The Greenhouse at High Country Living

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It's February 2nd, 2018 in central Colorado at 9000' above sea level. And, here's what the inside of our greenhouse looks like:

OK, so I'm bragging a bit. But, hey, wouldn't you?

We're eating fresh, organically grown veggies in the middle of the winter in Colorado and loving it!

Assuming I've got your attention, I'd like to share our greenhouse journey with you and hopefully inspire you to take on a similar project.

Disclaimer

This article and any links to other articles are for informational purposes only. I take no responsibility for what you do with this information. By utilizing any information from this article, you assume all risks for how you utilize this information.

I am a Do-It-Yourself-er. I'm not a professional plumber, electrician, builder, architect or engineer. I do not take any responsibility whatever for the correctness of the design or construction ideas given in this article. I do not take any responsibility whatever for any damage or pain or inconvenience that may be the result of the reader utilizing any of the information in this article. You (the reader) have to take on all the risks involved in utilizing and implementing any of the information presented in this article--

Do Your Own Homework and Assume Your Own Risks!

Background

About Us

If you want to know a bit about us click here.

Our Prior Gardening Experience

Before retiring, we lived north of Fort Collins, CO at 5200’ elevation. We started raising much of our food back in 2009. We began our garden (using raised beds) and expanded on it over the next several years. We also added ducks (for eggs). We utilize purely organic gardening methods. We added an unheated greenhouse that was attached to the deck of the house. We utilized containers in the greenhouse (GH), raised cold-hardy veggies and enjoyed fresh salads all winter long.

Our Current Gardening Situation

In 2015 we retired and moved to a 40 acre paradise near Guffey, CO, elevation 9000’. The first two years were focused on building our house (we lived in an RV), a barn and fencing in the property for the horses. In 2017 we were finally able to put in our garden. We designed it to fend off the deer, rabbits and ground squirrels (so far so good). We also added shade-cloth protection from the high altitude UV and on some of the beds provided for roll-down plastic for frost protection and veggies that preferred warmer overnight temps.

Our first summer gardening at 9000’ was quite a success. Of course, not everything panned out as we hoped. We learned a few more things and will make adjustments for next year’s growing season.

Laurie maintains a blog on the garden and ducks here.

Next Up: Greenhouse

As the summer progressed we started thinking about building a greenhouse (GH). Even though we had had pretty good winter success growing cold-tolerant veggies with an unheated GH at 5200’ at our previous location, we didn’t think that was going to work very well at 9000’.

And, we had never seriously considered a heated greenhouse due to our reluctance to spend money on the energy required to heat a GH. However, that changed...

Going Solar

We built a VERY energy efficient, modestly sized (1000 sq. ft.) house. Our heating bills are really pretty low. Our electricity bills are pretty reasonable also (~$80). However, ~30% of that is for the hot water heater. I began considering a solar hot water system (also referred to as hydronic solar) that would provide most of our domestic hot water. I also wondered if such a system could provide some heating for a GH. Yes, this would involve a significant up front cost. But, it would eventually pay for itself over the years and we would be getting our heat for the GH from the sun for close to nothing. This would allow us to continue to grow organic vegetables, reduce our food bill and eat well over the winter (as well as reduce our electricity bill).

In addition, just having good work to do (as opposed to sitting in front of the TV) and benefiting from the fruits (veggies) of our labor is a benefit which cannot be overstated.

So, we made the decision to go for it. I knew nothing about hydronic solar starting out, but was eager to learn. I also wanted to do as much of it myself as possible, saving a lot of money as opposed to buying commercial products and paying professionals to install it. I found an invaluable resource for starting my journey into hydronics here: builditsolar.com.

This article is about the greenhouse and will not go into the details of the hydronics system. I plan on posting another article on my hydronics implementation later.

Do It Yourself (DIY)

Some brief comments on DIY. I have a lot of DIY skills from working as a teenager for my dad, who built custom houses. I also had several trade-type jobs in my earlier days (installing carpet, aerospace machinist, etc.) that added to my skill set. I eventually migrated into the computer industry and gained experience in Computer Aided Design (CAD) and IT architecture. A few years ago I started doing woodworking projects (building a dining table and chairs, etc.). So, I have quite a few skills to bring to the table. For those who are reading this article you might not have as much DIY background, but don't let that dissuade you. What you don't know, you can learn. Yes, you'll make mistakes; it's part of learning. But, when all is said and done you'll know a LOT more and you might even get hooked on thinking up other projects to work on. Doing things yourself is very satisfying in the long run and makes you more self-sufficient.

So, roll up your sleeves and jump in. Do lots of research (internet, youtube, etc.) but remember that there's a lot of bad advice out there along with the good. So, you'll have to use some common sense in trying to filter out the bad advice. Also, remember that lots of people post articles and videos when they're in the "honeymoon" phase of their project and everything is looking really good. However, many of these people later find out that their "totally awesome XYZ" project turned into a nightmare later and they don't have the integrity to update or remove their articles/videos.

Having said that, I fully intend to update this article if something comes up down the road that was just a bad idea and didn’t work out so good. I will also try to update this article as needed, including lessons learned and what I might have done differently if I had it to do over again.

All this background may be more than you wanted to know, but I hope it gives some good context. Let’s get started.

Greenhouse Design

Here is a picture of our house before starting on the GH. Yep, it looks like a yurt. It's made out of SIPs and is very efficient.

This view is from the south side of the house. Notice under the deck there is a door that goes into a walk-in crawlspace. The crawlspace is not heated but stays around 50 degrees year round.

