided it was a good time to perform an AC upgrade as well. In many places the lighting fixtures, switches, and receptacles are mounted side-by-side. Besides adding some CODE-required receptacles in the kitchen and arc fault protected CB's in the main AC-service panel box, I used a minimum of 12 AWG sized wiring to improve efficiency and safety.

As part of the upgrade, I also ripped out the two 220VAC (one was rated 17.7Amps) convective baseboard heating registers and replaced them with flush-mounted eheat/envi units (rated 475W max.- made in the USA by a Tennessee-based company). I got the idea from Andy Kerr's backup heating system (*The Path to Greener Buildings* H.P.135). Although eheat makes replacements easy by offering a line of 220VAC models, I chose to switch over to the less complicated 120VAC units and put in three different variations of them:

- 1 hardwire with built-in thermostat
- 1 hardwire remote thermostat unit
- 1 jet-black colored 120VAC plug in style

I also covered over my faulty electric burner on my 220VAC electric range with a single "burner" magnetic induction plate ("the off-gridders' choice – tip from SEI instructor Jay Peltz; also referenced in H.P.#179.59 *Heliospiti at 5 Years*). Measurements with my 220VAC EKM meter (for the 220VAC range) and Kill-O-Watt meter (for the induction plate) showed a 48% energy reduction in cooking the same food!

"Mr. Induction" brand 1300W magnetic induction plate – ordered through The Home Depot

EKM 220VAC (left); 120VAC Kill-O-Watt (right)

Making my own battery cable terminals.

Banking off of the training I received via a hands-on workshop held at SEI International in Paonia, Colorado, I decided to dive right in and start making my own custom battery cable terminations. After scoring on a used battery cable crimper from a local Amish-owned small engine repair shop, with a bit of practice I eventually got the hang of it. The most important part is filling the entire lug cavity with crimped wire. A good indication of your success rate is to cut and examine a cross section.

Regarding the crimping process, from the videos I have seen, a good method that can be used in pre-fabricating cables is to crimp the lug in a vice. Being that I do not have one yet coincident with the non-practicality of trying to hoist the vice up near a terminal box in instances where the cable is already in place inside the conduit for those tough custom-fit applications, I found that holding the cheek side of a 3-lb sledge underneath the lug while chasing the top side with a hammer after making the crimp with the crimpers makes for an even, smart-looking bond.

Tools of the trade: bolt cutters doubling as a cable cutter; heavy duty cable crimpers; 3lb sledge; claw hammer posing as a chasing hammer; 3/0 battery cables; 3/0 battery lugs w/ ¼”; 5/16”; 3/8” eyelets. Inset: x-section of a crimped cable.

Lessons learned.

<u>CB Tripping</u>. On two of the 12VDC receptacle circuits, the CB's kept tripping when attempting to close them for the first time. Turns out that I had inadvertently over-twisted the positive center pole, twisting it past its seat so that it's 90° flange brushed up against the negative outer cylinder. I ended up taking apart all the receptacles again and cutting off the positive metal flange at its base.

<u>Combiner box.</u> In sizing the strings so that they met the voltage input requirements of my charge controller, I habitually multiplied the Voc by the cwf (cold weather factor – 1.21 in State College, Pennsylvania) taking the value from the table found in NEC 690. This gave me a 47.8V per module. But lo and behold, the temperature coefficient for these -equipped DC-optimizer SumPremes is listed as -0.00%/C (a phenomenon I since found out was addressed in H.P. 162.72 *Module Level Performance*), meaning I could have used two strings of three instead of three strings of two since the total non-derated Voc of three modules in series is 118.2V (comfortably below the charge controller's 125V input limit). This would have saved me the time and expense ($132.00) of not having to install a combiner in lieu of a couple of "Y" connectors ($20.00). If I had only read the solar module spec sheet first!

<u>12VDC vs. 24VDC.</u> I kinda broke the general rule of thumb for sizing the voltage of a battery bank (generally: 12V for <1kW; 24V for 1-2kW; 36V for 2-3kW; 48V for 3kW+). My PV system capacity is 1.86kW. Not wanting to spend an extra $2,700 at the time to get ten more NiFe's to make a 24VDC system, or to take another efficiency hit with a linear DC voltage booster, and not being sure of the availability of 24V appliances anyway, I trudged ahead with the 12V plans. In retrospect, it would have been well worth the time saved not having to wrestle with heavier gauge wire, and the dollars which could have been saved with thinner conductors.

