

# Serpentine Drainback System Design Manual



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## **System Overview:**

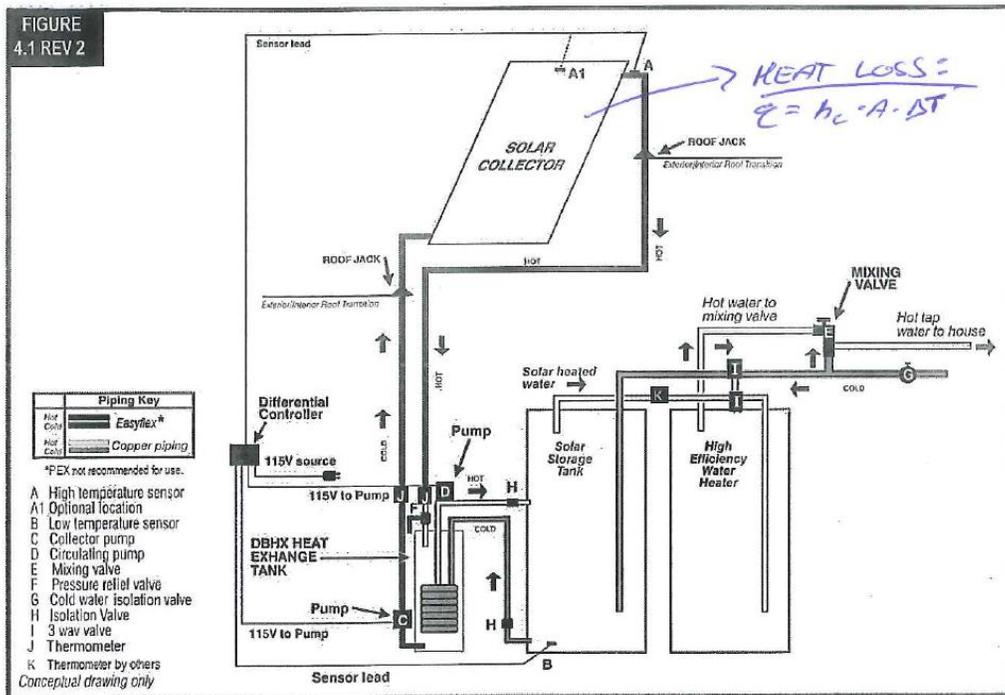
This is a 225 square foot active solar collector. The collector is located in New England and achieves freeze protection by utilizing a drain back design; gravity purges most of the water out of the collector when the collector pump turns off. The collector pump is controlled with a differential controller: two temperature sensors are used, one in the collector and one in the storage tank. When the temperature in the collector is 10 degrees warmer than the temperature in the storage tank, the pump turns on and stays on as long as the collector is warmer than the storage tank. When the pump turns off, the water drains back from the collector to the tank, thus providing freeze protection for the collector.

All supply and return lines going to and from the collector are therefore sloped. The collector is vertical and located on the south facing wall; the copper piping inside the collector is serpentine as opposed to parallel. This allowed us to use the entire south facing wall, a very unique shape, as the collector instead of standard 4 X 8 collectors plumbed in series or parallel. The heat captured by the solar collector is transferred to 2 storage tanks – utilizing multi-tank storage. And finally heat is distributed from the storage tank to the first floor of the home by a radiant floor heating system.

## **Resources and References:**

1. Gary Reysa's \$2000 drain back system:  
<http://www.builditsolar.com/Projects/SpaceHeating/DHWplusSpace/Main.htm>
2. How to Build a Solar Hot Water System by John Canivan:  
[http://www.ic-solarhomes.com/how\\_to.htm](http://www.ic-solarhomes.com/how_to.htm)
3. Simply Solar Yahoo Group:  
<https://groups.yahoo.com/neo/groups/SimplySolar/info>

## System Design and Thermodynamics:



**Picture Courtesy of Radco:** A two tank drain back system. There are several differences between this layout and our design but the diagram provides a general schematic.

