DIY Geothermal Heat Pump + PV System – No Heat Bills!

Planning the System

I'd like to start off by saying that this is not a simple DIY project. It is a lot of work both mentally and physically. I spent countless hours on the internet researching to make sure that after the investment in time and money I would have a fully functioning reliable and well designed system. I don't want to discourage anyone from trying something like this but you really have to love doing it to see it through to the end. I love challenges and I love doing as much as I can all by myself. It can be done I did it.

My goal for this system was to completely eliminate my energy cost for heat, HW, and air conditioning. This is what I came up with, there are probably better ways but this was my way. I love this technology and love the work as well so it seemed ideal for me.

The first stage was to install the PV array. I decided on the garage roof for location it faces 202 degrees with a pitch of 21 degrees not ideal but an ok option for me. I settled on the garage roof because it was the most south facing area I had and gets a good deal of sun. A ground mount which is what I would have liked was shot down by the wife as not esthetically pleasing and takes up a lot of yard space. In the end I'm happy with the way it looks on the garage roof. The PVwatts website estimated my production at 5720 kWh for the year actual was 5631kWh pretty close. It predicted 5915 kWh for an optimally oriented array so I lose about $28/yr. I can live with that. I opted for a grid tied system, due to cost, simplicity and the relatively reliable grid in my area. The utility company JCP&L in NJ installs a net meter that tracks kWh out and kWh metered they subtract those two numbers to come up with net usage. If there is a surplus it gets tracked as a credit, and if not used up by the end of the year they will settle up the difference owed you.

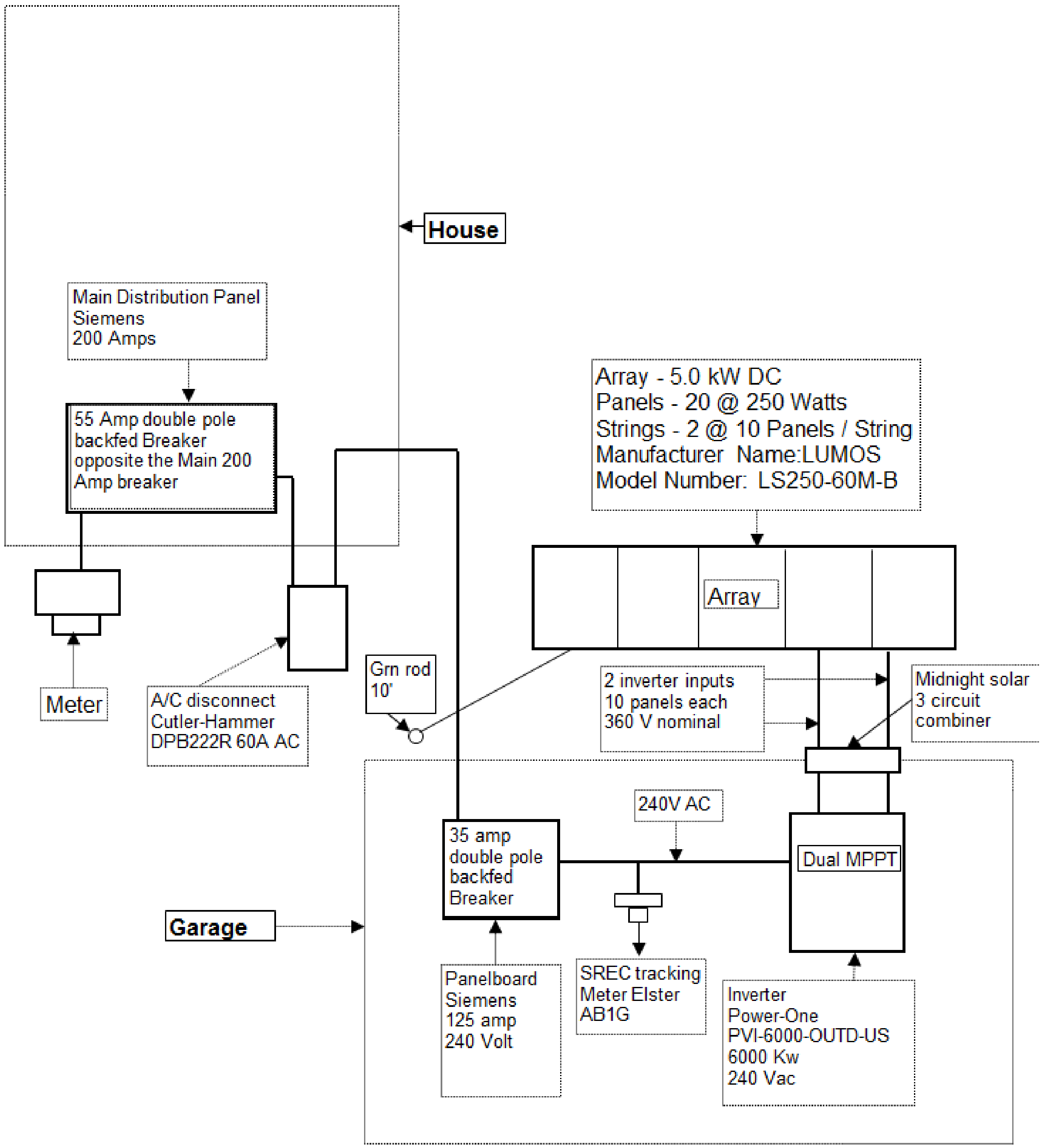
I registered the system with the state of NJ to generate Solar Renewable Energy Credits (SREC). An SREC is equal to 1000kWh. The utilities are required to produce a certain amount of renewable energy each year (a number set by the state). They do not have the facilities to generate that amount on their own. They must buy the remaining credits in the form of SRECs. These are traded somewhat like commodities the price fluctuates by supply and demand. The state uses this program as an incentive for people to install solar.