<u>Melted bulbs.</u> Turns out my cheapo 12Vdc bulbs purchased from Banggood Tech. did not quite cut the mustard. They started melting within a few hours after use. My guess is that they are unable to roll with the typical 14 – 16.5Vdc supplied by my NiFe Battery bank. I plan to replace them all with higher quality HALCO brand bulbs rated at 10- (supplied by commercialbulbs.com). I already purchased the GU5.3/Gu10 base adaptors needed for the HALCO bulbs, but the $16.95@ price for them is going to hold me up for a while.

Melted 12Vdc bulbs from Banggood Tech.

Future Plans

Flywheel bicycle generator. Gleaning information from a website article on how to build one's own flywheel bicycle generator out of plywood and steel (http://www.los-gatos.ca.us/davidbu/pedgen.html), I think I can produce approximately 400Wh of energy with two 45-minute bicycling sessions, probably enough to power my refrigerator for a day – all for roughly $600. I aim to hard wire a wall socket with a one-way diode and dedicated charge controller, connecting to my battery bus bar for direct charging.

Hydride storage. Motivated by a self-sufficient house developed by Empa (Swiss Federal Laboratories for Materials Science), my goal is to purchase a couple of hydride storage cylinders, in conjunction with an electrolyzer kit, and use PV power to fill them with hydrogen. An interchangeable cylinder could then be loaded under a catalytic hydrogen stove (https://www.empa.ch/web/self/hydrogen-cooker - developed by Empa). I would like to implement the concept of extra energy in high production months being stored in hydrides in order to cover seasonal discrepancies, obviating the use of extra storage batteries (hydrides are suitable for long-term storage at regular atmospheric pressures), and then tapping into it during the winter months not only for direct use in cooking and heating but also to generate, via fuel cells, extra electricity when I need it. Especially for off-grid living, I hope to display what that balanced relationship between PV and hydrides can do - no extra summertime energy generation going to waste, and no extra input needed throughout the low solar insolation months.

Hot water dump load. After riding out this first winter, by spring I hope to install a DC electric element, as an over-production dump load, into the building's existing 50-gallon electric hot water tank.

Major components summary and price

Materials = $14,357

Modules: (6) x Sunpreme GxB310W w/ built-in DC optimizers (kit supplied by CIVIC Solar):	$2,697
Batteries: (10) x NiFe 300Ah; 1.2V (supplied by Iron Edison, Colorado):	$2,698
Refrigerator: 9.5cf 12/24 SunStar (supplied by Stored Energy Products Tech.-Florida):	$1,275
Aluminum angle (2”x2”x1/4”) (supplied by OnlineStructuralMetals.com):	$480
Lighting: 12VDC fixtures and bulbs: (12VDC GU10 bulbs supplied by Banggood Tech.):	$322
MidNite Solar MNDC 125PLUS main panel:	$264
C.controller: Schneider Electric C40 w/ remote temperature sensor and battery monitor:	$233
MORNINGSTAR 150L GFPD:	$163

PV DC disconnect IMO (supplied by
Industrial Control Direct)-50Amp $127
Battery box (LIFETIME brand) 80gal: $116
Labels-laminate and placards (supplied by
PVLabels.com): $35
(All prices include shipping)

Closing Remarks

In setting out to maximize energy harvest from a tiny production area and to de-mystify storage application of the nickel-iron battery all the while keeping to a direct current system basis, I learned a lot about design integration, parts availability, pricing, suppliers, and installation techniques. Hopefully I have been able to answer many questions that people generally have while providing encouragement to tackle similar projects. □

<u>Addendum</u>

Snow and wind loads: determination of triangular bracing attachments.

In order to determine the lag bolt thread depths for affixing the braces to the wall I needed four pieces of information: 1) the span for supporting the rails; 2) the number of attachment points; 3) the snow and wind load data; 4) and the type and thickness of the wall material. 1) According to the manufacturer's specs for my Unirac rail, it needs supports every 4ft. 2) Eight braces x 2-attachemnt points each = 16 attachment points.

