Wood Heat Controller

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Summary

We have been heating with wood ever since we built our home almost thirty years ago. In addition to space heating wood provides most of our winter hot water. Thirty years ago heating with wood was seen as a rather quaint activity limited to rural poor. Today heating with cordwood or wood pellets is at the cutting edge of cost effective green energy. Over the long haul wood heat is greenhouse gas (GHG) neutral, burning wood is simply oxidation at a faster rate than decay.

Heating with wood is not for everyone. Cordwood is a rather dirty fuel, architectural magazine articles notwithstanding. Our stove is located in walk out basement minimizing dirt problem. Being solid, wood has very different operational characteristics then other types of home heating fuel. Putting up a year's supply of cordwood requires time consuming physical labor. We are lucky our property is large enough so we are able to harvest cordwood from our own land eliminating need to purchase or transport it from a remote wood lot. We consume 2.5 to 3 cords a year. Here in New England sustainable cordwood yield is from one half to one cord per acre per year. For those without ample land there are many cordwood suppliers. Cordwood pricing tends to be highly variable driven by cost of other heating fuels.

This Paper discusses purpose built controller designed to increase safety and maximize efficiency. Ionization fire alarm and temperature sensor monitor immediate stove area for dangerous conditions. Air temperature near stove is used to control circulator fans minimizing temperature gradient between wood stove and second floor bedrooms. Flue temperature is displayed and alarm sounds if stove runs too hot. Heat exchanger in stove preheats hot water whenever stove is in operation. Preheat tank temperature controls circulator pump. Pump mixes wood stove heated water with electric water heater to increase thermal efficiency.

System Overview

Safety and control functions are implemented with a combination of off the shelf and custom built devices. Design has evolved over the years.

When we designed our home explored various heating options. Choose air tight wood stove located in walkout basement. Electric resistive baseboards serve as backup heat source. Stove is located in center of basement under multistory stairway allowing unimpeded airflow to first and second floors. Small fan above stove blows hot air up and larger second floor fan blows air back to basement. Due to high level of insulation even without fans there is minimal temperature stratification. This is an important consideration during power outages to prevent area around stove from overheating.

As former city dwellers took us a while to become comfortable heating with wood. First time I fired up the stove used Pine construction scraps. When stove began glowing Cherry Red learned to my chagrin that kiln dried softwood produces an incredibly hot fire. Stove is Mohawk Industries Tempwood II (no longer in business) top loader rated at 55,000 BTUs. Two air inlets control temperature. They run wide open when fire is started then closed down to control temperature. Stove works extremely well but is entirely manual.

Fire Detection

Stove area is protected by AC powered battery backed ionization detector wired to detectors on other floors. Battery backup is important to ensure fire warning in event of power outage. Detectors are interconnected, if any detector trips alarm sounds on all. Ionization alarm detects combustion products but does not react to temperature. To address this shortcoming mounted a temperature detector in ceiling near the stove. If air temperature exceeds 190 degrees F (87.8 C) alarm sounds. This is a safeguard in case stove overheats for an extended period.

Air Circulation

Fans are controlled by thermostat located near stove. A small fan, located directly above stove, blows air into living room. A second larger fan, located on second floor, pushes air back to basement. Fans reduce temperature stratification between floors.

Flue Temperature Monitor

Maintaining proper flue temperature is critical for safe wood stove operation. Burning wood is a complex process called pyrolysis. If temperature is too low creosote builds up in chimney risking a chimney fire, too high and energy is wasted as hot gas exits the chimney heating the great outdoors. If stove runs extremely hot there is a risk of chimney damage. Flue temperature should be hot enough so volatiles are burned in stove. If combustion temperature is too low volatiles are carried off in flue gas where they condense in chimney coating it with creosote. Creosote is combustible causing a dangerous situation if it builds up to any appreciable thickness on flue lining.

Chimney is located in the center of house rather than the more typical location on an exterior wall. This has several advantages. Chimney mass stores heat so it continues to provide warmth even after stove goes out. Not being exposed to outside cold, except for short section above roof, flue stays hot minimizing creosote buildup.