Here is a SketchUp drawing of the GH. The GH will be under and extended past the deck. The back wall of the GH is the crawlspace wall.

The GH is an active/passive solar design. The concrete floor, garden beds and water mass (we refer to it as a "pond") all provide thermal mass which absorb heat during the day and release it overnight. The hydronic system will add supplemental heat to the GH when needed and will also provide domestic hot water (DHW) heat to the house. You can see the planned solar collector to the left of the GH. In addition to providing thermal mass, the pond might ultimately be used to provide a waterfall feature to provide evaporative cooling in the summer. A bonus will be to add fish and water plants for fun.

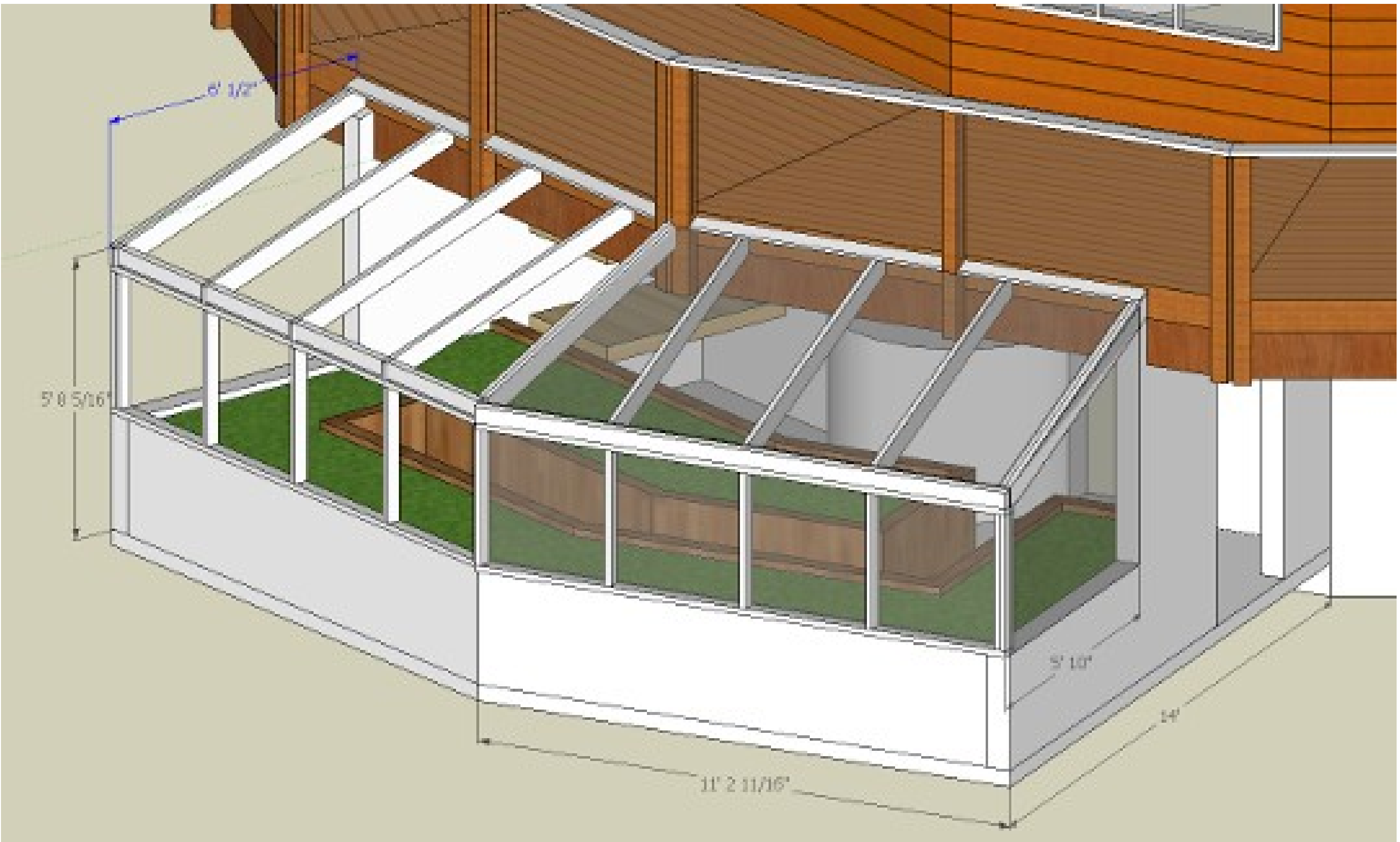
The floor space of the GH is 267 sq. ft. There is 110 sq. ft. of raised beds.

Here is a finished outside picture of the GH:

[I posted a walk-thru video here](#).

Greenhouse Dimensions

This drawing gives an idea of GH dimensions and layout.



Deck

The under side of the deck over the greenhouse had to be modified so it would not leak water into the greenhouse area. Details on this below.