I did the design, permit applications, state registration, utility authorizations all myself. I spent countless hrs on the internet and in the electrical code book during the design process. I think anyone with enough determination could do it as well, as I am no genius. The state permit process was somewhat burdensome as it usually is. I was required to get an architect to evaluate the roof structure (he determined that I needed to double up the 2x6 rafters and add collar ties to each one which I did). I was also required to have an engineer certify the mounting rack and attachment process. I argued about this since the rack manufacture (SnapNrack) already had this documentation, but to no avail. Eventually my plan was approved and I started acquiring the system components.

I purchase an NEC (national electric code) handbook as a reference for the design of the system, it's not easy navigating it. You will get referenced from article to article and back again before you come up with a complete answer, so you will get to know the book really well. It was well worth the $100 investment. You probably could surf the net and get a lot of the info but it may or may not be accurate. I know that wire ampacities are easy to find for wire sizing just search wire ampacity.

The state registration for SRECs was another bureaucratic headache all the I's dotted and T's crossed all documents are time sensitive and must be filed in order and within time limits. Do your research on this prior to starting the project, and make sure you follow the guidelines.
The utility interconnect was the third approval I had to get. I don't recall any real issues with this it went pretty smoothly. They just want to verify the estimated production and that the system is ok for connection to the grid, which required an insp.