Several decisions were made to optimize system efficiency. Two tanks were used instead of one; this allows lower temperature water to circulate through the collector. The inside of the south facing wall was insulated instead of insulated the outside of the wall, this reduce the area exposed to the cold outdoor air. And finally a radiant floor heating system was used to distribute the heat. Because of the large effective area of radiant floor heating, low temperature water (low grade heat) can be used. In this case low grade heat can be as low as 90 degrees Fahrenheit and still provide enough BTU's to heat the first floor of the home. Most heat distribution systems, like standard finned tube baseboard heaters, use high grade heat or water at 180 degrees Fahrenheit or hotter. Lower water circulating equates to higher system efficiency.

The design intent for the multi-tank storage, inside insulation and the radiant floor heating system was therefore to increase system efficiency. Below is equation governing convective heat transfer:

$$q = hc * A * \Delta T$$

q = Heat gain or loss

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A = Area

$\Delta T$  = Temperature difference

Q in this case can be heat gained or lost. Heat lost through collector increases as the temperature difference and effective area of the collector increase.

Theoretical Cost Savings and System Sizing: In general when installing solar heating use as much area as available for the collector. This is because the heat storage tank (or tanks), controls, heat distribution system and controls are fixed costs. Therefore it makes sense to get as much free heat from the system to justify the cost of the system. Here is a theoretical assessment of the heat gained through the collector on a typical sunny winter day:

Collector Size = 225 square feet

Theoretical heat gain from collector = 800 BTU's per square foot of collector per day

Solar BTU's on a sunny day = 225 \* 800 = 180,000 BTU's

BTU's in #2 Heating Oil burned at 90% efficiency = 138,000 BTU's \* .9 = 124,200 BTU's

Therefore on a sunny day the collector should save almost 1.5 gallons of #2 heating oil assuming all the heat stored gets used (180,000/124,200 = 1.5 gallons of oil).

### **Pump, Supply and Return Line Sizing:**

Reference: <http://www.buiditsolar.com/Projects/SpaceHeating/PipeSizing/PipeSizing.htm>

I followed the instructions on builditsolar almost exactly when sizing my pumps, so instead of re-writing it I provided the link. This project was unique because of its very long supply and return lines, each about 30 feet. Because of that, over-sizing the supply, return, top and bottom manifolds eliminated a significant amount of frictional loss in the pipe and also allowed better drainage when the collector pump shuts off. We used 1 ¼ inch pipe for the manifolds, supply and return lines. This also made selecting a pump easier as it reduced the pressure loss. Selecting piping over 1 inch in diameter does significantly increase cost so it's best to only do it if necessary.

## **Insulating the Wall:**

Insulating the Wall: We decided to insulate the inside of the south facing wall for several reasons: first we were able to use R13 fiberglass insulation which is considerably cheaper than equivalent R13 blue board (rigid foam) insulation on the outside wall; insulating the inside wall allows the aluminum backing to be secured directly to the south facing wall (much easier than securing it to insulation). Finally the collector itself is more efficient because the heat loss from the sides of the collector is much smaller because the depth of the collector is only 1.5 inches (as opposed to adding an extra 2 inches for the rigid foam insulation).

The south facing wall in this project is adjacent to the garage which was previously un-insulated. First we had to remove the sheet rock with a sledge hammer and staple R13 fiberglass insulation to the studs. The window was also removed to allow for more collector surface; also routing the collector piping became much easier.



**South Facing Wall Prior to Insulating:** Note window still in place.



**South Facing Wall with Dry Wall Striped:**



**Fiberglass Insulation Mounted to Most of Wall:**



**Window Removed and Sheet Rock Added:**

## Prepping the South Facing Wall:

**Prepping the South Wall:** First the shingles were removed from the South side wall. Then tar paper was stapled onto the chip board. Finally 4 x 8 sheets of aluminum were tacked to the wall.