Raised Beds

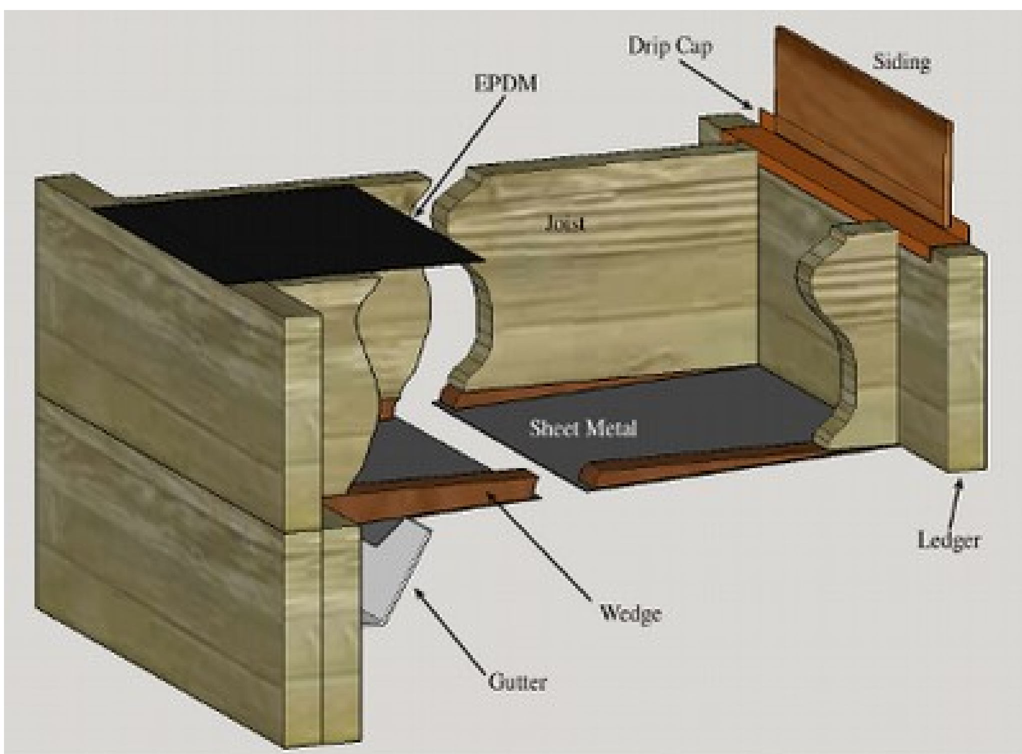
The raised beds are constructed of wood and lined with EPDM. Details on this below.

Preparing the Deck

Our deck is pretty typical with joists and deck boards on top; water drips right thru it to the ground. Obviously, this won't work over top of a GH. My research turned up several methods for waterproofing a deck so you can add a dry space underneath it. Most of them were quite expensive. Here is what I did.

Concept

I had to have something to capture water and direct it away to the outside of the GH. To do this, I created a "ceiling" in the GH (or a "bottom" on the deck depending on how you want to look at it) with a slope. The slope directs the water to a gutter which then directs it outside of the GH. To the right is a conceptual picture.



Wedges are attached to the bottom of the joists providing a slope. Sheet metal is installed on the bottom of the wedges. Water on the house siding falls onto the drip cap, down the face of the ledger board and then onto the sheet metal. Water coming thru the deck boards falls thru to the top of the sheet metal. The sheet metal drains the water to the gutter where it is channeled outside of the GH area. The EPDM captures water on the outer edge of the deck and also drains it back onto the sheet metal.

Gutter, Wedge and Sheet Metal

I mounted the gutter on the support beam, extending it past where the end of the GH would be.

I ripped 2x4x8’s diagonally to create wedges and attached them into the bottom of the joists to create a slope.

The sheet metal was screwed to the wedges using metal siding screws (with rubber washers). The metal was bent to drain into the gutter.

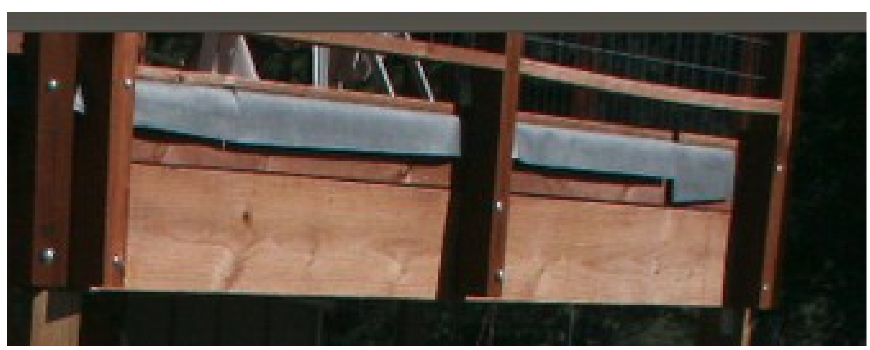
Here is a picture looking at the other end (where the house siding drains).

Where sheet metal pieces overlapped, I used caulking to make sure they didn’t leak.

EPDM on the Top of the Deck

I removed the first two rows of deck board. I then laid down EPDM and cut a slit thru the EPDM over the top of each joist and used staples to hold it in place. This allows it to droop in between the joists but it also leaves a “crack” between each section. I caulked the slits and on top of the perimeter and replaced the deck boards over top of the EPDM.

Water is captured by the EPDM and drained onto the sheet metal underneath, which is then dumped into the gutter.



I got my EPDM here. The size was large enough to do all my raised beds (see below) as well as what I needed here. Do a little planning before you start cutting it up.

I also left 4” wide of extra to hang over the outside of the deck. This will lap on top of the GH roof when I build it. That will direct water that runs to the outside of the deck onto the GH roof where it will drain off.

More Work on the GH Ceiling Later

This was enough to water proof the GH area. I will come back to finishing off the GH ceiling (underneath the sheet metal) later.