Here is a line diagram of my system



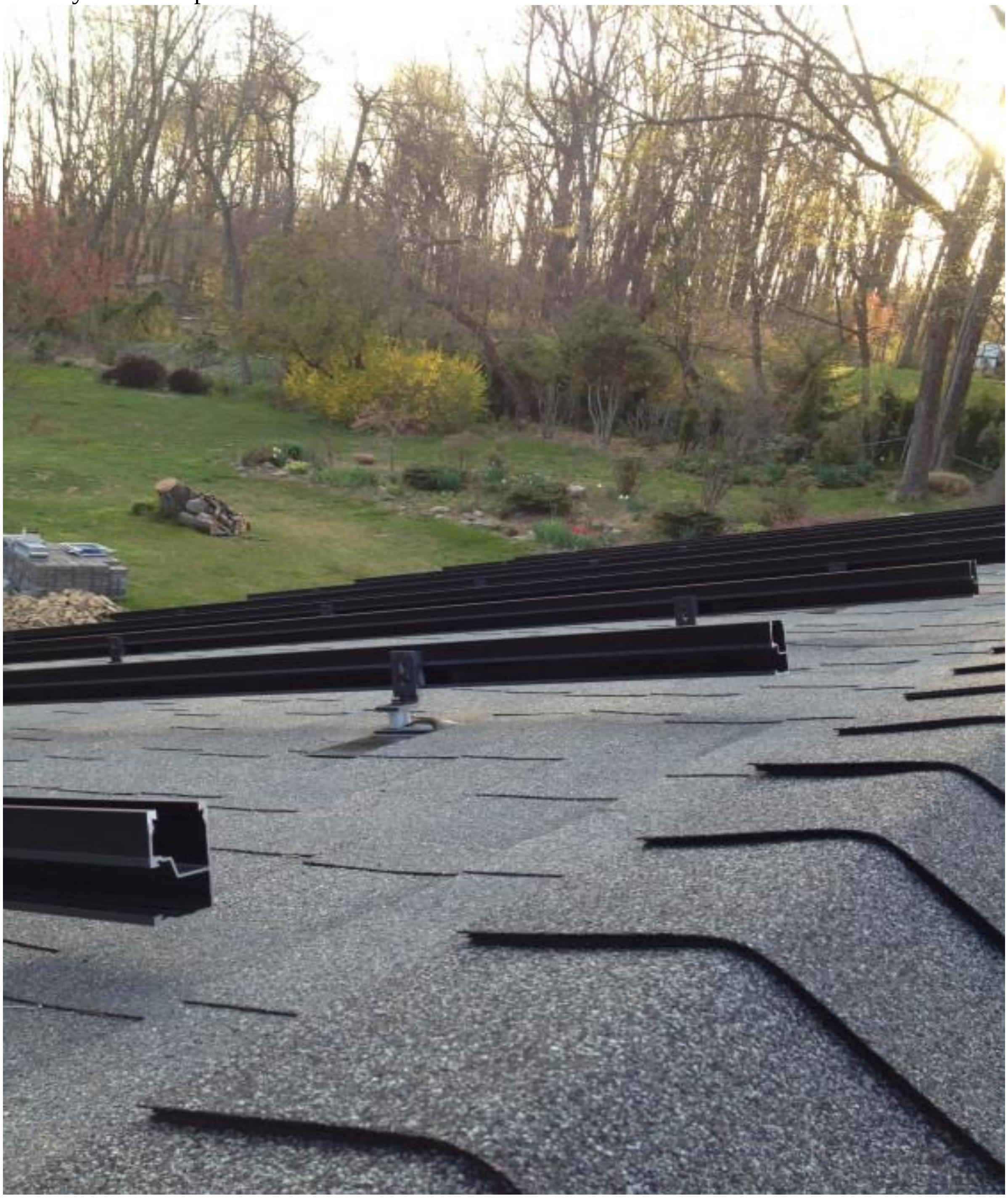
PV Installation

I ended up going with a company called Colorado Solar for all of my equipment. The racking shipped from their warehouse in Colorado to NJ where I live. The inverter and the panels were drop shipped directly to me from the manufactures. I dealt with Loren Geist he was very helpful and matched price for equipment that I found elsewhere. They did the panel layout from the roof dimensions that I sent them and recommended a landscape layout for the panels to best fit the most panels and still be esthetically pleasing. This was the only design service that they provided me although all of the components were recommended by them as well. They may provide system design services as well I'm not sure. Loren was knowledgeable and I did pick his brain on a few things. They sell DIY kits on their website and I enquired about modifying the kits to suit my needs, that is how I initially started working with them. They also recommended the SnapNrack mounting system which I am very happy with, very solid and easy to install. The inverter I settled on is the PowerOne PVI 6000. If I did it again I think I would go with the Enphase micro inverters there is a lot more flexibility with them. They control single panels so if you have shading issues it won't draw down the entire array as with the PowerOne inverter. You can also have panels oriented in different directions or have one getting weak and it won't affect anything else as far as output. Another nice feature is individual tracking of the panels you can see exactly what each panel is producing real time I think you may have to have an account with them or buy software for this service. Gary has indicated to me that the monitoring service may be free with the purchase of the EMU (the unit that collects the data and sends it to Enphase). The panels I used are (20) Lumos Solar LS250-60M-B (These particular panels were made in the USA right in Colorado) @ 250W each for a total 5000W rated although I rarely see this output (due to the less than ideal orientation) except in the spring when insolation is high and temps are cool I have actually seen over 6000 watts coming out!!

Once all parts were acquired I began installation:
First even though the roof was in ok condition I opted to re-roof it to prevent having to take the panels off anytime soon to redo it.

Next as per the architect I doubled all the rafters and added collar ties. Good strong roof now!

After this the racking went up I don't think it took more than a day to install. The racking is easy to install. For the length of my racks I was required to have three attachment points, the instructions cover all of this. They come with the shields that slide up under the shingle. I used the sealant recommended to seal all of the shingle penetration points. The bolts which are required to be stainless steel by local code must have 1 ½" thread engagement into the rafters. For leveling purposes, the angles that attach to the rails are slotted for adjustment. If your roof is as out of level as mine these will not be enough you will have to buy spacers to make up the difference as you can see in the picture. They are the round pieces under the angles. I used a string stretched tight across the rails to get all the rails perfectly even with each other. The rails also come with rubber end caps to make a nice clean look. I opted to leave them off because I felt they would trap water and debris.



