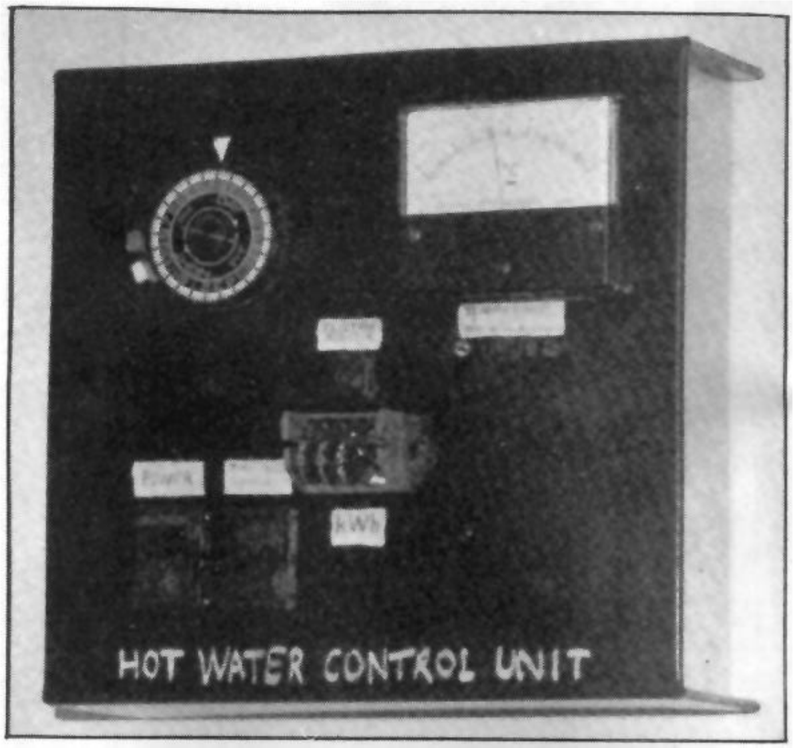
THE BLACK BOX

MONITORING AND CONTROL OF SOLAR WATER HEATERS



This article gives details of the "black box" mentioned in a previous article "Customizing a commercial solar water heater".

The device is basically very simple: it senses temperatures in the hot water tank, gives a visual display of them, and relies on you to make the right decisions about switching on backup systems (electric, gas or wood-fire boosters) or altering your patterns of water use.

It is equally applicable to thermo-syphon or pumped solar hot water systems. It is completely separate from the differential temperature sensor which controls the pump.

The Electronic Thermometer (Fig. 1)

Each temperature sensor consists of five low power silicon diodes in series (e.g. IN 91.4). They can either be all mounted at one point (e.g. glued to an old penny - sensor B) to measure the temperature at the top of the tank, or strung-out with inter-connecting wires to perform a crude integrating function and measure the average temperature of a large object, i.e. the average temperature of all the water in your storage tank (sensor A). The average temperature is a very useful parameter, as I will discuss later.

Circuit Theory

When either sensor is switched into the circuit, it has a small forward current flowing through it. The voltage drop across each PN junction is about 600 mV (millivolts) at 20°C. However it is affected by temperature, falling by about 2.2 mV for every degree rise in temperature.

For five diodes the voltage change is 11 mV/°C, so as the temperature of the sensor changes from freezing to boiling, the voltage across the sensor changes from 3.22 volts to 2.12 volts.

This voltage change is modified by the adjacent resistors, and buffered by the operational amplifier, which simply acts as a voltage follower with high input impedance and low output impedance. The resistors and meter between the amplifier output and the zero voltage source act as an accurate voltmeter.

During calibration with the sensor in an ice bath, the zero-set potentiometer is adjusted until there is a voltage of -5.1 + 3.22 = -1.88 volts across the 47K resistor. Thus the voltage at the non-inverting input of the op. amp. will be exactly zero. The current through the diodes is about 40uA.

Calibration

After wiring up the circuit as shown in Fig. 1, switch sensor B into the circuit. Put the sensor in a small freezer bag and place the bag into a cup of iced water. The diodes and connecting wires must be kept dry. Ten minutes later, switch on the circuit and adjust the ZERO SET potentiometer until the meter reads ZERO current. Then put the bag into a thermos of hot water at 50°C and adjust the GAIN potentiometer until the meter reads 0.5mA.

