Passive Solar with Embedded Air Tube and Heat Battery House Construction

Part I, Why we build.

Introduction

First off before I get into technical engineering details I thought it would be appropriate to introduce you to who I am, and why I am building. I am an engineer and a bit of a DIY enthusiast as are many of you who will come and view this information. Engineering is my profession, but my childhood was as hardscrabble as likely any in my generation (millennials) are likely to have experienced. My childhood was not one I would consider poor but others would, and do sometimes, certainly seem to think so. It offered me a great advancement in life on learning many skills that are practically a lost art these days. More importantly it taught me to think strategically, to always try and consider the outcomes and repercussions of my actions. As a result of this upbringing I do not take many things for granted; for instance I do not know if it is likely that electrical service or specifically grid connected electrical service will always be something available to myself or my family. I seek to find ways to avoid future risk along these lines in the event that something happens and I am not there I want to do my best to ensure the basics are handled for my family. On a more practical note this will also allow for an earlier more secure retirement should I be lucky enough to get there.

Secondly, there is my family. My wife and I have four young children (soon to be five). Her parents are similarly technical in nature, but without my rural upbringing and have chosen to co-locate with us. My parents are my parents, they taught me almost everything I am from frugality, to how to grow, clean, and can a green bean I owe it to them. Most importantly my parents showed me that there is very little that cannot be accomplished reasonably well by an individual or family even on limited means. It is important to me to raise my children to learn the same lessons as they grow, that I had the opportunity to learn as I grew.

Part II, A farm it is

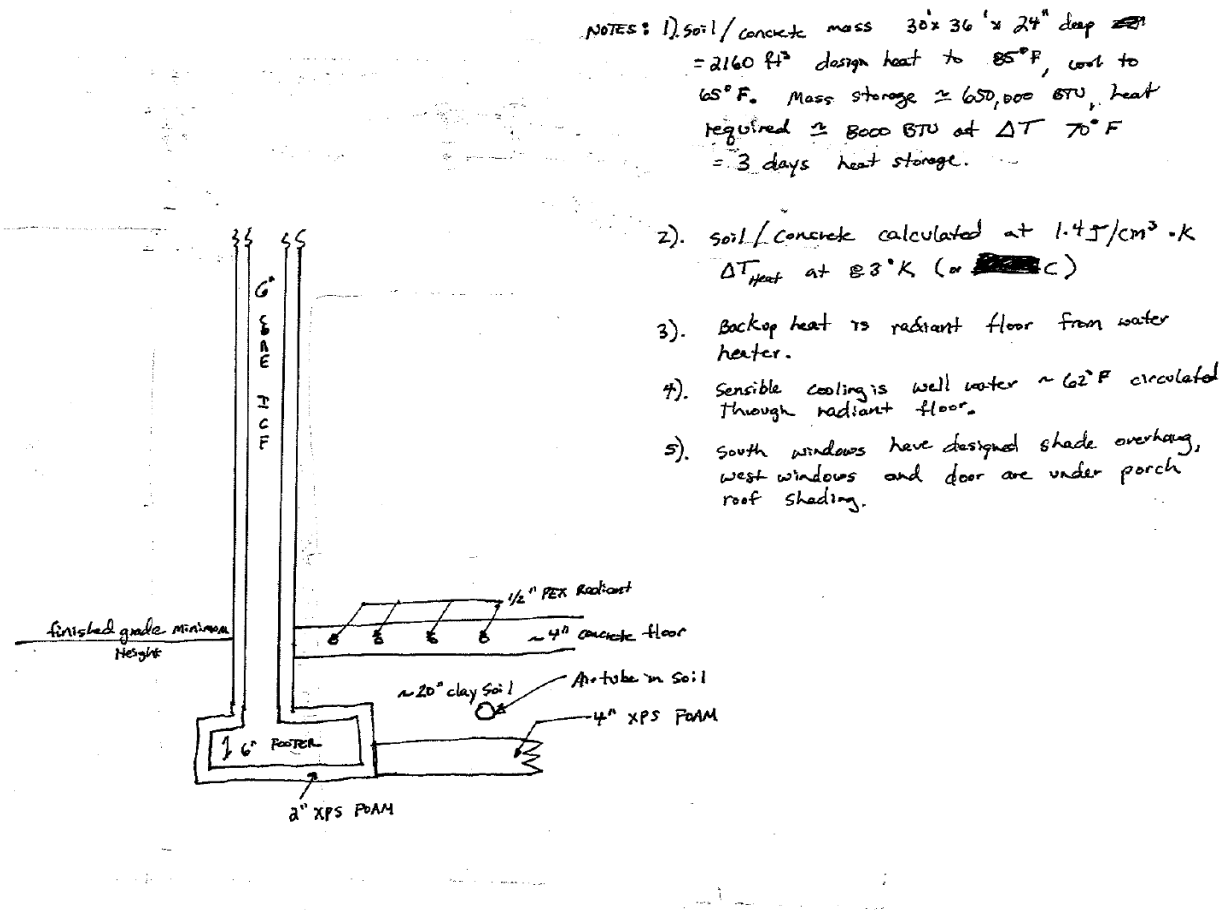
The idea that I would come back to the land was one that was always in my head, and in my own personal plans. Actually, if I had had my own way of things I probably would never have left. That being said the family farm was rather poor ground, and my knowledge of agriculture at the time outside of traditional row crop/ cattle grazing was minimal. I determined that to have a successful farm a technical education and an outside career would have to be a necessary life detour for me. I was lucky enough to find and marry a beautiful woman who also happened to believe in me and my dreams even though she had no background. It just so happens that her parents also grew dissatisfied with a more urban lifestyle and were seeking a place where something could be built that would outlast their own generation. So it happened that after 10 long years city dwelling the search began, and after a year and a half of looking we finally settled on an acreage in SE Missouri. As a part of the search I had primarily been seeking acreages with good water access of multiple types, and good solar potential. We were lucky enough to find such a location both reasonably close to the city for me to work (no I am not yet independently wealthy) but also far enough out for the land to be affordable. What I did do during the intervening 10 years is spend a lot of time developing ideas for self sufficiency, and so with much research including much at BIS I had formulated a plan.