## Removing Shingles from South Wall:



## After Shingles Removed:



**Aluminum Backing Added to South Wall:** Wooden hangers were made to hang each circuit; this made securing the circuit to the wall much easier.

## **Collector Design and Construction:**

Bottom Manifold: 1.25" copper piping was used on the bottom manifold. The bottom manifold was sloped  $\frac{1}{4}$ " per foot to allow for appropriate drainage. 1  $\frac{1}{4}$  X 1  $\frac{1}{4}$  X  $\frac{1}{2}$  reducing Tee's were soldered to the manifold for the parallel serpentine circuits as shown:



### **Soldering the bottom manifold:**



**Mounting Bottom manifold:** Plastic pipe hangers were used to temporarily secure the bottom manifold. They were eventually replaced with metal pipe hangers because the collector would be too hot for the plastic. Plastic hangers were a good low cost and temporary support system.

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**Installing the 5 Parallel Serpentine Circuits:**  $\frac{1}{2}$  soft (bendable) copper is very difficult, if not impossible to bend by hand. Furthermore, when bending it, special care must be taken not to kink the copper turning it into scrap. We designed a jig to bend the copper and make repeatable 6" diameter, 180 degree turns. To accomplish this we soldered 3' 4" straight copper to 12" of bendable copper (using a straight coupling) and then soldered another piece of 3' 4" straight copper to the 12" piece of bendable copper. The 3' 4" straight copper piece acted as a lever to provide all the mechanical advantage we needed to bend the copper without a lot of effort.



**Jig – Before Bending:**



**Jig – After Bending:**

**Jig Construction:** The jig was constructed of a 6" diameter half circle, and a recycled piece of an old 2' X 4' mounted on an old piece of plywood. The 6" diameter half circle was created by a friend and co-worker who has a laser in his basement. It can also be created with a jig saw as long as you sand any sharp corners or imperfections. When using the jig the most important part is to make sure the copper is flush with the jig at all times; if not you'll run the risk of kinking the copper.

**Leak Testing:** All parallel circuits were leak tested before mounting on the wall. It's best to leak test under pressure.



**Leak Testing Pic:** It's best to examine every solder joint very carefully especially on a very hot and humid day where condensation can occur. For best results, plug the outlet with a thumb to pressurize the system.



**Hooking the Hose to the Copper Circuit:** A straight piece of copper piping was soldered to a hose bib. Inexpensive C-Clamps were obtained from the hardware store, with some plastic tubing to allow for easy on / off method for leak testing.

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**Mounting Pararrel Circuits onto Wall:** We made wooden hangers out of extra plywood and 2 X 4's to hang the circuits. This was important because the pararrel circuits acted like slinkies, and the additional supports allowed them to be soldered and secured with only 1 person.



**Mounting the 1<sup>st</sup> Pararrel Circuit:** Wooden hangers in use



**Soldering a Circuit to the Bottom Manifold:** Wet rags were used so the other solder joints would not come apart.

**Securing Circuits to Wall:** Circuits were secured to wall using ½ copper clamps. Hex Drive Screws were the easist to drive into the wall.

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**Securing Circuits with ½ Copper Clamps:**



**4 of 5 Circuits in Place:**



**5 of 5 Circuits in Place:**

**Creating the Fins:** The fins were created using aluminum flashing cut with tin snips. The sledge hammer method from [Build-It-Solar](#) was used.



**Copper Pipe Inside Fin:**



**Securing Fins to Wall:** Roofing nails were used to secure fins to wall. Pre-drilling was necessary to penetrate the aluminum backing.



**Fins Secured to Wall:**

**Painting the Wall:** We used a Wagner sprayer to paint the wall. This is highly recommended as painting is very fast and clean. A sprayer can be picked up for \$20 - \$30 at the hardware store. We used high temperature black paint; make sure to buy the one with the non-reflective finish.