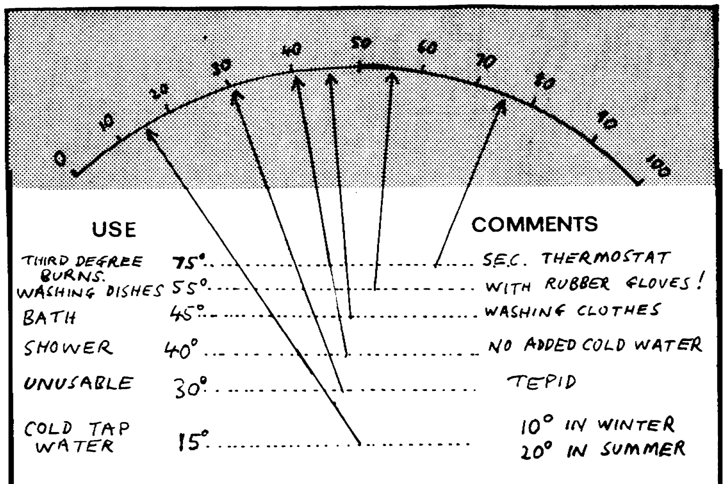
Leave the circuit switched on for a couple of hours, and repeat the above procedure to fine-tune the calibration.

If you have used good stability resistors and Zener diodes, you now have an accurate thermometer reading from 0°C to 100°C.

Re-calibrate the meter dial:
(0-1mA becomes 0°C to 100°C)

Installing the sensors

The two sensors must be in close thermal contact with, but electrically insulated from the hot water tank. I wrapped mine in PVC tape, but made sure they were then touching the copper wall of the tank, inside the layer of mineral fibre insulation. The easiest way to do this was to remove a small metal partition from around the heating



METER CALIBRATION

element, and shove the sensors into position using a piece of coat-hanger wire.

The "Other Bits"

1. Adjustable thermostat:

IT SHOULD BE A STANDARD ITEM IN ALL ELECTRIC-BOOSTED SOLAR HEATERS. Mine is a Robertshaw Type EA C81N but there are probably other suitable types.

Its temperature probe is a cylindrical copper bulb on the end of some flexible copper capillary tube which leads back to the switch itself on which is mounted a dial and knob calibrated from 20°-120°C. I have wired it up in place of the standard 75°C pre-set thermostat which was supplied in the original tank. The probe is pushed up inside the insulation, just like the other two probes. The probe is non-electrical and does not have to be wrapped in PVC tape. If you place the probe about 2/3rds of the way up the tank, it means the booster won't switch