At first we used a magnetic thermometer to measure flue temperature. It was cheap but easy to dislodge and did not provide audible over temperature warning. If inlets were not closed down in a timely manner stove ran very hot until someone noticed and went downstairs to damp it down.

Obtained several used Analogic AN2572 digital temperature panel meters with BCD outputs and replaced thermometer with a Type J thermocouple. Thermocouple is inserted into flue pipe a couple of feet from junction between stove and flue. Thermocouple is formed by joining two dissimilar metals. Heat generates a small voltage proportional to temperature, the higher the temperature the greater the voltage. Thermocouple voltage is processed by a digital controller to display flue temperate and output a digital signal to sound alarm. A simple comparator circuit sounds audible alarm if stove is too hot. Alarm sounds if flue temperature exceeds 500 C (932 F). This provides an audible alert that stove is running too hot and needs to be damped down. During normal operation we try to keep flue temperature between 150-200 C.

Hot Water Preheater

About the same time I installed the digital flue temperature display added a preheater. Mounted a Holly Solar Products stainless steel heat exchanger inside stove plumbed to a 30 gallon copper storage tank. Heat exchanger forms a thermo siphon loop to storage tank. Heated water, being lighter then cold, rises to top of heat exchanger. In doing so it pulls heavier cold water from bottom of preheat tank, replacing it with warmer water on top. As long as stove is hotter than tank heat is transferred from stove to water.

A pressure temperature relief valve PTRV is plumbed into top of tank where hot water from heat exchanger enters. It opens if water gets too hot (99 C) or pressure too high (150 PSI). This is an important safety feature as a boiling water explosion is extremely dangerous. Mythbusters did an experiment to see what happens when a water heater explodes due to excessive pressure, video is pretty dramatic.

A Type J thermocouple is located at hot water outlet of preheat tank. A second digital panel meter displays preheater tank temperature. Water temperature is much lower than flue gas so thermocouple is simply a piece of thermocouple extension cable twisted together and insulated from tank.

Was lucky to find the ideal tank at a local scrap metal dealer. Tank has two top fitting, two on the side and one on the bottom. Attached drain valve to bottom fitting. Thermo siphon loop connects to the two side fittings. Attached PTRV to top side fitting where hot water enters from heat exchanger. Cold water enters one of the top fittings and hot water exits the other. Tank did not come with a dip tube for cold water inlet but was able to fashion one by soldering ½" copper pipe inside ¾" cold water inlet.

In researching this paper discovered Holly no longer makes the heat exchanger I used. Found another company Therma-Coil that makes wood stove heat exchangers. The Holly product was a welded stainless steel tank. Therma-Coil is a formed stainless steel pipe. Pipe style heat exchanger should be easier to retrofit into modern wood stoves with catalytic converters.

Preheat tank is plumbed in series with electric water heater cold water inlet. As hot water is used water heater draws replacement water from preheat tank. When stove is operating "cold" water entering electric water heater is warmer than normal reducing or eliminating need for additional energy. During summertime when stove is not in use water continues to flow through preheat tank. In that case water temperature entering water heater is the same as if preheat tank did not exist. System is entirely passive. Whenever wood stove is in operation heated water is delivered to conventional electric water heater reducing energy consumption. System worked so well when I first installed it Electric Utility asked me to explain why our electricity consumption had gone down.

Passive system worked well and had been trouble free for many years but does have a drawback. During periods of cold weather and low hot water consumption preheat tank gets hot enough to open PTRV discharging excess water. Having worked hard cutting/stacking/splitting cordwood this waste of energy and hard work was rather heartbreaking. After many years of procrastination decided to tackle preheater over temperature issue. I was replacing the electric water heater so took the opportunity to installed a small circulator pump and check valve between electric water heater hot-water outlet and pre heat tank cold-water inlet. When water in preheat tank reaches temperature set point pump circulates water from 55-gallon electric water heater back to preheat tank thus lowering preheat tank temperature. This increases preheat water storage capacity from 30 to 85 gallons. Pump turns on at 70 C well above normal water heater operating temperature of 49 C (120 F) but below PTRV trip point.