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**Wall Penetrations and Top Manifold:** The top manifold is located inside the crawl space. Drilling was necessary to penetrate the aluminum backing. Tin snips were used to clean up hole and enlarge it. A spade drill was used to penetrate the wall to allow for the ½ copper piping. The top manifold was sloped to facilitate drainage. Also temperature gages and ball valves were added. Because the circuits were different lengths, balancing the circuits based on the temperature of water improves system efficiency. A shark bite connection was used to transition from 1 ¼ copper to 1 ¼ PEX. Shark bites were very easy to use and did not leak. The only draw-back is the price tag but my crimping tool only had attachments up to 1 inch.



**Tin Snips Used to Enlarge and Clean Up Hole:**



**Top Manifold:** Notice the sloping of the line, the temperature gages, shark bite connection and electric wires for both the temperature sensor and data logger.

**Vacuum Breaker:** Many people in the builditsolar community have stated that they did not need a vacuum breaker. We were on the fence about installing one. Ultimately, because we had a very high height difference between the top of the collector and storage tank we felt it was best to install one. The height difference was over 20 feet and we felt that too much negative pressure would impede drainage. The vacuum breaker cost was about \$100.



**Top Manifold:** Vacuum breaker shown, note vacuum breaker must be at the high point of the circuit.



**South Wall Complete and Painted:** The only step remaining on the wall is the twin wall polycarbonate

**Applying the Polycarbonate to the Collector:** The twin wall polycarbonate was purchased from a green house supplier called “Griffins Greenhouse” in Bristol, CT. They sold me the polycarbonate and the mounting hardware. Basically the polycarbonate fits between the aluminum channels and the channels are secured to the wall. Large amounts of silicon were added when securing the channels to the wall to reduce heat loss.

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Because the collector was custom built with a lot of unique angles and shapes, special attention to detail was necessary to add the twin wall polycarbonate. Every piece was placed on the wall and marked before cutting. Then a piece of  $\frac{3}{4}$  inch plywood was clamped to the polycarbonate which acted as a guide for cutting. We made the cuts with a skill saw with a fine tool blade - the blade selection is very important. A Diablo fine tooth blade rated for sheet metal and plastic is just one option. This insured that every piece was essentially cut line to line. This was absolutely necessary because any gaps would result in heat loss from the collector and a poor aesthetically looking collector. The channels were also marked before cutting; angled cuts were performed on a miter saw.



**Polycarbonate Cut on an Angle:** Saw dust and debris would get inside the twin walls, so we used a hose to clean out the polycarbonate before mounting. Moisture would dry out over time.



**Hose with a Nozzle used to Clean Polycarbonate after Cutting:**

Aluminum tape was used on the top of the polycarbonate to prevent moisture from getting into the channels. Fine cloth tape was used on the bottom of the polycarbonate to allow for drainage. Small holes were drilled in the bottom of the aluminum channels to also allow for drainage.



**Aluminum and cloth tape added to top and bottom of polycarbonate respectively:**



**Adding the Last Piece of Twin Wall Polycarbonate:** Note the heavy bead of silicon along the perimeter.

## **SUPPLY AND RETURN LINES:**

The most difficult part of the planning process, especially in a drain back design, is finding where to run the supply and return lines to the collector back to the storage tank. In this project the supply line went from the basement up into the first floor of the house, across the living room, across the garage and onto the South facing wall. This supply line was about 30 feet long. The return line ran through a crawl space about both the garage and living room and then straight down into the basement. A chase will be added to hide the plumbing going into crawl space. Not to mention that all plumbing, especially plumbing in unconditioned spaces must be sloped. We broke this rule and had some of the plumbing in a conditioned space that was not sloped. The thought being that the water will have enough momentum to get into the storage tank and any excess water, if any, would be stuck in a conditioned space (well above freezing). The system made it through one of the coldest winters on record without any issues.

### **Return (Hot) Line Through Crawl Space:**



**Return Line Through Crawl Space:** Plastic pipe hangers were used to secure piping. Note that all piping was sloped at all times, especially since this is an unconditioned space.



