EHS/MCS Refugee Hut Design

by

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I have significant sensitivities to cell phone and WiFi signals, 60 Hz magnetic fields, and many foods and drinks. I have Electromagnetic HyperSensitivity (EHS) and Multiple Chemical Sensitivity (MCS). I want to build a small house, reasonably adequate for one or two people, on some property I own in the town of Rockvale, Colorado (about 40 miles southwest of Colorado Springs). This document is my attempt to design such a small house, or what might be called a refugee hut. I am sharing my design with the hope that others in the EHS/MCS community will find suggestions for their own building plans and also for others to make suggestions for improvements in my design.

ON GRID OR OFF GRID?

It is 1170 ft from the nearest power pole to the center of the hut. For a few thousand dollars the power line could be extended to the hut and I could enjoy all the benefits of a central electric supply. I have decided to not do so, but to spend probably a lesser amount on photovoltaic panels. The hut will have batteries for lights and electronics but will not have an inverter (a device that converts dc to ac).

There was a battle called "The War of the Currents" fought in the early 1890s between Thomas Edison and Nikola Tesla. Edison had developed a dc system and Tesla had patented an ac system. The battle was fierce! Edison took the position that ac was inherently dangerous to human health. He would go to county fairs, catch a stray dog, and electrocute it on stage with ac. He even once electrocuted an elephant! He persuaded the New York State Legislature to adopt electrocution (by ac) as the method of executing criminals rather than hanging. But society went with the lower cost and greater convenience of the ac power grid, ignoring the safety aspects. The Tesla system is universally used today. We accept the accidental electrocutions as part of the cost of doing business.

I believe Edison was right about 60 Hz electricity being dangerous, not only for electrocutions but also the low level (and probably accumulative for many of us) effects of 60 Hz electric fields and 60 Hz magnetic fields. AC electricity has not been universal for all that many years. My parents and I moved into a house with electricity when I was 11 years old. I distinctly remember the satisfaction of having a better source of light for reading than the coal oil lamps we had used up to that time. So we are quickly reaching the point where *all* the elderly have been exposed to 60 Hz electric and magnetic fields their *entire* lives. If the accumulative effect of these fields has negative health effects, we would expect life expectancy to decline, along with the quality of life of the elderly. I believe we are seeing exactly that in this country! People blame this decreased life expectancy on all sorts of causes: increased use of drugs, obesity, pesticides, herbicides, cell phones and WiFi, etc. I will not argue against any of these having a significant effect, but we should not ignore the 60 Hz electric and magnetic fields.

If I am right, then continued use of 60 Hz electricity would be as stupid as continuing to smoke after seeing convincing data about lung cancer. We need to shift entirely to dc. DC has both electric and magnetic fields, but mankind has been living in dc fields for thousands of years without obvious ill effects. The earth has a net negative charge which causes a vertical electric field on the order of 100 V/m, directed downward. The earth's magnetic field is on the order of 500 mG, used by many lifeforms (including man) for navigation. Many with EHS have significant problems with 60 Hz electric fields above 1 V/m and magnetic fields above 3 mG, but no problem at all with the much higher dc fields.

The plan is to entirely avoid any 60 Hz voltages or currents. If electric motors or pumps are necessary, and they produce fields at frequencies above, say 10 Hz, then these devices should be separated a maximum distance from the living space.

SIZE AND LAYOUT

Size and layout are mostly a function of one's personal taste. Nothing is inherently good or bad about choosing 1600 ft^2 over 800 ft^2 or 400 ft^2. I chose an outside dimension of $20' \times 40'$ for the living portion, split into a combination living and kitchen area, a bedroom with walk-in closet, and a toilet/shower room. This is an experimental structure so there needs to be adequate space for experiments. I chose to attach a $10' \times 24'$ utility room on the side of the living space. This is unheated space for batteries, water heaters, pumps, and instrumentation.