Concrete Floor

I decided to pour a concrete floor for two reasons:

- Thermal Mass
- In-floor radiant heating

Even if you don't plan to do the in-floor radiant heating, thermal mass is really important. It's also important to spend a few extra bucks on insulating the concrete from the earth. This helps keep the heat inside the GH.

I formed the area for the floor with 2x6's. This gave me height for 2" rigid insulation and 3 1/2" for the concrete. I had some extra gravel so I put it down; it's much easier to level out. A layer of 6 mil poly acts as a vapor barrier.

If you look at the underneath side of the deck you can see the metal sheeting and gutter from the previous step.

I laid down 2" thick rigid foam insulation on top of the plastic (be sure it's rated for this type of use).

On top of that I put down wire mesh, risers for the PEX tubing and then the tubing itself. I will explain this in more detail when I post the doc on my hydronics system. If you're not doing in-floor radiant heating you should still put down the 2” foam before you pour the concrete. This really helps keep the heat inside the GH where you want it.

NOTE: The in-floor radiant heating didn’t work out as hoped. However, I was able to use the floor loop for another purpose. More on this later.

End and Knee Wall Framing

I built the end and knee walls first and left the rest of the framing until later. This made it easier to haul in the material for the raised beds with my tractor loader and dump material into the beds. Once you get the GH enclosed, it’s a lot of work to haul in material for the raised beds.

All the walls are 2x6 and are insulated with fiberglass batt insulation. I used 3/4” pressure treated plywood on the outsides of the walls. I got the kind that is rated for ground contact.

I put anchor bolts thru the bottom plates and into the concrete. If you have in-floor heating, you better know where your pipes are! You don’t want to drill into one of those. My pipe layout started 10” in from the perimeter, so I knew I wasn’t going to hit any of the pipes.

Raised Beds

Next, I built the raised beds. These are made of 2x4s and OSB. The top and bottom plates are laid horizontally while the vertical 2x4s are turned sideways. The OSB is mounted on the inside of the beds.

NOTE: all bottom plates for the walls and beds (in contact with the concrete) are made out of pressure treated (PT) wood (the rest of the wood is not PT). This is because there may occasionally be water that seeps down thru the beds to the concrete and come in contact with the bottom plates.

I also put spacers under the bottom plate to raise the plate off the concrete and to make it easier for any water to seep out and not just sit there and soak the plates for long periods of time. I used scrap pieces of the 3/4” PT plywood from the outside walls for this.

I cut EPDM and stapled it at the top, just under the top plate. I overlapped end pieces by about 8”. It also laps onto the floor a bit.

EPDM is inert; it will not leach any chemicals into the soil to be absorbed by the plants. Yes it’s a little pricey, but it should last a very long time.

The outside beds are 36” wide. The inside beds are 48” wide since they can be reached from either side. The walkways between the beds are 24” wide.

I laid down about 1” of gravel and put weed barrier over top of the gravel. The weed barrier keeps the dirt from leaching down into the gravel but allows excess water to drain thru.

Next was the fun part of filling up the raised beds. As I mentioned above, we are strictly organic with our gardening. We make our own compost and have an abundance of horse manure, which we allow to age a bit before using it in the garden. We also add a few other organic amendments which we purchase.

To reiterate, filling the beds at this point is a lot easier to do than after the GH is fully enclosed.

Here’s a pic of the finished beds and the beginnings of the rest of the framing.

Note the plastic on top and sides of the knee walls. Some of the outside wall surfaces are back filled with dirt to smooth out the landscaping. The plastic provides an additional layer of water protection to the PT plywood. The outside walls will be covered with metal siding.

Perimeter Insulation Around the Slab

Before back filling around the slab, it's important to insulate the slab from the ground around the perimeter. I had some leftover scrap rigid insulation that I used underneath the concrete slab. This pic shows the 2" wide insulation cut to the width of the slab (3 1/2") placed against the slab and backfilled with dirt/gravel.

Framing

(Remember the Disclaimer at the beginning of this article)

Framing Design References

Following are a few references that I reviewed in determining my GH design.

These guides shows framing options for various spans and snow loads:

http://cdn.greenhousemegastore.com/downloads/pdf/palram-thermaglas-technical-and-installation.pdf

http://www.mycarpentry.com/rafter-span-tables.html

Here are a few links to design guides using polycarbonate:

Sundance Design Guide:

http://www.builditsolar.com/Projects/Sunspace/SundanceDesignGuide.pdf

The Polycarbonate Store (Charley's Greenhouse):

http://www.charleysgreenhouse.com/pgs2/tech_tips/How-to-install-polycarbonate.pdf

There are a lot of different ways to build the framing and attach the polycarbonate. I did a lot of research and used what I thought were the best ideas.

Details

Unfortunately, I didn't take pictures of the framing process. I was on a roll and didn't think about it. However, here are a few pics showing the finished product from the outside and inside.

I used 16mm (5/8") multi-wall polycarbonate for the glazing. If you have to order this online, you'll have to pay as much for shipping as you do for the poly itself. If you can, find a supplier (even if it's a few hours drive) and go pick it up.

Note the downspout coming from behind the deck beam and directing the deck water away from the GH. Also, note the deck EPDM lapping over the GH roof.

Here's an inside pic showing the framing. Yep, I'm not done with the GH and there are already veggies growing. Laurie had started seedlings when I first started working on the GH so she would be ready to plant as soon as it was enclosed. The pressure was on; I finished enclosing it just in time for when the seedlings were ready to be transplanted.

Laurie has an amazing setup for starting seedlings. If you're interested you can read more about how Laurie starts her seedlings.