**Insulating the Pipe:** All piping to and from the collector should be insulated, especially the hot (return) line. Insulating was easy; just remove the adhesive tape and touch the tabs together.



**Copper to PEX Transition:** All copper to PEX transitions were performed using shark bite Connectors.



**Supply and Return Lines:** A chase will be built to cover the plumbing. Supply and return lines will also be insulated. The vertical line is the hot return coming from the crawl space. The lower line is the cold supply line feeding the bottom of the collector.



**Supply and Return Lines in Basement:** The picture on the left is before the lines were insulated and supported to the wall. The picture on the right the lines are both insulated and supported. One line feeds into the tank (not shown).

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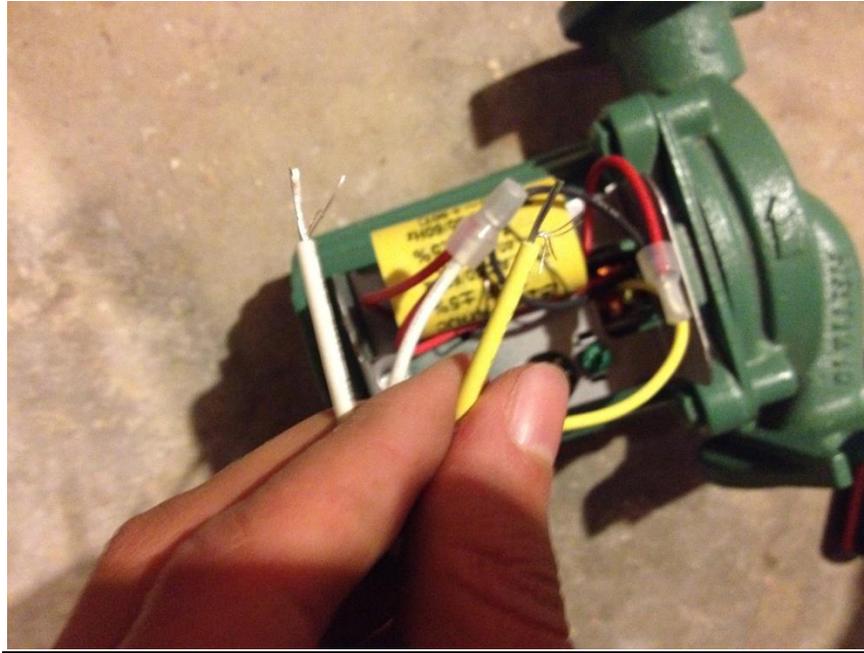


### **Supply Line High Head Pump:**

**Installing High Head Pump:** A flange is soldered to the copper pipe. A gasket is seated inside the flange - as torque is applied to the hex nuts; the gasket creates a water tight seal. A U-Tube shape was used for the copper piping to prevent any penetrations on the rubber lining (similar to Gary Reysa's design). A hose bib is also soldered onto the piping to charge the system. Also two valves are soldered onto the circuit: one between the hose bib and pump and one after the pump; all water must be purged behind the pump before starting it.



**Wiring the Pump:** After reading the manual that came with the pump, it stated that either wire could be wired to the hot and neutral line (the polarity did not matter). So we wired the pump in series with the differential controller. Take off the cover of the pump to expose the 2 leads.