The next morning the panels went up they just plug together in series. The array is split into two separate arrays Right and Left 10 panels each, the inverter has two inputs and controls the outputs separately with individual MPPT.

After the panels were up I started on the electrical connections. The inverter is installed in the garage. I had installed an electrical panel in the garage a few years earlier (I ran 6 gauge wire to the garage) so I tied into that with a backfeedable breaker and from there to the main panel. NJ requires a utility grade meter now to track SREC production so I picked one up for around $100 I think… wasn't much more than that. A shut off for the system is also required that is accessible to the utility and is placarded as a PV array shut off. I installed it between the panel in the garage and the main utility panel and located it next to the utility meter. The connection to the main electrical panel was a simple backfeedable breaker. It is required to be at the farthest breaker slot from the main breaker if I remember correctly. And also must be placarded. The PV wires from the arrays to the inverter also had to be fused. I used a midnight solar combiner box for this.

A picture showing all of the components that are located in the garage, the inverter, PV wire fuse box, the SREC meter, and the subpanel.

The combiner box opened showing fuses. Fuses protect inverter from over current. There are 4 20 amp 600v fast acting fuses one for each PV array wire to inverter. The PV wires also must be encased in metal conduit from the entrance into any structure to the inverter. Outside can be PVC.

The safety disconnect with utility meter on the left.

There were three separate inspections required before going into operation. First was my local code enforcement office inspection. These guys are all pretty good to deal with no issues with this. The next was the state inspection to qualify the system to generate SRECS and verify system configuration to what was represented in my drawings. The third was the utility inspection for interconnection. I had no problems with any of these inspections

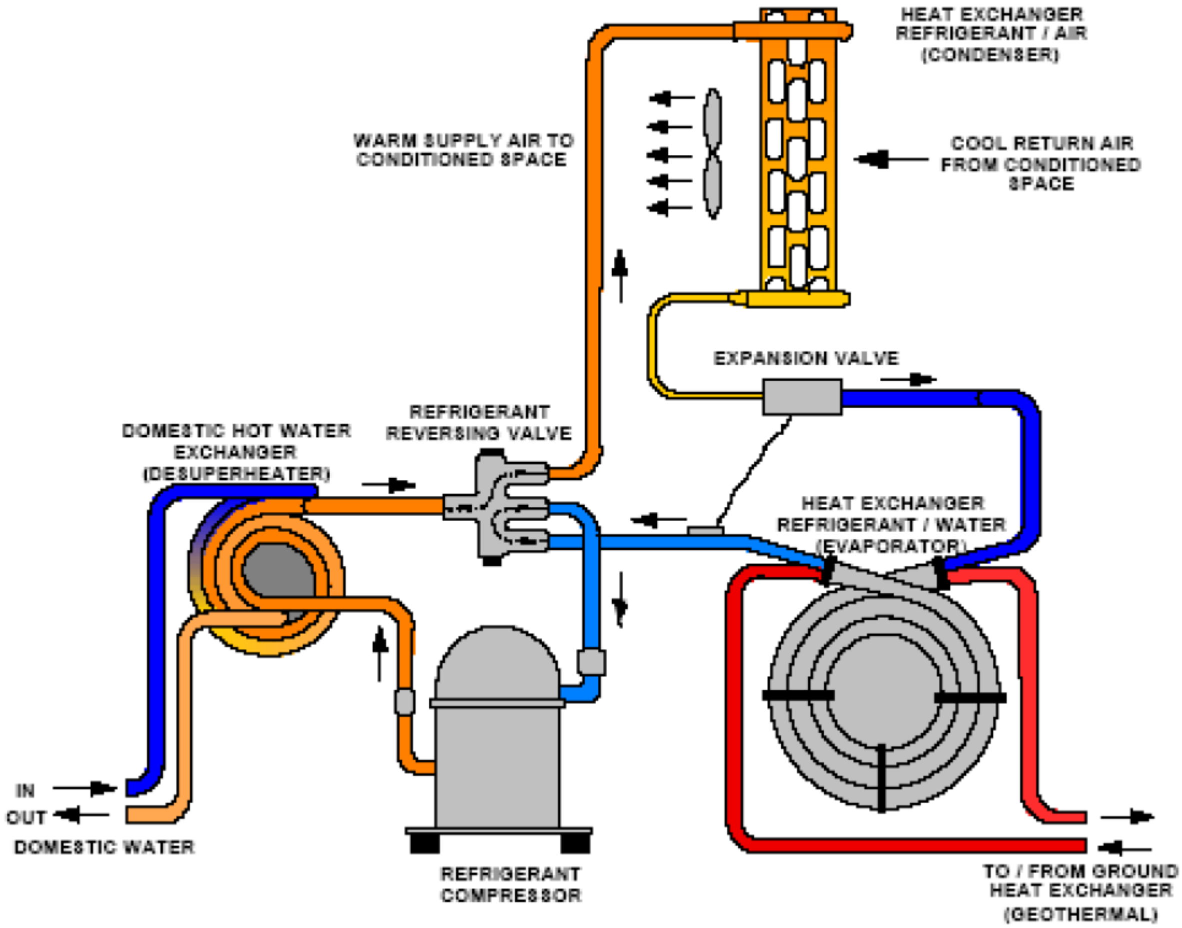
For the first full year the system produced 5600kWhs which equates to 5 NJ SRECS which I sold for an average of $130 each.