WATER

Town water is available near the last power pole. It would be technically feasible to trench a pipe from the existing water supply to the hut. Water pressure is low at the connection point, barely enough for the adjacent house. It would not be enough to reach the hut without the addition of a booster pump. Town water is relatively expensive (I think $6000 for a meter and then $50/month plus water usage). My plan is to put a 1500 gallon tank inside the utility room and collect rainwater for house water usage.

SEPTIC

The town of Rockvale does not have a central sewage treatment plant. Everyone is on a septic system. Colorado has recently changed the rules on septic systems, making them more expensive. Certainly the water required for flush toilets is a problem here in the high desert. I have read the book *The Humanure Handbook* by Joseph Jenkins (both the second and third editions) and agree fully with him that it is better to compost our humanure and use the resulting compost on our gardens. One poops in a five gallon bucket, covers the poop with sawdust for odor control, and dumps the bucket on a compost pile when full. He has walked the walk, raising a family in Pennsylvania using this technique. He claims there has never been a documented case of disease transfer while using compost toilets. I had a 62 year old woman with severe EHS and MCS live in my shop for two months, and used a compost toilet for that time without complaint. Jenkins acts as a resource person for government bodies considering how to best handle our 'waste', and comments that some states (Arizona, California) are relaxing their requirements for flush toilets in favor of compost toilets. This hut will use a compost toilet.

GRAY WATER

Also known as grey water, this is the household output from showers, washers, and the like. It is distinguished from black water, the household output from flush toilets and garbage disposals. There are the usual bureaucratic rules, but it is generally legal to use in wetlands, on gardens, etc. I plan to install three plastic drain pipes under the concrete slab, one from the floor drain in the utility room, one from the shower and vanity in the bathroom, and one from the kitchen sink, draining to daylight on the downhill side of the hut. This area will be a small garden after the removal of rocks and the addition of rabbit manure and compost.

HEATING OPTIONS

Heating options include wood, propane, passive solar (sunlight through south facing windows onto the thermal mass of a concrete floor), solar thermal (direct heating of water in solar receivers, and photovoltaic. Wood is a common heat source for off grid cabins. There is not enough biomass growing on my 60 acres to supply a wood stove long term, but I am sure that wood can be acquired from area sawmills or tree trimming crews. I would like to put a dozen or more similar cabins on this property and wood smoke from all these cabins would definitely lower the air quality in the gulch. The main argument for me is that I might want to live in this cabin past the age of 85 or 90, when handling wood is no longer physically possible. I also do not like the dust and ash that are associated with a wood fire. So wood is rejected.

Propane is also a common choice for off grid cabins. One can heat with it, cook with it, and even use it for refrigeration. It works for us old geezers! I have never experienced any reaction from propane fumes. But I know people who are extremely sensitive to propane. They need to isolate the propane appliances from the air in the living quarters, perhaps cooking outside, or using strong exhaust fans. This is a research hut, hopefully safe for a large fraction of the EHS and MCS population. Propane is a known problem to some of us, so it is rejected.

Passive solar has been well known for many years. It is easy to find guidelines on the Internet for the size of the south facing windows and the amount of overhang necessary to shade the windows in the warm months. It requires a bit of management to work well, such as closing curtains at night to prevent heat loss back outside. It also requires some tolerance for a diurnal temperature swing of 5-6^{o}F or more from late afternoon to early morning. And the house will cool off significantly after a couple of days of cloudy, cold weather unless there is some form of backup heat. I do not do well with wide diurnal temperature swings and do not want to put in any backup heating system so passive solar is rejected.

Solar thermal was a bit of a fad 40 years ago. I just do not see very many people using it today, suggesting it does not live up to its hype. I have tried resurrecting old technologies in research projects in the past, and found out that they were dead for a reason. Without further discussion, solar thermal is rejected.

Using photovoltaic (PV) panels for space heating is a relatively new concept. Just a few years ago, PV panels would have produced space heating at a cost perhaps ten times as much as one could heat space with wood or propane. But PV panel costs have dropped to where it is thinkable to do it. There are plenty of research opportunities regarding heat storage, smart thermostats, etc. so this is the technique I will try.