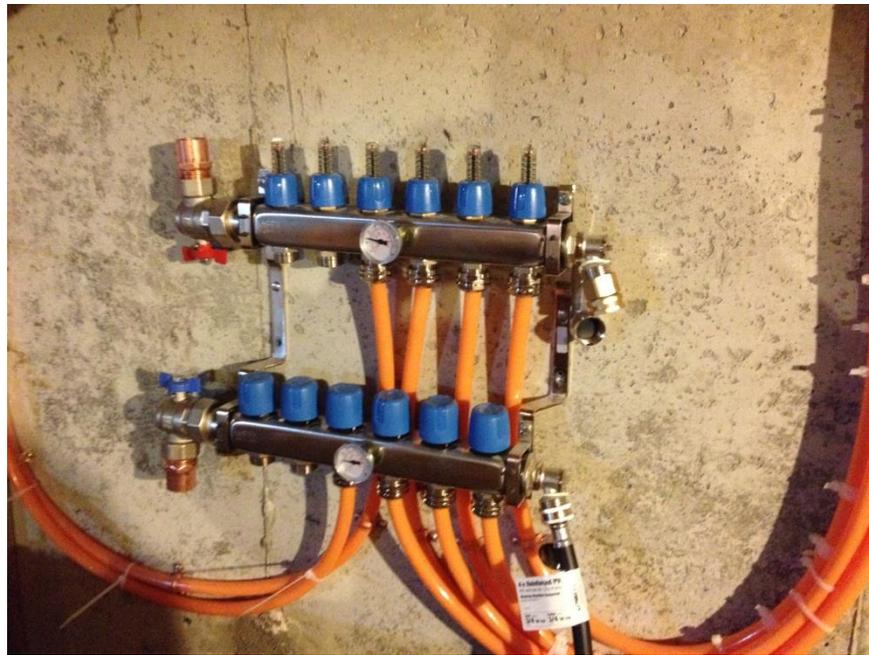
**Wiring the 2 Leads for the Pump:** In this particular case the polarity (hot and neutral wires) did not matter. Check the manual before you make that assumption.

## HEAT DISTRIBUTION:

How the heat is distributed in the house will be a primary factor determining overall system efficiency. For water systems, any heat distribution that circulates low grade heat (water between 90 and 120 degrees) is ideal. To accomplish this heat emitter with large active systems should be used. In this case a radiant floor heating system was installed. Alternatives to consider are: low temperature fin-tube baseboard like the Heating Edge and radiant walls and ceilings (see Home Power Magazine issue 152).

While it's not as well suited to solar heating systems as radiant floor or wall heating, hydronic baseboard heater can also be used to distribute heat. It should be sized using enough baseboard so that the solar heat collected on a sunny day can be distributed to the house over a period of 12 hours or so. This [Slant Fin baseboard heat output chart](#) may be helpful in determining how much baseboard is needed.

Radiant Floor Manifold: A Mr. PEX radiant floor manifold was used. The unit was reasonably priced, about \$225 for 6 circuits in series. The unit came with balancing valves and flow meters. However, if the circuits are about the same length, making your own manifold is a good low cost alternative. I recommend piping the manifold in parallel for a more even flow rate between circuits.



**Mr. Pex Radiant Floor Manifold:** With about half of the connections complete.

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**Aluminum Flashing Between Floor Joists:** Aluminum flashing was placed between the floor joists. A hand stapler with T-50 staples was strong enough to pierce through the flashing and secure it to the floor.



**Flashing Installed Between Floor Joists:**

**Piping Between Floor Joists:** ½ inch copper tubing was used instead of PEX. This was done as part of an experiment, most radiant floor heating systems use PEX tubing which does not conduct heat as well as copper. PEX however is about ¼ the cost per square foot not counting the additional cost for the fittings and the longer time required to install it. In this setup, we used copper tubing and transitioned to PEX around the floor joists and transitioned back to copper. A crimping tool was used to make the transitions. This turned out to be disastrous because crimped transitions leaked during startup and they had to be replaced with sharkbite connectors which greatly increased cost and time.



**Installing the Copper Between the Floor Joists:** Note the PEX transitions around the bends.

**Adding the Fins:** Fins were added on top of the copper the same way they were on the collector. Again the sledge hammer method was used. A hand stapler with T-50 staples was strong enough to pierce through both layers of aluminum and secured the fins nicely to the ceiling.