I’m not good at keeping records so I’m not sure about the exact cost of the entire install but I estimate it to be around $17000 which includes everything including the structural mods and new roof on the garage, engineer and architect cost all permit fees etc.

Designing the Geothermal Heat Pump System

To take advantage of the PV array I decided to go with a geothermal ground source heat pump forced air. I went with forced air to get the added use of central air-conditioning. I’m pretty sure they make combined units now that provide both water to water and water to air. I believe the water to water would be the most efficient.

I used the horizontal loop method which required in my case 300 ft of trench 6ft deep (I went 8ft). I chose this method one because I had the yard space to do it and two because I could rent a machine and dig the trench myself. A little bit of research should be done before settling on a method of loop installation there are several. If you have access to a lake or pond you could do what is called a pond loop where the loops are coiled up at the bottom of the pond. If you have a deep enough body of water I think this is the easiest cheapest and most efficient method. Vertical boring is another option but is expensive and maybe not so DIY friendly. The third is the horizontal method which I chose, before deciding on this I would recommend digging some test holes to make sure you don’t hit any shallow bedrock or anything that might prevent you from getting the loops down at least six feet.



How a GSHP works. Diagram from: Eastern Connecticut State University: Understanding a GSHP.

I purchased a DIY kit from a company called TerraSource. The kit comes complete with pre charged with antifreeze (alcohol) ¾" ground loops. In my case it consisted of 3 600' coils, a Climatemaster Tranquility 30 2 ton heat pump with desuperheater for domestic hot water and the loop manifold with pump. It also came with the Climatemaster communicating programmable thermostat. I would highly recommend this piece of equipment to take full advantage of the capabilities of this Heat pump. You can check system parameters right from the thermostat such as entering and leaving water temp, fan speed, leaving air temp compressor discharge temp etc. It has an easy to navigate on screen menu and is fully programmable with different heating and cooling algorithms to suit your needs. From the installer menu you can select CFM output for the various operating conditions and many other features.

The installation of the kit is not too technically difficult but is a huge undertaking for one person. I had to remove an old oil burner that also produced my DHW and all of the associated baseboard units and plumbing. Then install duct work. The duct work was quite a project in itself not only the actual installation but all of the design calculations that must be done to create a balanced, and properly working efficient delivery system. Again, countless hours on the internet researching, performing heat loss calculations, duct sizing calculations, cfm calculations, best practices and methods etc. In the end

I'm happy to report that the system is very well balanced, quiet and provides a very even and comfortable environment. Time spent in design is worth every minute. As far as cost goes again I'm going to have to estimate as I don't keep good records, I believe for everything including duct work it was in the $9000-10000 range. Considering the oil burner was long overdue for replacement anyway I could deduct $3000 off of the total bringing the investment down to $6000-7000 range.

The design process started with an accurate heat loss/gain calculation. I purchase a short term license for a program called HVAC calc. I think it was $40 for 3 months. You can download a trial version first. Worked good for me. Once I had those numbers I could size the heat pump to my conditions. I worked with Nick Rueble the owner of TerraSource where I got my DIY kit we concluded that the 2 ton unit would be fine. Now that I had my heat gain/loss numbers and my Heat pump sized I could start designing my duct work. Using the CFM and BTU numbers from the unit I was getting (TE 026) I set about designing my air delivery system. There are a lot of resources on the web regarding duct design and the information tends to be a little different from different sources and there are a lot of rules of thumb that you will see quoted. I basically determined from my heat loss/gain calcs (designing more for heating than air conditioning because it is the more major use) and the HP manufactures design specs for my unit, the total CFM I would need to heat my house at design temp I think I used 10 def F. Then with my heat loss calcs from each individual room I calculated required CFM per room. I then determined the amount and placement of the outlet registers.