HEAT LOSS AND INSULATION

How many PV panels are needed to heat the hut? This depends on the heat loss through the building exterior and also on my tolerance to how many days per year the building temperature dropped below some desired level. It will take more panels to keep the hut temperature above 65^oF except for one day in ten years, than to keep the hut temperature above 55^o except for ten days per winter. I think I will go with the minimum number of panels and just move into the grid connected shop or house if the hut gets too cold.

It will also take more panels to heat a poorly insulated building. There is a direct correlation. I can either buy more panels or buy more insulation. We have enjoyed cheap energy in the USA for many years, so the common practice has been to put in minimum insulation to save on the initial cost, and let the poor house buyer pay larger monthly utility bills. The building codes specify minimum insulation levels well below what is easily achieved. I think I will go with a well insulated or even superinsulated hut, at least R30 for the walls and R60 for the ceiling.

One way of reaching R30 for the walls is to build a double wall. In my case this will be a standard 2×4 wall with 24" spacing on the exterior, then a 2" sheet of foam insulation, then another 2×4 wall with the studs offset by 12" from the studs of the first wall to prevent thermal bridging through the studs. There will be fiberglass batts between the wall studs. With nailers and metal siding, the overall wall thickness will be on the order of one foot thick. The interior space of the living portion of the hut will be about $18' \times 38' \times 8'$. The gross wall area is $(2)(18)(8) + (2)(38)(8) = 896$ ft^2. There will be one door of standard $3' \times 6'8$" size or 20 ft^2. There will be three windows of about 12 ft^2 each or a total of 36 ft^2. The net wall area is then $896 - 20 - 36 = 840$ ft^2. The ceiling area is $(18)(38) = 684$ ft^2.

The heat loss through a building component is

$$Q = \frac{A}{R}(T_{in} - T_{out}) \tag{1}$$

where Q is the rate of heat transfer through the material in BTU/hr, T_{in} is the inside temperature in ^{o}F, T_{out} is the outside temperature, A is the area in ft^2, and R is the R value of the material. I will be using the notation in the book *Modern Hydronic Heating, Third Edition* by John Siegenthaler. This hut will generally resemble the Morton building recently built on my property. The R values that Morton listed for their construction were 38 for the ceiling, 21.3 for the walls, 3.5 for the double glazed windows, and 1.67 for the doors. I will assume R60 for the hut ceiling, R30 for the hut walls, and the Morton values for the windows and door. I will also assume a target indoor temperature of 65^oF.

Another important heat loss is due to infiltration or leakage. Siegenthaler gives an equation for this, Eq. 2.8, as

$$Q_i = (0.018)(N)(V)(\Delta T) \ \ \text{BTU/hr} \tag{2}$$

where 0.018 is the heat capacity of air, N is the number of air changes per hour, V is the interior volume of the heated space in ft^2, and ΔT is the inside air temperature minus the outside air temperature in ^{o}F.

The long term average temperature for Canon City in December and January is 33.75^{o}F. I hope to have a hut with several days of heat storage, so a selection of $T_{out} = 30^o$F might be adequate for design purposes. This yields a $\Delta T = 35^o$F.

The various heat losses are calculated as

$$Q_{walls} = \frac{840}{30}(35) = 980 \tag{3}$$

$$Q_{ceiling} = \frac{684}{60}(35) = 399 \tag{4}$$

$$Q_{windows} = \frac{36}{3.5}(35) = 360 \tag{5}$$

$$Q_{door} = \frac{20}{1.67}(35) = 419 \tag{6}$$

$$Q_i = (0.018)(0.4)(18)(38)(8)(35) = 1379 \tag{7}$$

Siegenthaler shows in his Fig. 2-15 that $N = 0.4$ air changes per hour is appropriate for the "best" construction.