**Securing the Fins to the Ceiling:**

**Insulating Between the Floor Joists:** Insulating between the joists serves two very important functions: first this area should have been insulated as part of a conservation effort years ago. The majority of the heat loss in a building leaves through the roof and the floor. This was observed during the heart of winter, although the basement is an unconditioned space, it was often very warm in winter due to all the heat loss from the first floor the building. According to Home Power Magazine, up to 15% of the space heating costs can be saved by insulated between the basement and first floor. Insulation was also necessary to insure that the radiant floor heating functions properly. Ideally foil faced insulation should be used to reflect the heat upwards to the space; due to time constraints and lack of availability locally we used Kraft face insulation and stapled the tabs on the floor joists. It's important to maintain a 1 ½" gap

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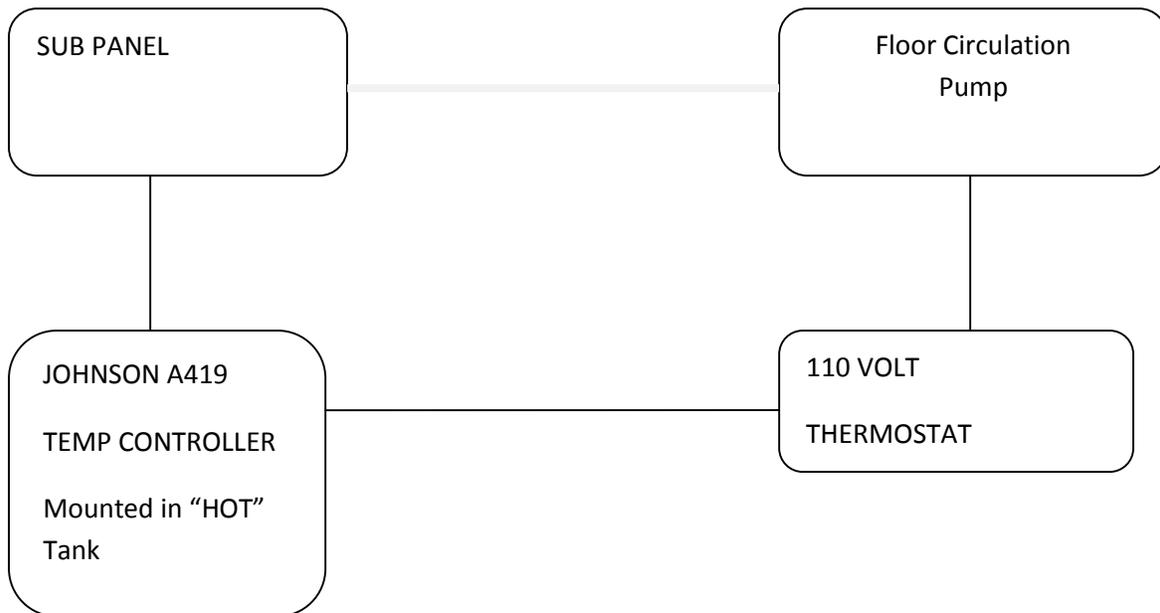
between the piping and the insulation; an air gap provides additional insulation and prevents heat from conducting downwards.



**Insulating Between Floor Joists:** Heat loss from the first floor of the home is minimized by adding batt insulation. This also insures the heat from the radiant floor heating system goes up into the first floor of the home instead of down into the basement.

**CONTROLS:**

**Controls for Radiant Floor Heating System:** Controlling the radiant floor heating system is easy. First understand the conditions necessary for the system to work: a hot collector tank and space that requires heating. A hot collector tank will be a result of the solar gain collected from the collector; therefore a temperature sensor was mounted inside the “HOT” tank. Space heat is required when the temperature in a zone drops below the thermostat’s set point, closing the electric contact. Here is a very simple electrical diagram, all wiring is in series and the order is not important.



Tools Required: Current tester, small screw driver, wire splicer, needle nose pliers and hole saw.