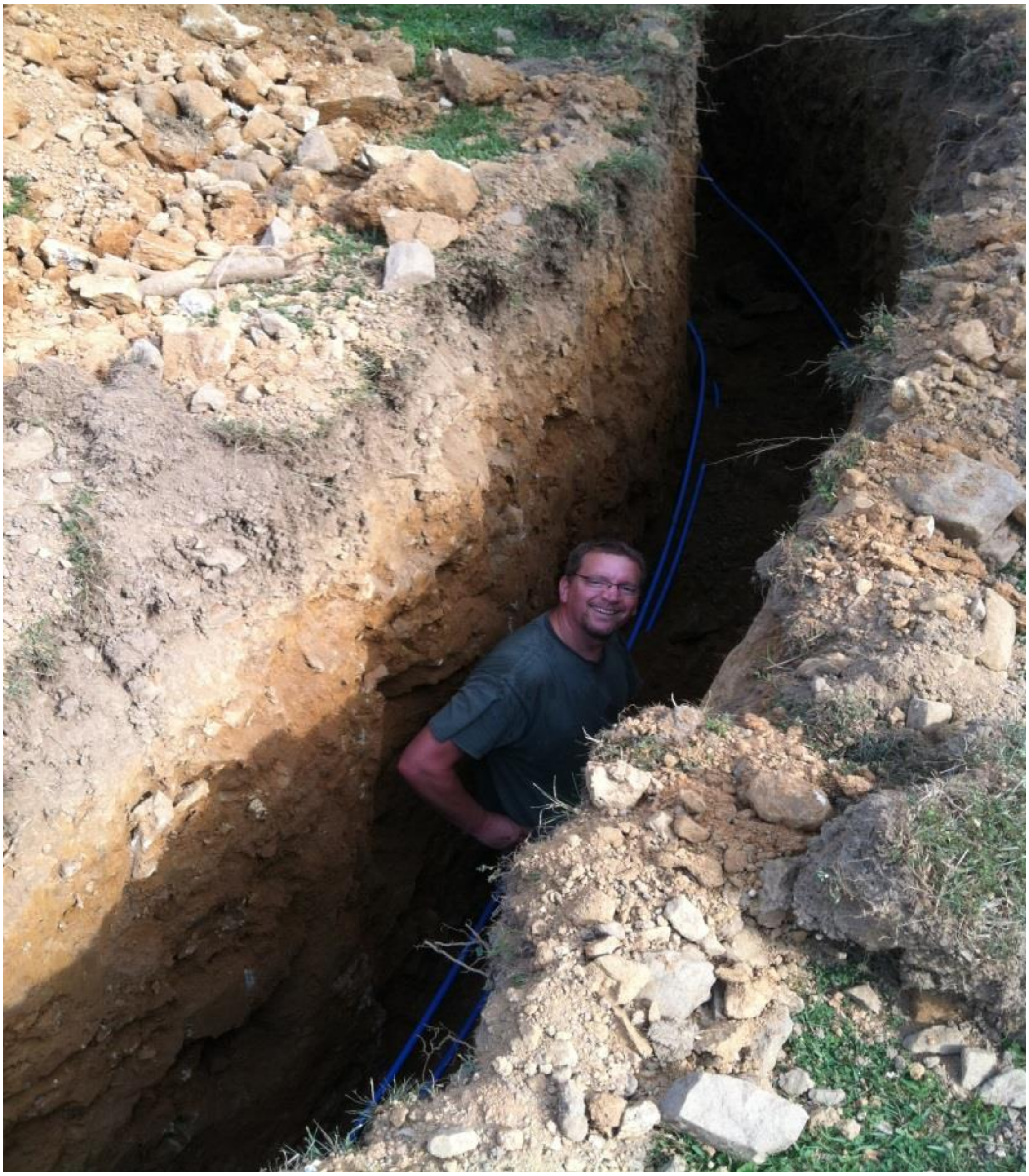
The final stage was to design the duct work to deliver the required heating to each room. There are a lot of resources on the web to find charts regarding duct size and design air flow, but this is one that I like: http://www.mrrepairs.net/mh/ductwork/duct-sizing-chart.pdf.   I installed a trunk and branch system. I ran a main duct down the center of the basement and from this all of the branch ducts to the registers are taken off. The main duct becomes incrementally smaller as the CFM requirement becomes less on the way to the last register. You want to be careful, duct design is very important a poorly designed duct system will ruin your whole system; it will not allow your Heatpump to perform up to its potential. If the ducts are two small for the CFM required for example, the system will be very noisy and the air will be coming out of the registers at a high rate causing drafts. If you design your own duct system, take your time and do the calculations size it as accurately as you can. As you research it you will see all the horror stories that go along with poorly designed systems. The return air portion of the system is just as important as the delivery side. I went with a central return system which consists of one large duct to return all of the air to the HP. One thing to keep in mind if you go this route rather than individual returns in each room is that you must allow for return air to exit the room when the door is closed. This is accomplished by cutting down the bottom of the door to allow the required CFM to escape back to the return air duct.