The sum of the above heat losses is 3537 BTU/hr, or 84888 BTU/day, or 24.9 kWh/day. That is, we need our PV panels to provide an average of 24.9 kWh/day to meet our average heating needs.

SOLAR PANELS

Photovoltaic (PV) panels have gotten cheap in the last few years, so are being installed in large numbers, including by homeowners. One would assume that the Big box stores would carry at least one or two brands and several of the popular sizes. But that does not seem to be the case. One surfs the Internet, orders a particular panel, and waits for delivery by an 18 wheeler. (The appropriate panels are too large/awkward/fragile to ship by FedEx or UPS). They come on a pallet that requires a fork lift to take off the truck. The truck will deliver a pallet of say 10 panels to a commercial address (that has a fork lift) for perhaps \$150 or to your home for perhaps \$300. For home deliveries, the truck carries its own fork lift on the rear of the truck. My hut is located along side a narrow, steep driveway that does not have room for an 18 wheeler to turn around, so I will have to ship panels to some place where they can be unloaded, then manually transfer them to my F-150 for the final transfer to the hut.

I identified six manufacturers that have at least some manufacturing capability in the USA or Canada. These are

1. Heliene Solar, Ontario
2. Mission Solar, San Antonio
3. Seraphim, Jackson, Miss.
4. Silfab Solar, Washington State
5. Solar Tech Universal, Florida
6. Sun Spark Technology, California

I like the looks of the Mission Solar MSE375SQ9S, 375W, 78.23" × 39.33" × 1.57" (close to 2 m by 1 m), 72 cell, V_{oc} = 48.16 V, V_{mp} = 39.76 V, I_{sc} = 9.83 A, I_{mp} = 9.43 A, efficiency = 18.89%, 47.6 pounds. The lowest bid I got over the phone was \$236.54 each for quantity 10, plus \$275 shipping, plus \$192.78 tax for a total of \$2833.18. This bid was from www.solarpanelstore.com in New Castle, Colorado (not far from Grand Junction). The panels would be shipped from their California warehouse and could be picked up at their facility in New Castle. This 3-4 hour trip one way would be tempting in the summer. But not so much in February when roads through the Continental Divide are likely covered with snow and ice.

The power output of 375 W is obtained at standard conditions of 1 kW solar radiation per m^2 and the panel aimed directly at the sun.The power output drops with increased cloudiness, increased angle to the sun, and increased ambient temperature. The power output may exceed 375 W slightly on a cold, clear day, especially if there is snow on the ground.

It is possible to build trackers that keep the panels pointed at the sun, but at this low price for panels, the small amount of extra energy would not begin to pay for the tracker.

For fixed panels, the power output at any moment is given by the solar radiation in W/m^2 times the cosine of the angle between the normal to the panel and the sun times the panel area in m^2 times the efficiency. Using spherical trigonometry to determine the angle can be a bit tedious. The National Renewable Energy Laboratory (NREL) has written a nice online program to do this, available at pvwatts.nrel.gov. You enter the tilt and the azimuth of the panel and it gives you the monthly average integrated solar radiation on the panel surface in kWh/m^2/day. Just multiply by the efficiency and you have the desired daily energy production.

The average solar radiation for the months of November-March is about 5.6 kWh/m^2/day. The area of each panel is close to 2 m^2. The average energy production is $(5.6)(2)(.1889) =$ 2.12 kWh per panel per day. We needed our panels to provide an average of 24.9 kWh/day, which requires $24.9/2.12 = 11.75$ panels, which we round off to 12 panels.

HEAT STORAGE

We have chosen to not have energy storage in the form of a wood pile or propane tank. There are two other methods of storing energy, in batteries or in thermal mass. Batteries are expensive, have a relatively short life, and generally require considerable care in charging and discharging. I will look at thermal mass first. In our situation, the best thermal mass is water.

Home Depot sells a Vestil 275 gallon intermediate bulk container for $527 that is rated to 190^{o}F. PV panels can be connected to resistive heating elements in this tank to heat the water. The hot water can then be pumped through PEX tubing in a concrete slab to heat the hut.