110 Volt Thermostat Overview: The thermostat should be mounted on an interior wall about 4' or 5' off the floor. Because we treated our entire radiant floor circuit as 1 zone, we mounted the thermostat on an interior wall at about the midpoint of the zone. The thermostat was about \$20 at the local hardware store and was very easy to install; simply wire the hot and neutral wires to the leads; there are input and output leads. The thermostat basically worked on a bi-metallic strip; it was selected because of its low cost and simplicity.

Installing the 110 Volt Thermostat: A 1 inch hole saw was used to cut through the drywall. A ½ hole was drilled through the subfloor using a spade bit. Finding the right location for the hole between the basement and the first floor of the house is the most difficult part of the process – look for clues. We looked for other holes that were drilled for electrical receptacles; these receptacles and the door frame provided reference points to measure off of. This is important so that you don't accidentally drill through the floor in a living space. Once the holes are drilled just tape the standard 12 gauge wire to the snake and feed it through the wall. It may be easier to snake it from the bottom going up.



Snaking the Wire through the Wall Into the Basement: Use 1 inch hole saw to drill through the dry wall. Tape the electrical wire to the snake and feed through the wall into the basement.

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**Thermostat Mounted:** Use Drywall Anchors to mount thermostat to the wall

**Installing Johnson A419 Thermostat:** Wiring this thermostat can look intimidating. Look at its overall function and the inputs and outputs: electrically we have 1 input and 1 output. Therefore we have 2 hot wires and 2 neutral wires (plus our ground wires). There are a number of ways to do this. The picture below shows how I wired 1 hot wire (the black wires) to each the input and output (designated 120V and NO – nominal open respectively). The 2 neutral wires were wired together on the input common and a jumper wire created an electrical contact between the hot wire from the input to the common on the output.



**Controls for Differential Controller:** A differential controller simply takes the temperature at 2 different locations and compares them. The desired temperature differential is set by the user. In our case, we mounted a temperature sensor in the top of our collector and an additional temperature sensor in the “COLD” tank. The controller measures the 2 temperatures and takes the difference. For example if the collector temperature is 120 degrees and the tank temperature is 80 degrees, the difference is 40 degrees. I programmed the controller to have a temperature differential of at least 10 degrees. Therefore the collector temperature must be at

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least 10 degrees hotter than the “COLD” tank temperature for the electrical contacts to close and turn on the collector pump.

## **Tank Construction:**

The tank was construction similarly to a wall. We used bottom and top headers, 2 X 6 construction spaced 24 inches apart. R-18 fiberglass insulation was inserted between the studs. ¾ inch plywood was used in the interior of the tank and ½ inch plywood was used in the exterior of the tank. A center partition was created to allow for 2 tanks: “HOT” and “COLD.” EPDM pond liner was used to hold the water it the tank.

How the 2 Tank System Works: Water from the Cold Tank feeds the collector and dumps the hot water into the hot tank. Likewise, hot water from the “HOT” tank circulates the water through the radiant floor heating system and dumps it into the “COLD” tank. Of course, there is a fundamental problem here, what happens if the flow rates are different between these 2 pumps, or one pump is on and the other is off? To get around this problem an equalizer is used. An equalizer is simply a U-TUBE arrangement of ¾ copper piping. All air was removed from the piping and inserted into the 2 tanks. The pressure difference between the 2 tanks is driven by the following equation:

$$Pressure = density\ of\ water * difference\ in\ height * acceleration\ due\ to\ gravity(G)$$

Therefore the greater the difference in water between the 2 tanks the greater the pressure differential. This pressure differential ultimately creates a current and drives water from the tank with greater water to the one with lower water. See picture below for clarity:



**Bottom Heater and Studs in Place:** Tank built in a similar way to framing a wall.



**Top Header and Center Partition in Place:** Tank complete without EPDM liner, sensors and plumbing.



**EPDM Liner and U-TUBE equalizer installed:** EPDM liner tacked onto tank with roofing nails.

Tim

December 12, 2014