Installing the Ground Source Heat Pump System

The trench: I rented a case loader backhoe for the weekend and spent 8hrs on it Saturday digging the trench. Sunday was spent installing the loops and then backfilling.

This picture shows the end of the 300’ long trench. The trench starts at the opposite side of the house goes out to the front then along the property line all the way around and ends just in the back yard. The ground loops at this point make a u-turn and head back through the trench to the house. So the 600 ft coils go out 300’ to the end and back 300’ to the house.

This is the suggested loop layout in the bottom of the trench you want to keep them separated (6" at least) so they don't interfere with each others heat transfer to and from the ground. As far as backfilling and rocks are concerned I asked Nick at TerraSource about this being my soil contains a lot of rocks his response was don't worry about it at all the pipe is extremely tough. From my experience he was correct. The short time frame that I had the machine I was not that careful backfilling and have had no leaks or restrictions in any of the loops.



Happily working in my 8’ deep very cool very humid mosquito filled trench.

A Note On Trench Safety

A safer way to install the pipes in the trench is shown in this picture.

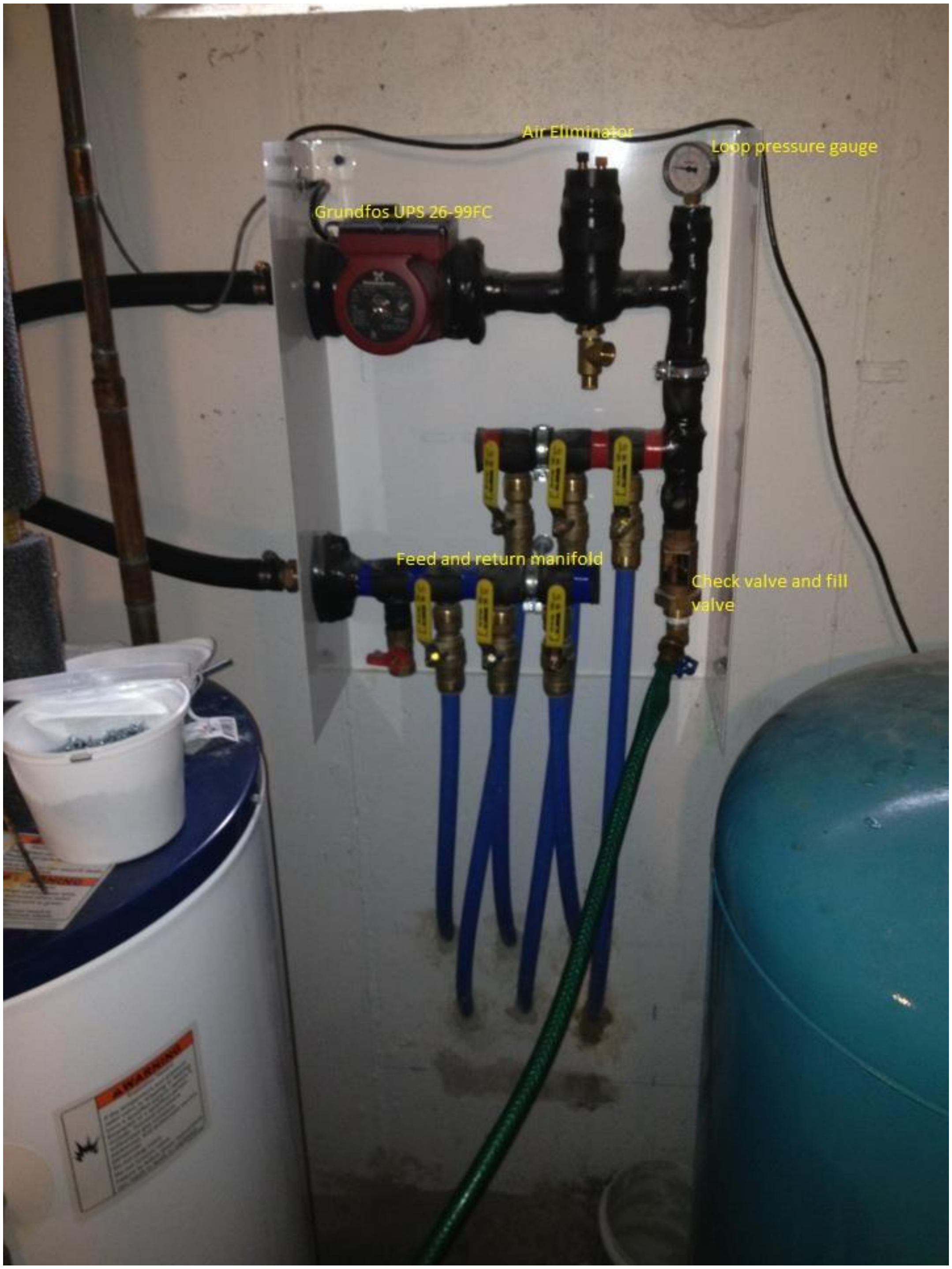
The tools allow the heat pump loop pipes to be positioned without going into the trench and avoid the possibility of being trapped, injured, or killed by a trench cave in.