Framing Around the Gutter

Here is a pic showing how I framed the end walls around the gutter. As you can see the gutter extends past the end of the GH wall. I used a jig saw to cut the profile in the plywood around the gutter. I also caulked the top where it meets the sheet metal.

The opposite end wall is similar. However, it does not have a downspout.

I may come back later and box in the gutter and stuff in some more insulation. But, for the moment I'm letting it stay like this.

Greenhouse Insulation

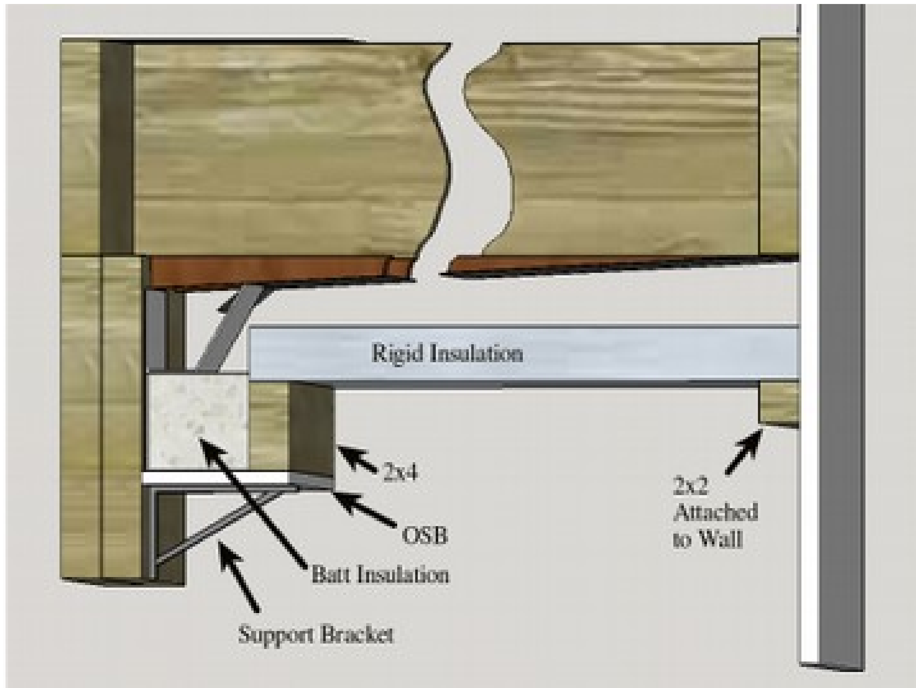
In colder climates like ours insulation is a key factor to the success of a GH. Here's what I did.

Exterior Walls

All exterior walls are 2x6 and insulated with fiberglass batt insulation.

Ceiling

The ceiling underneath the deck was made waterproof in a previous step. Now it needs to be insulated or the GH heat will go right thru the metal sheeting and up thru the deck. I couldn't just screw in insulation from the bottom because that would poke holes in the metal for the water to come thru. So, I put up a "suspended" ceiling.



I mounted a 2x2 to the side of the house leaving about 3" between the top of the 2x2 and the metal sheeting above. I put up 2x4s on the beam side of the deck supporting them from the bottom, again leaving about 3" between the top of the 2x4 and the metal sheeting above. I then slid in sheets of 2" polyisocyanuate rigid insulation on top of the 2x2's and 2x4's. The joints were taped with aluminum tape.

I boxed in the gutter with OSB on the bottom. I supported the bottom with shelf brackets. The cavity around the gutter was stuffed with scrap pieces of fiberglass insulation before finishing up the enclosure.

The "ceiling" made out of the rigid insulation is very light. So, you don't have to worry a lot about having real beefy supports.

Here is a pic after finishing.

Glazing

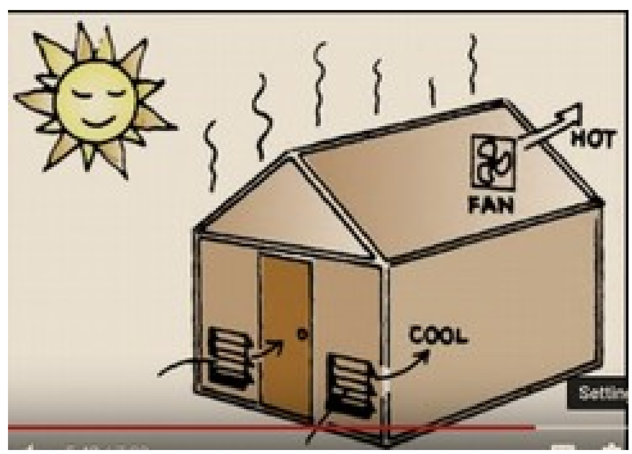
Selecting glazing is always a balance of insulation factor vs. light transmission. The more the glazing insulates, the less light it lets thru. The 16mm, 5-wall RDC polycarbonate I used has an insulation factor of about R2.8 and light transmission of 65%.

Removable Insulation

I spent time (and money) creating removable insulation that I would up at night and take down every day during the cold season. However, I found with the hydronic system that I put in to heat the GH the added removable insulation just wasn't needed and certainly not worth the daily effort.

Managing Excess Heat

Concepts



Ideally, air intake should be low (where the air is cooler) while exhaust should be high (where the hotter air rises and will naturally escape.

Here is a useful reference link to review.

Roof Vents

I created two roof vents 6' long and installed Gigavent openers.