Water weighs 8.344 pounds per gallon, so 275 gallons weighs 2295 pounds. It takes one BTU to raise the temperature of one pound of water one degree Fahrenheit, so at 170^{o}F the tank holds 229,500 BTU more than at 70^{o}F. This is the same as 67.3 kWh. If we got zero power from our panels for several days, it would take $67.3/24.9 = 2.7$ days to lower the water temperature to 70^{o}F.

The concrete slab itself is a large thermal mass. I calculate that it requires 2.73 kWh to change the slab temperature 1^{o}F. So if we had a long period with zero power from the panels, the hut and slab temperature could be maintained at the desired level for 2.7 days by water heat storage, and then would drop only 10^{o}F the following day due to concrete heat storage.

I perhaps should be concerned about putting very hot water into the concrete slab. Heating and cooling will cause expansion and contraction, which may produce popping and cracking noises. It may also cause cracks in the slab, even disintegration. One possibility would be to install a second 275 gallon tank. Half the panels could be connected to resistors in one tank and half to the other tank. I could get my 2.7 days of storage with a ΔT of only 50^{o}F rather than 100^{o}F.

HYDRONIC SYSTEM THERMOSTAT

I personally have no experience with hydronic heating. Information on the Internet suggests that it is a very nice system regarding the thermal comfort of the house occupants. But it seems that the 'standard' practice is to have a boiler that heats water to a desired temperature, slightly above room temperature, before it is circulated through the PEX tubing. The circulation pump is on a good fraction of the time, even up to continuous operation. This obviously does not work when the storage tank is kept at 170^{o}F! Even 120^{o}F water would overheat the space with continuous pumping.

PEX comes in sizes from 3/8th inch to 1 inch or more. I arbitrarily chose the 1/2 inch size. According to Siegenthaler, flow rates for 1/2" PEX should be kept between 1.2 and 2.4 gpm (gallons per minute). The maximum allowable length of 1/2"PEX in underfloor heating is 300 ft. I assume that two circuits will be needed in this floor, or a maximum of 600 ft of PEX. This length of 1/2" PEX holds 11.54 gallons of water (96.3 pounds). A circulation pump that pumps at a rate of 2.4 gpm is able to replace the entire 11.54 gallons in $11.54/2.4 = 4.8$ minutes. If the 11.54 gallons was originally at 170^oF and cooled to 70^oF it would have transferred $(96.3)(100) = 9630$ BTU = 2.82 kWh to the concrete slab and on to the hut interior. To transfer a total of 24.9 kWh to the hut the pump would need to operate less than 9 times per day, for a total of about 42 minutes per day.

This will require a *very* sophisticated thermostat. I anticipate measuring the indoor temperature, outdoor temperature, water temperature, and maybe wind speed (infiltration loss), inputting these numbers into a computer, and calculating the minutes to run the pump and the proper delay before running the pump again. It could easily take an entire heating season to get the computer program working properly.

PV PANEL CONNECTIONS

The PV panels are connected to electric heating elements in the hot water storage tank to heat the water. Connecting several panels in series will enable the use of smaller wires and increase the fraction of solar energy actually delivered to the water. The maximum power point voltage for the Mission Solar panel is 39.76 VDC. The maximum power point current is 9.43 A. Connecting six of these panels in series would yield 238.6 VDC, very close to the widely used 240 VAC value. The power output of six panels at maximum solar radiation is $(375)(6) = 2250$ W. The load resistance needs to be $R_{mp} = V_{mp}/I_{mp} = 238.6/9.43 = 25.3\Omega$.

This cannot be a single fixed resistance due to the fact that PV panels are current limited, with the current proportional to the number of incident photons. If the available solar radiation drops in half, the available current immediately drops in half. The voltage only decreases slightly. Half the current at about the same voltage means the load resistance needs to double. I need a variable resistor heating element, or several switched fixed elements, that can follow the variation in solar radiation, and get the maximum energy from the panels as the radiation varies through the day. The elements need to be rated for 240 VDC.