The pipes in the photos are 3" PVC with a 3" – 2" – 2" Y. The end allows you to move the heat loop tubing around. The 3 inch pipe also has a 1" hole drilled through it with a piece of 1" PVC slid through the hole to use as a handle to lift the pipes. Thanks to Ray for providing information on this tool.

Another possibility is to excavate a wide enough to avoid the possibility of being caught in a cave in – the wider excavation would allow more runs of the heat loop pipe to be placed side by side and reduce the length of the trench. Searching YouTube for "GSHP trenching" brings up some other possibilities.

OSHA provides material on trench safety here…

After the back filling I ran the pipes though the foundation wall into the basement next to the heat pump. I have poured concrete foundation and was able to drill six 1" holes with a Bosch bulldog hammer drill without too much trouble although it did take a while. I drilled them on almost a 45 degree angle so that I could run the pipes right in the wall and up to the loop manifold without any additional fittings. I run the loops a 10 psi, although it's not required to run the loops under pressure, it is a good way to monitor the integrity of the system.



A picture of the heat pump before installing the return air duct and plenum. You can also see the electric hot water heater that I installed at the same time to take the place of the old oil burners DHW. This will be supplemented with solar in the future for sure. The desuperheater (for domestic hot water) connections are on the lower right side of the unit just above the loop connections. I connected these later but soon shut them off; it seemed to make the water heater to run more often. I have to look into this and see what I might have done wrong.

After this it was just a matter of making electrical connections filling the loops purging the air from the system and performing system startup procedures. All went without a hitch system up and operating.

Performance

I installed an eGauge data logging unit in my electrical panel at end of May 2013 so I don't have quite a full year worth of data but the data looks very good so far. If I estimate the numbers over the few missing months these are the results I come up with.

My total PV generation for the year was 5631 kWh this is an accurate number that I get from the utility grade SREC meter in the garage. The PVwatts website predicted 5720 kWh for the year. The GSHP for the year used 2182 kWh. The hot water heater used 5703kWhr. So my goal of getting free heat, hot water and air conditioning has been achieved:

Total PV generation 5631kWh generated @ .14/kWh = $788.34

The new HP and elec HW 2182KWH + 5703 KWH = 7885 KWH used @.14/kWh = $1103.90

Total production revenue 5631 kWh = $788

Total usage 7885 kWh = $1103.90

Total $1103.90 (usage) - $788 (production) = $315.90 (out of pocket)

5 NJ SRECS sold @ $130 = $650

So in total $650 (SREC) - $315.90 (out of pocket) = a positive $334.10

So the way I figure my payback for these systems is:

If I use my old inefficient oil burner for a reference my pay back would be

+$2800 for oil savings

+$334.10 for generation

Equals a positive $3134.10 / yr.

Total systems cost including the 30% federal tax credit = $16800 / $3134.10 = 5.36 year payback period. This doesn't include window air conditioning units that ran quite a bit during the summer that are no longer necessary but I don't have numbers for those would be a total guess.

There are many options besides the one I took to getting to a low energy bill and lower emissions. Things such as thermal envelop improvements, efficient heating plant, and solar space and water heating. The best solution often depends on your existing home and heat plant, the choice of fuels available, and your lifestyle. Be sure that you look at all of your options and pick the best for you. I do know that the GSHP plus PV system has worked out very well for my family.

Jerry

January 12, 2014