Well water entering preheat tank is roughly 12 degrees C (54 F). Raising water temperature to 70 degrees C (158 F) takes 25,896 BTUs (158 – 54 x 30 gal x 8.3 BTU).

Electric water heater is 55 gallons set to 49 C (120 F). Increasing water temperature to 70 C takes 17,347 BTUs (158 – 120 x 55 x 8.3 BTU).

At pump set point of 70 C assuming entire 30 gallons of water is mixed with 55 gallons at 49 C resulting temperature will be 56 C (133 F). If pump turns on a second time temperature increases to 61 C (142 F). These temperatures assume complete mixing and zero hot water usage. In calculating BTUs we are also ignoring effect of temperature change on density.

Using electric water heater tank for storage significantly increases thermal storage capacity. In addition by lower preheat tank temperature it increases heat transfer from wood stove to water.

Caution: increasing water temperature dramatically increases risk of being scalded. Use of tempering valve or antiscald valve decreases risk.

Temperature	Time to produce 3rd degree burns on adult skin
160 F (71 C)	½ second
150 F (66 C)	1.5 seconds
140 F (60 C)	5 seconds
130 F (54 C)	30 seconds
120 F (49 C)	10 minutes
110 F (43 C)	3 hours
100 F (38 C)	Safe Temperature

Wood Heat Controller - Theory of Operation

Figure 1 Wood Heat Controller - front panel

Controller consists of three Analogic AN2572 Type J thermocouple digital displays with BCD outputs. Top display monitors wood stove flue temp. Middle displays preheater water temperature. A third is intended for future batch solar water heater. An LED above alarm indicates when preheat pump is on.

User controls consist of a line voltage thermostat and ON and OFF push buttons. When stove is started ON button is pressed latching power relay energizing unit. Pressing OFF button deenergizes relay powering unit down.

Fan Control

Line voltage thermostat monitors air temperature near stove. When temperature exceeds set point it turns on fans. Fans run as long as temperature is above set point.

During normal operation when fire is started ON button is pressed latching power relay. This turns on power supply used by temperature displays and monitoring circuit. Power relay remains energized until thermostat turns on fans. When that occurs relay is deenergized however power is maintained by thermostat. Controller remains on until air temperature drops low enough for thermostat to turn fans off. OFF pushbutton turns controller off unless fans are on. In that case OFF button has no effect, controller remains on until temperature near thermostat causes thermostat to switch off. This insures controller is operational even if it was not turned on when fire started.

Flue Temperature Alarm

A Type J thermocouple probe is inserted into flue pipe a couple of feet above stove. Digital readout displays flue temperature. In addition to visible display meter outputs a BCD temperature value. Display PRINT command is used to latch BCD output once each conversion cycle. If temperature rises above set point comparator activates Sonalert audible alarm. It also energizes a reed relay contact closure to activate a remote alarm. So far that feature has not been implemented. Sonalert is loud enough to be heard throughput house.

A 4-bit comparator monitors the hundreds BCD output. The 1000's bit bypasses the comparator. Alarm trip point can be set between 500-800 C in 100-degree increments by two DIP switches.

Preheater Pump

This is the most recent upgrade. Normally a differential temperature controller would be used in this type of application. I opted to simply monitor preheat tank temperature. I did this for two reasons:

1) Did not have a differential temperature controller
2) At very high temperature even if preheat and electric heat tanks are at the same temperature keeping water flowing minimizes temperature at thermo siphon hot water inlet reducing chance PTRV will open.

Thermocouple attached to preheat tank hot water outlet measures temperature. BCD comparator is similar to one used for flue temperature with addition of a 555 timer configured as a one shot. When set point is reached SSR is activated turning on pump and LED indicator. Pump activation triggers 555 timer. 555 output is looped back forcing pump to remain running for several minutes regardless of temperature reading. Hysteresis eliminates short cycling pump.

A 4-bit comparator monitors the tens BCD output. Pump activation temperature can be set between 50-80 C in 10-degree increments by two DIP switches. PTRV limits maximum water temperature to less than 100 C.