The vents start opening when the inside temp gets around 60°.

There are several models of this type of vent which vary in support load and cost. I went for the heaviest one mainly because I live in a high wind area and the return springs on a lighter model might not be able to withstand high winds. I also braced the vent from end to end with an L bracket.

The vent opener is positioned in the middle of the vent. When it's windy the ends of the vent can flop around a bit.

So, I attached screen door chains and springs on each end. I put a bit of tension in the springs when the vent is in the fully opened position. This helps keep the vent ends from moving too much in high wind conditions.

The piston is removed (unscrewed) at night when I need put up the insulation; it hangs below the rafters a bit.

Raised Pond

The more thermal mass you can incorporate into a GH design, the less energy it will take to heat it. Many GH's utilize barrels filled with water placed on the north side of the GH to store heat during the day and release it overnight.

I came across the idea of putting in a raised pond here. I saw that the raised pond consisted of sheet metal lined with EPDM. I thought it was a great idea, so that's what I did in my GH.

(The picture is from the link above; this is not a picture from my GH.)

Right now, the pond provides simple thermal mass. Next summer, we will consider adding water plants and fish. The nutrient enriched water can be used to water the plants in the GH. I'll update this article if we do that.

I purchased a piece of 18 gauge sheet metal 42" high by 8' long from a local steel supply house. Bending this into a semi-circle gave me a container that stores 200 gallons of water. This is almost as much as four 55 gallon drums and takes up **much** less space.

Note the angle iron running vertically on the left side of the sheet metal. I attached this to the wall running long screws all the way thru the wall and thru a flat piece of metal on the far side.

I then screwed the sheet metal into the angle irons. This provides support for the weight of the pond when it filled up.

Here are closeups of the angle iron and flat metal on the opposite side of the wall:

I trimmed off the EPDM and made a cover for the pond for now. Here’s the final pond:

I know, I haven’t painted it yet...

Grow Benches

I built grow benches for Laurie to start her seedlings. The lights are attached to pulleys so she can raise and lower them as needed.

They are located in the north section of the GH that doesn't get sunlight; they have their own lighting. Here's a pic:

Laurie has an amazing setup for starting seedlings. If you're interested you can read more about [how Laurie starts her seedlings](#).

Making the Most of the GH Space

Laurie does all the plant layout and growing. She has become an expert at laying out the garden and GH for maximum use of space. You need to think about various things such as lighting requirements of various plants and not having taller plants blocking out light from getting to the shorter plants. There are also plants that do pretty well with indirect light and some that need direct light.

Here a few ideas that she incorporated. Refer to this picture:

Hanging Plants

Hanging plants can be located high to capture sunlight that is not directly hitting any other plants.

Trellising

Some plants can be trained to grow vertically (tomatoes trained up the pole and spreading to either side), or zucchini growing vertically on a string.

Wall Mounting

If you have wall space, some plants can be grown in wall planters depending on how much direct sun they need.

Succession Planting

Laurie estimates when plants will produce and when they may stop producing. She times the starting of seedlings so they will be ready to replace plants that are no longer producing.

Adding Supplemental Energy to Warm the GH

If we planned on growing only cold-hardy veggies in the GH, we could probably get away with not providing supplemental heat. However, our objective was to eat fresh veggies all winter long, and not just the cold-hardy variety (there's nothing like a fresh tomato in the middle of winter).

So, I knew that I was going to have to add supplemental heat during the cold season, especially at night. Ultimately, I wanted to install a hydronic system (solar hot water collection) to provide heat to the GH and also to heat my house domestic hot water.

Installing an active hydronic system is a pretty involved project, not to mention the cost. There are those who might not want to undertake such a project; there's a lot to learn about hydronics. It is certainly worth considering building a well designed passive solar greenhouse and providing supplemental heat when needed without going hydronic. The keys to minimizing costs on supplemental heat is **lots of thermal mass and good insulation**.

Some Notes About Plant Temperature Needs

Plants obviously need a minimum amount of heat to thrive. Plants with warmer temperature needs (e.g. tomatoes, green peppers, etc.) won't do well or they won't set fruit if the temperature gets too cold.

If you're focusing on cold-tolerant plants (e.g. lettuce, brassicas, chard, etc.) then your GH temperature needs are considerably less. In a cold-tolerant scenario, with enough solar mass storage you might not even need any supplemental heat (especially if you're in a warmer climate than I am).

But, there are two areas of temperature requirements to consider:

- Air temperature
- Soil temperature

Recent studies seem to indicate that soil temperature is more important (at least to a certain degree) than air temperatures for plants. Although there doesn't seem to be a definitive conclusion on this yet, I lean towards thinking that this is true and is a major factor in the success of our GH.

Electric Supplemental Heat

To begin with, my GH was up and running before my hydronic system was in place. When needed, I used an oil radiant heater similar to the one shown here to add supplemental heat. It was actually good that I had to use an electric heater. I used a Kill-O-Watt meter to monitor energy usage.

In the winter on sunny days, I didn't need to turn on the heater during the day. The solar gain kept the GH nice and warm and would add to the heat stored in the thermal mass (raised beds, concrete floor and pond). I would turn on the heater at night, setting it to maintain a minimum of 52 degrees. If you're growing only cold-hearty plants you can set this lower (~ 40 degrees) and save more money on energy costs. However, we're growing plants that like warmer temperatures (e.g. tomatoes, green peppers, etc.) so we want to keep it warmer.