Wind and snow load analysis

The Meetinghouse PV/Battery Grid system 01/18/2017

<u>Pressure Force Load Calculations</u>

1) Snow Load: State College: <u>30psf</u>

2) Module – 310gSB SunPreme: 55.6lbs/17.7sf – <u>3.14psf</u>/module

3) Racking: (8) braces x 6 lbs/brace + 54' rail at 1lbs/ft spread over 51.8sf (27' wide x 1.92' contact with wall) = 103lbs/51.8sf = <u>1.99psf</u>

4) Design Wind Pressure: Exposure B; 90mph zone; <25': siimplified procedure = <u>14psf</u>

Total: **49.1psf.**

<u>Design Live Load.</u>

5-module overhang x 17.7sf = 88.5sf x 49.1psf = 4,345lbs

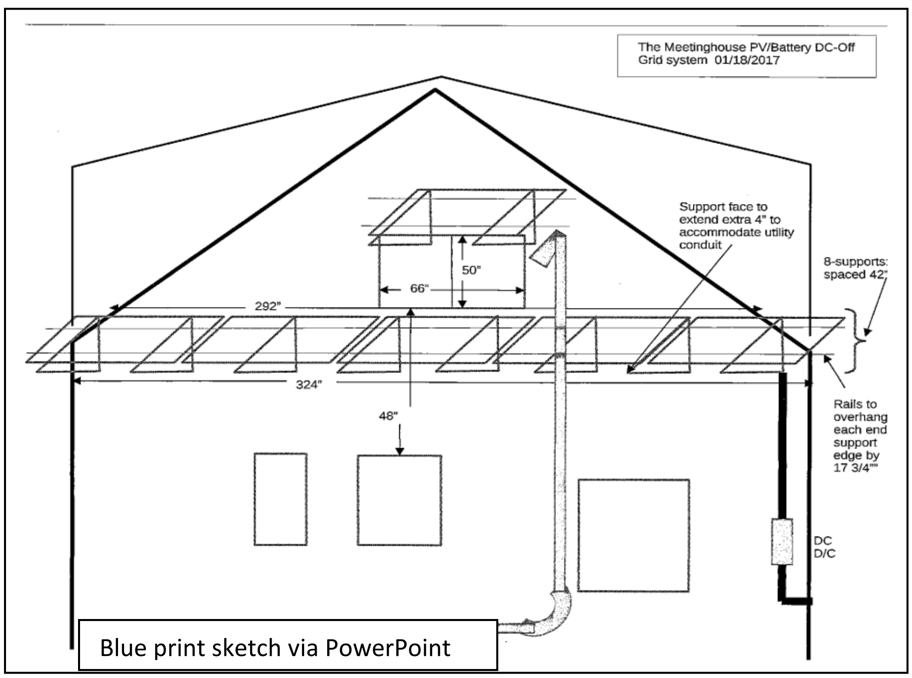
8-braces with (2) attachment points @: 4,345lbs/16 = 272lbs/attachment

Wall = 3/4" cedar (238 value) and 1" hemlock(311 value) ~ 279 value for 3/8" lag (244 value for 5/16" lag)

Minimum thread depth for **3/8" lag = 1"** (1 1/4" for 5/16" lag).

Mike making first aluminum angle brace attachments:

3) Snow load: downloaded data for my area. Wind load: after searching the Internet, I downloaded the "simplified" approach method to calculate wind load for a wall, plugged all the numbers in and came up with 49.1psf. 4) I had 1 ¾" total wood thickness and averaged the two types of layered wood, downloaded the appropriate values and divided the result into the pounds per attachment to get the minimum 1" thread depth. I chose 2" thread after making slight left-to-right adjustments in order to position the brackets over the vertical wall studs, and screwing into them. (Excellent resource for obtaining thread depth values based on specific gravity of wood: *National Design Specification for Wood Construction* [http:// www.awc.org/ pdf/ codes-standards/ publications/nds/AWC-NDS2012-ViewOnly-1506.pdf](http://www.awc.org/pdf/codes-standards/publications/nds/AWC-NDS2012-ViewOnly-1506.pdf); or H.P.161.45 *The Right Fit*).



Blue print sketch via PowerPoint

About the author: Mike is a NABCEP solar designer and installer in the Pittsburgh area. He is founder and President of Redstone Renewable Energy, LLC. When off duty he enjoys writing, activism, volunteering at local farms, and composing songs.