Part III, The location

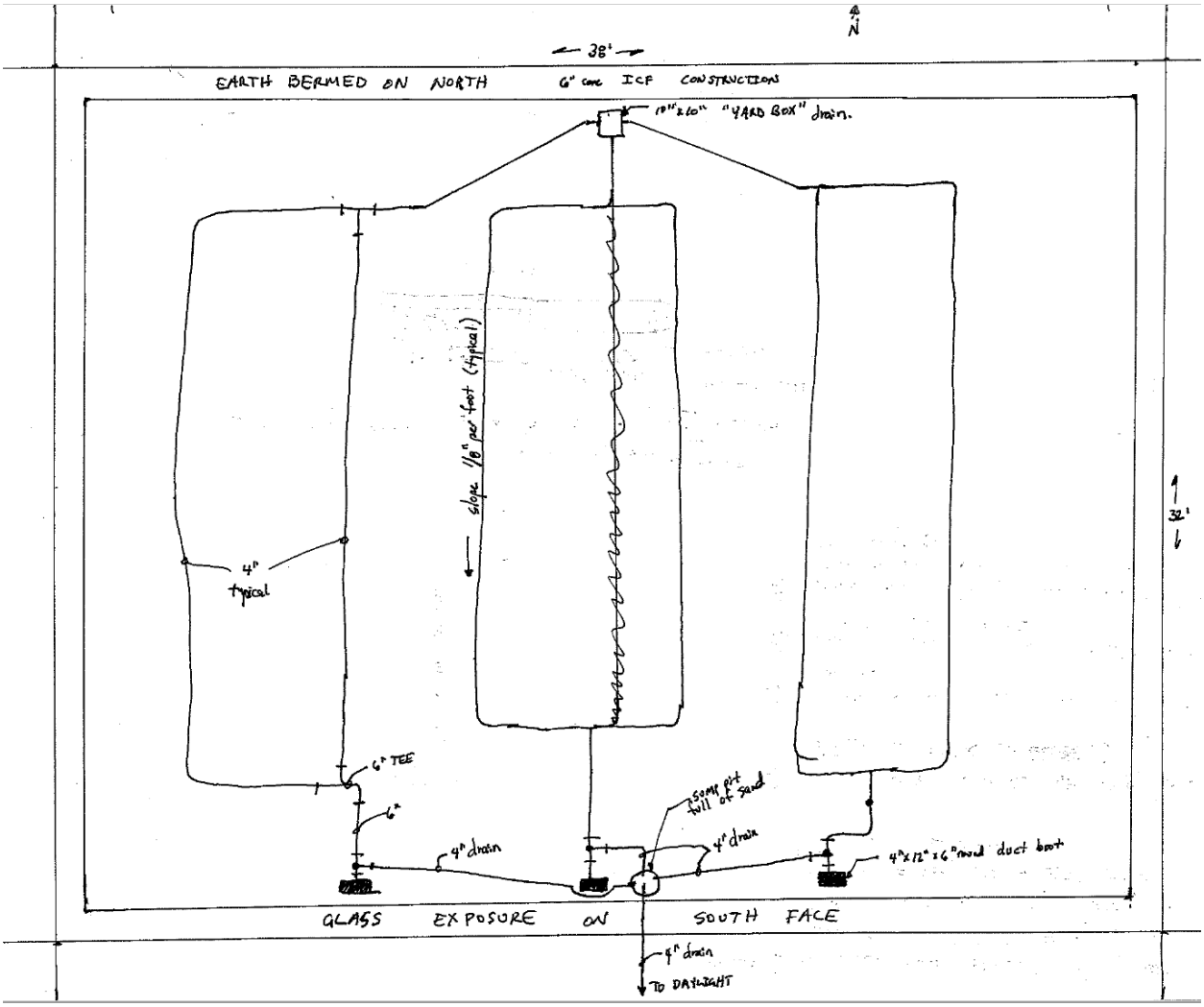
My in-laws, the wifes parents, had purchased the house on the property while we purchased the bulk of the acreage. This left me the task of designing and building a shelter for the family. Now my wife is not a picky type on such things but she does expect a certain degree of normalcy so my initial plan to build a brush lean-to was quickly abandoned in favor of a design which would cost money and time. Initially we had determined to build on a bluff on the property with a sweeping view of the river valley. After doing the initial clearing work we switched gears to a smaller less ideally situated location which was the former site of a trailer due to the location of a well and power line at that point. Not only would this be quicker and less costly to build but it would allow me to test the design concepts on a smaller scale. Also, we had chosen a location with no planning or zoning in place, and no permitting or inspections process. There is much to be said about having the liberty to build as you desire without seeking approval from an army of bureaucrats, who are not prone to approve alternate designs, and also don't really care.