One way of dealing with load resistances is to have several in parallel. I will illustrate with the choice of five resistors, all the same value of $(5)(25.3) = 126.5\Omega$. One of these resistors is permanently connected to the panels and absorbs all the available energy until it rises above 20% of the maximum. At that point a second resistor is switched into the circuit. The two resistors absorb the available energy until it rises above 40% of the maximum. The last resistor is switched on when the available energy rises above 80% of the maximum. Resistors are switched out as the solar radiation declines late in the day, or as clouds come by. The wattage rating of each resistor needs to be $2250/5 = 450$W. We have a problem in that the water heater elements available at the big box stores have ratings from perhaps 2500 W to 5500 W at 240 VAC. The corresponding resistance values range from 23Ω to 10.5Ω. The available resistances are much too small. One could get fairly close to the desired values by putting several of the commercial resistors in series, but this is costly and complicated.

I may have to wind my own resistors. One possibility would be to use copper magnet wire, which has a insulating coating that should remain intact well above the boiling point of water. Each resistor will see a maximum current of about 2 A, so 30 gauge wire might work. The resistance of 30 gauge copper wire is 103.7 Ω/1000 ft. It therefore requires 1225 ft to obtain a 126.5 Ω resistor. A close wound coil 4" in diameter and 14" long would have about this much wire. I would place this coil vertically in the bottom of the water heating storage tank, on a small support which would allow water in the tank to circulate through the center of the coil. One immediate problem is to find a coil form that maintains its integrity at the temperture of the boiling point of water, or even a little above. This would probably be ceramic or perhaps pyrex glass.

Another possibility would be to use a resistance wire such as Kanthal wire. This wire has a resistance 12.4 times that of a copper wire of the same size. I bought a 2000' spool of 20 gauge Kanthal wire on Ebay to test. It will take about 150 turns on a 4" diameter coil form to get the needed 126.5 Ω resistance.

COOKING

We have 12 PV panels dedicated to heating water for space heating during the heating season. We also need hot water at 120^oF for a shower, and energy to cook food. Part of the shower water goes down the drain and is lost to the heating budget, but energy used for cooking stays in the living space unless an exhaust fan is used. At noon voltage of each cluster of six panels will be close to 240 VDC, quite adequate for operating an electric stove element. We will need to use a Power MOSFET as a switch since the standard mechanical switch will not be able to turn off a direct current. All mechanical switches arc as they open, and the arc dissipates as the AC voltage goes through zero 120 times per second. But a direct current driving an arc never goes to zero, so the arc just continues until the switch is destroyed.

This will be a lifestyle adjustment for some people, doing the cooking and eating the main meal of the day around noon when the electrical power is available. I grew up on a small farm in eastern Kansas. Our main meal was at noon and we called it *dinner*. The evening meal was then *supper*.

BATTERIES FOR LIGHTING AND ELECTRONICS

Besides hot water and cooking (without batteries) we need a steady source of power for lighting and whatever electronics we might bring into the hut. This means batteries, of course. I am leaning toward a 24 VDC system. I bought four deep discharge 6 V Trojan batteries for a test system a number of years ago. They functioned well, so I might go that route again. These are very heavy batteries that hold about 1.5 kWh each, or 6 kWh total. It is strongly recommended that one not discharge a battery past the 50% point, so we really have 3 kWh of battery storage. Assuming a single panel would be able to put in 2.12 kWh on average each day, the 3 kWh could be replaced in about a day and a half. Or we could buy an extra panel, connect it in parallel to the first, and restore the 3 kWh in less than a day. Or we could buy another four batteries in addition to the extra panel, and have two separate battery systems, say one for the lighting and the other for the electronics. Given the truck delivery of PV panels, it would make sense to buy the extra panel with the others. The extra batteries could be delayed until it was obvious that four batteries were just not enough.