Controller Schematic

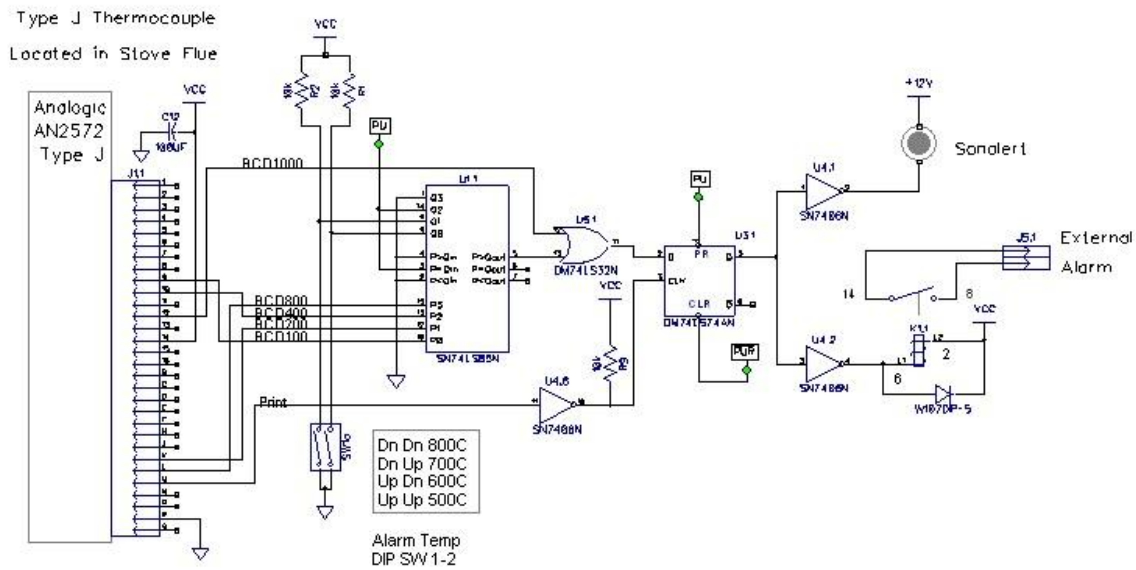

Figure 2 Flue Temperature Monitor

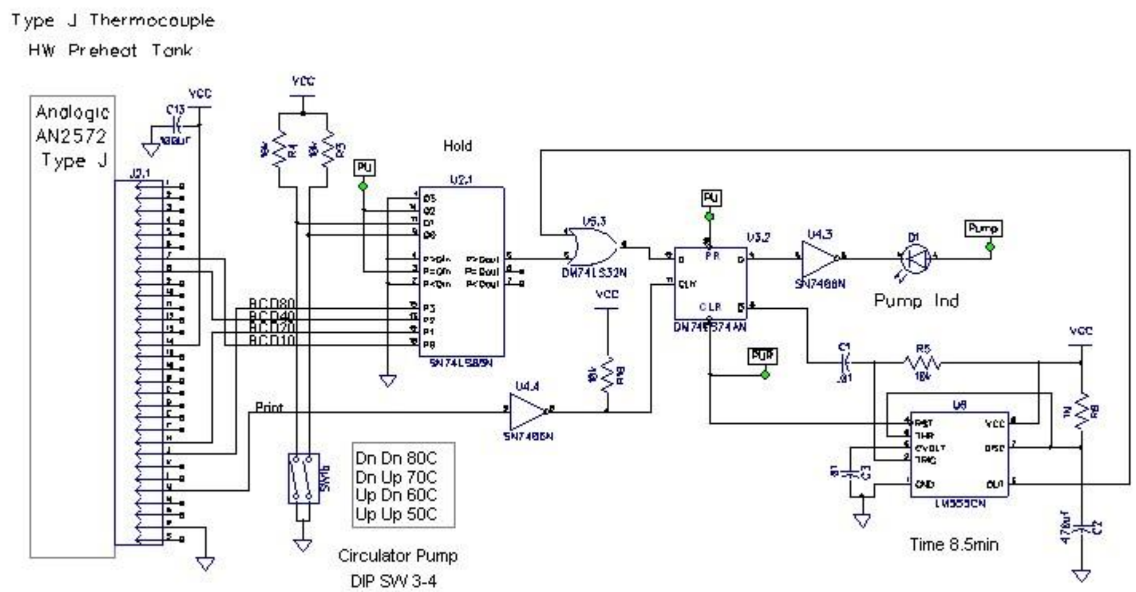

Figure 3 Preheat Recirculate Pump Control

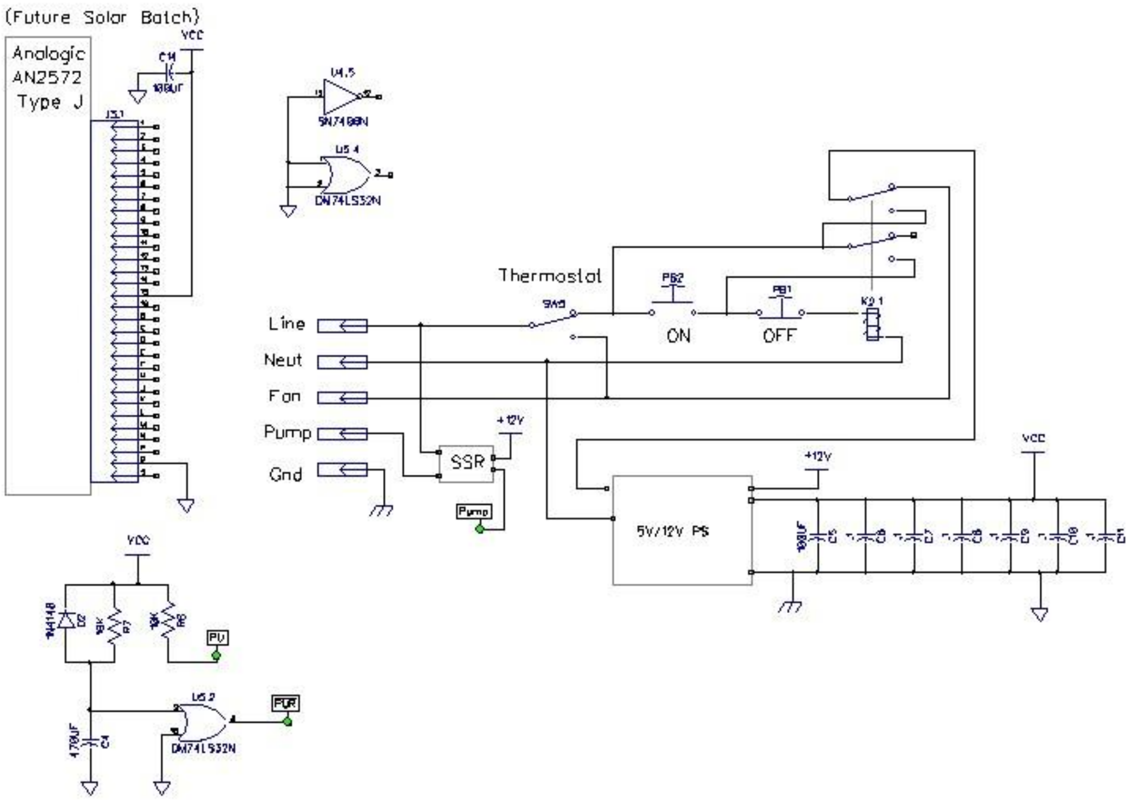

Figure 4 AC Switching

Conclusion

System has evolved over the years; keeping us warm in an environmentally friendly manner, providing hot water and saving money.

Heating with wood requires some accommodation – it involves more than simply setting temperature on a thermostat. Having a stack of cordwood outside bring peace of mind in these troubled times. No matter what happens we know at least we will be able to stay warm. In December 2008 Northeast was hit by a severe ice storm knocking out power to tens of thousands of people in Southern NH. We lost power for six days but did not have to worry about freezing pipes or going to a shelter because we were able to stay warm without electricity.

Often time's environmentally conscious projects seem overly complex and expensive. This paper describes what we have been able to do using a combination of new and used components and a little ingenuity. Hopefully it will encourage others to experiment.