Keep in mind, we live in Colorado at 9000' elevation. Although we can get some harsh blizzards, we also get an awful lot of sun (over 300 days of sunshine / year). It's amazing how warm the GH can be on a sunny day when it's freezing outside and how much the heat gain captured by the solar mass will contribute to keeping the GH warm longer into the night.

Here are a few examples of electric costs to keep the GH to a minimum of 52 degrees. Our current electric rate is $.12 / kWh.

		Outside Temps		GH Temps			
Row #	**Date**	**High**	**Low**	**High**	**Low**	**Kwh**	**Cost**
1	10/27/17	55.7	12.4	69.8	52.8	4.6	$.55
2	10/30/17	35.9	13.5	62	52.6	12.4	$1.49
3	11/1/17	52.5	34.2	70.6	52.5	6.3	$.75

You can see that it costs three times more to keep the GH warm on a cold, cloudy day than on a warmer, sunnier day. But, if we do a bit of extrapolation (also known as educated guessing) we could conservatively estimate $30 / month during the winter to warm the GH. So, if we spend $180 / year (over a 6 month period) to have fresh, organic veggies all year round, that is still cheaper than buying them at the grocery store.

Also, note on 11/1/17 the temps were warmer overnight, but it cost more to heat the GH. That’s because it was very windy. Wind has an amazing effect on greenhouses. It sucks the heat right thru the glazing.

Converting to Estimate Hydronic Usage

Now that I had an idea of electrical usage, I could convert the kWh values to BTUs and estimate hydronic usage for my future-planned hydronic system. If you’re interested in these calculations, see the Appendix: Estimate Hydronic Usage.

Hydronic Supplemental Heat

If you add a hydronic system to supply essentially free heat (after the initial costs, of course), and it provides domestic hot water heat as well, the payback becomes even more impressive. I was able to build and implement my hydronic system the next year.

Radiant Floor Heating

As I mentioned above, its important to not only heat the soil but also the air. The radiant-floor heating didn't work out as expected. It took too long for the heat to make its way up thru the mass (raised beds, pond, concrete floor) and into the air to really help.

In the end, I found that the thermal mass in the raised beds lost their heat very slowly and the soil temperature remained high enough (65° or greater) without any supplemental heating, even in the coldest of outside temperatures.

So, the only thing I really needed to heat was the air.

Air Heating

In the first phase, the supplemental electric heater met the need of heating the air when needed. However, when I implemented my hydronics system I was able to use it to heat the GH air and maintain the minimum temperature using a radiator. The floor loop was abandoned for heating purposes.

I installed the radiator in the GH. Here is a picture. The radiator is mounted on the wall behind the grow bench.

I have a thermostat in the GH which turns on the radiator when needed. A fan in the radiator distributes the heat throughout the GH. In the case of multiple cloudy, cold days when there is not enough eat in the solar storage tank to be of use, an electric heater is activated as a last backup. This is all automated and requires no manual intervention. When I implemented this in January, 2019 the electric heater never kicked on.

Refer to the Appendix for details on the hydronic system.

Costs and Benefits

At first I was going to entitle this section "Return on Investment". However, there is so much more to this picture than dollars spent vs. dollars saved. Certainly, monetary costs and benefits are important to consider. However, there are other "costs" and "benefits" that are, in my opinion, just as important. So, I'm going to discuss the non-monetary costs and benefits and then the monetary costs and benefits.

Non-Monetary Costs

- Building a GH is a big project. It takes time and effort. You need to do a lot of research and even soul-searching before you begin building.
- After the GH is built, there is the on-going time and effort involved in growing, harvesting and preserving veggies. You really have to commit yourself to a lifestyle which includes these activities as one of your core values. This is not something you do when you have some spare time.

Failing to adequately pay these "costs" will result in failure.

Non-Monetary Benefits

I believe all the things I listed in the previous section as costs also result in benefits. Plus there are other additional benefits.

- You get good exercise, both physical and mental.
- You learn and/or improve on your skills (which can make you more self-sufficient).
- You gain a sense of real accomplishment ("I built that").
- You commit to a healthier lifestyle.
- You are spending time on more worthwhile things (instead of watching TV, for example). Heck, you might even lose a little weight :)
- The food you do **not** buy at the grocery store contributes to the health of the planet.

- How much pollution is generated just running to the grocery store?
- When you buy that tomato in the winter, it didn't wasn't grown locally. How much pollution is generated buying food that comes from across the country or even around the world?
- Relationship building – If more than just yourself is involved in this project you have to build/improve relationships with others just to get it done. You really learn a lot about people when you work on a project with them, even if it's just your spouse.
- You are modeling a healthier lifestyle as an example for others. You might even find yourself mentoring someone else who wants to head down this path.
- Sharing your bounty – you will likely have more fresh veggies than you can use at times; you can share them with others

Sure, you can turn some of those benefits into negatives. For example, you can claim that you're taking away business from a local contractor, or a local farmer. Well, if you're flush with money and want to take that approach you're free to do that. For myself, doing as much as I can myself increases my skill, satisfaction with life and self-sufficiency. If I have an abundance of money and need to give it away, I would rather use it to help people in need. Everyone has to make those decisions for themselves.

Monetary Costs

OK, on to the "dollars" discussion.

Build Costs

My entire greenhouse project (not including the hydronics system used for heating the GH) was just over $7100. This included ~$400 for compost and other amendments for the raised beds. The most expensive item was the glazing: ~$1850. I spent extra on this to get the thicker (5/8") polycarbonate with a higher insulation value due to our high altitude/cold weather environment.