Part IV, The concept.

I have mentioned that BIS encouraged my thinking process in the passive solar design. I actually began with some hands on experiments in solar gain and thermal mass. What I discovered is that a greenhouse or passive solar house can often gather far more solar radiation than it can use during the day, and that the means of storing any excess heat for overnight or cloudy days is very hit or miss. Also most existing designs require mass in the direct sunlight meaning that the most desirable living areas of the house must have a large amount of mass right where you would prefer to put the couch. Also, a stone couch is not as comfortable as it first sounds! I was also fascinated by the concepts of earth tubes for greenhouses and the frugality of keeping a large space productive with only a blower fan to move excess daytime heat into the ground and pull it back out at night. Finally I was fascinated by deep bed thermal storage and the ability to store summers heat late into the fall. What I ended up with for a design was a cross of all three concepts as well as the addition of passive cooling. In my mind heat would be gained via direct solar gain through south facing glass, Excess daytime heat would be collected in a duct and circulated under the floor through an insulated mass of soil, and stored for nighttime use. Heating could then be controlled b the airflow through the duct system, and in the event of a long cold cloudy stretch of weather a standard radiant tubing system in the floor would provide backup heating. Of course once I had radiant tubing in an insulated mass I wondered if it couldn't be used for sensible cooling as well. The plan then was hatched to use well water (~62F year round) to chill the floor slab and thermal mass in the summer, and the duct system to cool and dehumidify the household air to a comfortable level. In any even the house would be built to such an insulation level that if none of the technologies proved of any use at all the place could be easily heated with a small heater, or cooled with a single window air unit.



Elevation view showing ICF walls and the soil heat storage bank.



Plan view showing layout of the air ducts through the heat storage area.

Part V, The construction

The construction work began with groundbreaking. I have a backhoe available to me, but opted to hire a dozer operator for the foundation instead. He was able to do in three hours what would have required me three days or more. I should note that this construction was a six hour drive removed from my home and job though the in-laws had already moved so I did have lodgings on site. I also took delivery of a shipment of BuildBlock ICF forms at this time and staged them on the construction site. Some weeks later I was able to return and construct a simple rectangular footing which was insulated on all sides with XPS foam board. In hindsight I would have approached this process differently, but more on that later. Yet another few weeks later I returned for several days and stacked and braced the ICF forms. In about five man days worth of work, and with about $1500 in lumber and hardware for the bracing, I was ready to pour.