Operating Costs

When I was heating with supplemental electric heating, it cost me ~$180 / year.

When I implemented my hydronic system for heat, my annual operating costs for heating the GH dropped to about $30 / year.

Costs for seeds, soil amendments and other miscellaneous items is about $??? / year.

Monetary Returns

Buying organic veggies at the store that we are growing in the GH would cost ~$??? / year.

So, we're spending ~$??? / year on the food that we can produce in the GH.
(Note: We're only estimating veggies we grow in the GH. We also have a garden; we're not including that).

Increase value of house – while I won't claim that the money I spent on building the GH will increase the value of the house by the same amount, I do know that a GH does increase the value of a house. Of course, you won't see this increase until you sell the house (or your inheritors do). But, in the big picture you should certainly keep that in mind.

One could argue that we make less trips to the grocery store, saving money on gas and car maintenance. I don't really know how to quantify that. But, another thing to keep in mind.

One could also argue that with the increased time spent in the GH, there is less time and money spent on other, less important "entertainment" activities. Again, something to keep in mind.

Cost and Benefit Summary

There is a saying that goes: "Figures don't lie; but liars will figure." It's true that people can justify anything they **want** to justify. I have to admit that I can also be accused of "figuring" to justify my activities.

But for us, growing our own veggies year round contributes to our overall health and gives us a great deal of satisfaction. It is a much better fit with our overall chosen lifestyle and worldview. And I really don't think that, in the long run, it costs us any more money to do that.

Everyone has to figure these types of things for themselves.

Retrospective - Things I might do differently

GH Ceiling

Due to the fact that greenhouses produce a lot of moisture, I found moisture was condensing on the bottom of the metal that I put underneath the deck. It then drips down on the ceiling polyiso insulation and finds its way out to a joint and drips into the GH. It's not much, just a minor annoyance. The polyiso is supposed to be highly water resistant, but I'm not sure how long before it starts to deteriorate. Also, since the space between the polyiso and the metal stays at a higher humidity, there is the possibility of mold developing. Our climate is pretty dry, so I don't know yet if that's going to be a problem. I took down the polyiso after the first summer (it's pretty quick to take down) and checked for mold and didn't find any.

If I were to do it again, I might consider using EPDM instead of sheet metal under deck to avoid/reduce condensation. I don't know if this would help that much, but I would give it more thought.

Appendix

Adjust for Your Specific Location

Keep in mind that my GH solution is geared to my specific situation: Colorado at 9000' elevation. We can't grow tomatoes outdoors here; the growing season is too short and cold. So, we use the GH for that and some other veggies that don't do well outside here.

Make adjustments for your specific location.

Growing Plants in the Winter

There are less hours of sunlight during the winter. That means your plants will grow more slowly, unless you add artificial lighting. We wanted to be as energy efficient as possible, so we didn't want to add artificial lighting. We simply take the slower winter growth into account when planting, starting seedlings for replacements, etc. It's working out very well for us.

Estimating Hydronic Usage

Once I had an idea of electrical usage to keep the GH heated with an electric heater, I could convert the kWh values to BTUs and estimate hydronic usage.

Here are a few examples of electric costs to keep the GH to a minimum of 52 degrees. Our current electric rate is $.12 / kWh.

		Outside Temps		GH Temps				
Row #	**Date**	**High**	**Low**	**High**	**Low**	**Kwh**	**Cost**	**Conditions**
1	10/27/17	55.7	12.4	69.8	52.8	4.6	$.55	Sunny during the day
2	10/30/17	35.9	13.5	62	52.6	12.4	$1.49	Cloudy all day (no solar gain); had to use the heater during the day
3	11/1/17	52.5	34.2	70.6	52.5	6.3	$.75	Very windy overnight.

The estimated solar storage tank size for my hydronic system is 200 gallons. There are 8.3lbs / gallon of water so 200 gallons X 8.3 lbs/gallon = 1660lbs of water. One BTU will raise one lb. of water by one degree F (BTU/lbs). So, it takes 1660 BTUs to raise 1660lbs of water by one degree.

In Row #1 in the table above, we used 4.6 kWh to run the heater. 4.6 kWh = 15704.4 BTUs. 15,704 BTUs will raise 200 gallons (1660 lbs.) of water 9.46 ºF (15,704 BTUs / 1660 lbs. = 9.46 BTUs per lb. or 9.46 ºF). Likewise, removing 15,704 BTUs from 1660 lbs. of water from the solar storage tank will lower its temperature by 9.46 ºF.

In Row #2 in the table above (a much colder and cloudier 24 hour period), we used 1.2 kWh. That equates to 42333.6 BTU’s which would be a 25.5 deg temperature drop in the storage tank.

Assuming I start with a fully heated storage tank temperature of 160 degrees, and that the minimum storage tank temperature is 70 degrees (any lower wouldn’t provide useful heat to the GH) I can get an idea of how many days of heating I can get when it’s cold and the sun isn’t shining to recharge the tank temperature. In the latter case (Row #2), I would have about 3 days before I ran out of heat for the GH. At that point, the electric heater would be used until the tank temperature got replenished. Three consecutive, cloudy days in Colorado is pretty rare. If it happens, it’s no big deal to turn on the supplemental heater for a bit.

Hydronic System

Details on the hydronic system can be found here.

SketchUp

For more details on SketchUp click here.

Questions / Comments ?

If you have any questions about our greenhouse, please feel free to contact us. On our highcountryliving.net web site click on the “Contact Us” link.