Figure 1The base is set, It's muddy

The concrete pour was interesting, first of all there was no concrete pump, but a telehandler truck. This is more of a conveyor system than anything else, but I imagine it has multiple good uses around a ready mix plant. It did the job admirably and for a budget price so no complaints from me. Also, the pour was accomplished in one mono-pour meaning the footers and wall were poured concurrently. Finally you may have noticed a lack of rebar in the ICF forms; for reinforcement I used Helix Microrebar. This product is a complete rebar replacement and is mixed directly into the concrete in the truck at the ready mix plant. This product was also used in all the flatwork later.

Next came the below grade systems: Air tubes, plumbing DWV, and radiant tubing. Initially the soil was covered with 4" XPS foam insulation, the same stuff used in the footer, and also as walkways to keep me somewhat out of the mud. The Insulation was covered with ~4" of soil, and air tubes were assembled and laid out. Since the air tubes ducting has no flow control some design effort went into trying to ensure an equal run length and number of bends so that the air will hopefully be distributed evenly.

Each run is 6” pipe split into two 4’ runs and recombined into a single 6” outlet. All runs are sloped to a sump pit to remove (hopefully) any condensate water from the system.

Pretty standard plumbing, nothing remarkable here really. In the rear of the last photo there is a 6” make-up air tube for fresh air, and a wall penetration for the potable water intake. Excess cooling water will also exit here and into the drain tile system which when collected in a cistern will be used to water the yard and the garden.

Finshed rock grade was reached, and steel remesh was used to secure the radiant tubing. In this case the remesh is not used as a concrete reinforcement though it may offer some benefit there. The main reinforcement is again the microrebar. In the foreground you see standard 6” duct boots for the air tube registers. To the layman this house will look like any other with maybe the exception of thicker than normal walls.

Concrete is poured. Ready for final grading and some grass.

Now for the after action: So far progress has been steady and only minor issues have occurred.

- Excessively muddy conditions were a general pain to work in, next time I will do an initial rock grade and lay out all the foam board all the way under the footer in one continuous flat sheet. This will improve constructability and keep me out of the mud. The soft ground also meant I should have used more bracing in the footer forms, I had some buckling during the first lift of footer/wall monopour but everything held in the end with some quick additional bracing.
- Filling the thermal battery with soil required going through the low wall section at the front repeatedly with heavy equipment, and damaged the ICF bucking in this area. While this is not a huge problem, it occurs to me that soil battery material could have been stockpiled on the foam before the ICF were even stacked across the front.
- Horses (and maybe other ruminants) seem to have a taste for foam insulation. Fence the area and keep the animals away.

Some of my better ideas

- Use future framing lumber and joist materials for bracing and walk boards to cut costs and reduce waste.

- Microrebar works great, and is a huge labor savings vs. cutting, bending, and placing traditional rebar. It is also a greener product as you use much fewer pounds of steel overall to achieve the same effect.
- Choice of ICF supplier matters, and not all are equal. Based on my research buildblock was the most versatile and heaviest in construction. They also worked with me on pricing and shipping to beat the foxblocks (available at Menards) pricing
- While I don't know if I really saw the pricing difference or not, doing the concrete pours in fewer larger batches reduces costs for the concrete crew on mobilization and allows them to do the work on a more cost effective basis.

Next up is framing and roofing. Other than double studding the south wall, and the attic end walls (non-ICF exterior walls) and adding extra insulation to the attic under the decking all the rest of the construction will be pretty standard fare. I'll try to do a finished update, and an update maybe a year down the road with some at least qualitative results. I don't intend to attempt any real sensor data, so performance will be limited to inside vs. exterior climate data, and maybe some air flow and temperature rise/drop measurements through the heat battery.

Update from Josh November 2018

The house is just about ready for drywall to start. I'll finish up some framing and electrical details this weekend before drywall next week. Insulation is limited to just the ICF walls, and 4" of Polyisocyanurate board on the roof deck. (eve end walls and the south walls between the windows are only sheeted, but will get 12" of densepack cellulose, while the roof framing (2x6) will get dense packed as well) but already the passive solar design is performing well. The house stays about 20-30F warmer on a cold night, and does not heat up noticeably on a sunny day. I was worried about the ability of the thermal mass floor to absorb the extra heat, but so far it has been working wonderfully in complete passive mode.

Josh