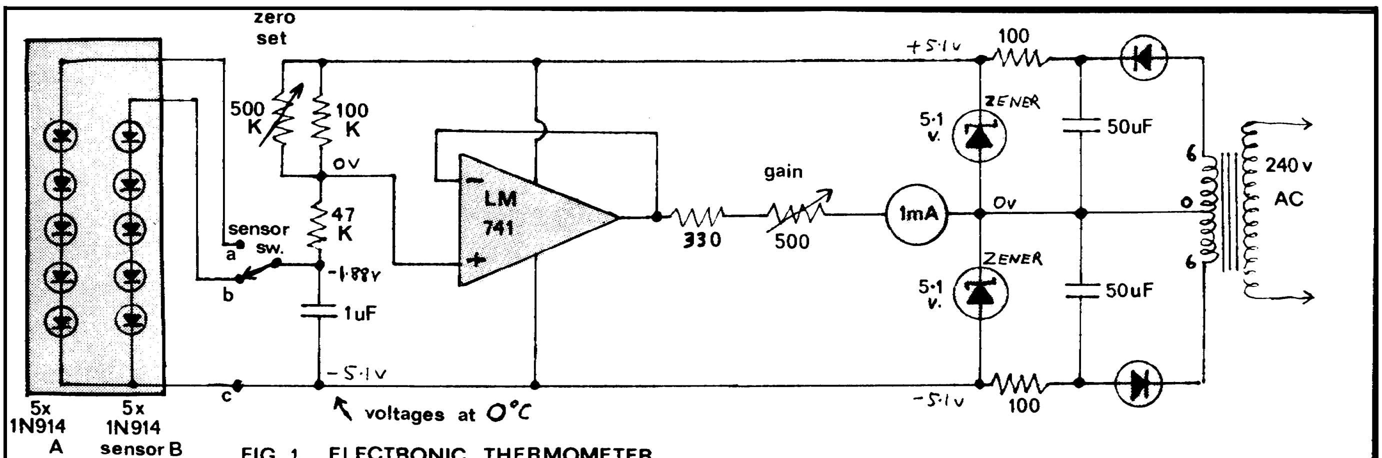


FIG 1 ELECTRONIC THERMOMETER

on until the supply is down to about 100 litres of water at a usable temperature.

2. Time Switch: Cannibalized from a Kambrook timer, Rated at 10 amps but happily switching a 3 kW booster (12.5 amps) in my system.

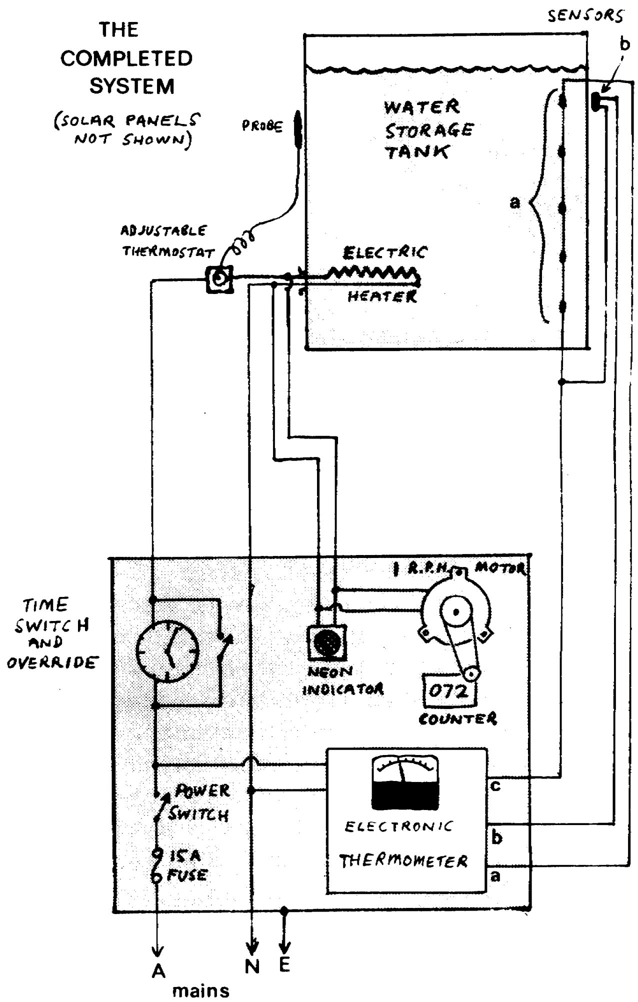
3. Override Switch (optional) : This is wired in parallel with the time switch, To be switched on when the water is too cold but you don't want to re-adjust the timer.

4. Watt-hour meter (very optional - only for obsessional enthusiasts): This was made from an old synchronous motor geared down to do 1 rev. per hour. It is connected to a cassette tape counter via a couple of plastic pulleys and a rubber band. The sizes of the pulleys must be worked out so that the counter registers one unit for every kilowatt-hour used. In my case with a 3 kW element, the counter advances one unit every 20 minutes. The synchronous motor must be wired up in parallel with the electric element, and this may involve considerable lengths of high voltage wiring. A perfectly adequate substitute is just a neon pilot light which glows whenever the heating element is on.

The Completed System

Typical Operation

1. Switch on the main power switch. The electronic thermometer uses only a tiny amount of power (probably about 1 watt) so may be left running continuously.
2. Up in the roof, adjust the thermostat to the minimum usable water temperature (say 40°C, but not above 50°C)
3. Adjust the time switch to come on in the evening. Typically 5 pm to 10 pm. Thus on cloudy days it will provide hot water if the solar panels have been unable to. If the family insists on hot water in the mornings, it could also switch on between 5 am and 7 am.



However it is more economical to have the time switch on only for brief periods in the evening. At other times of water use, switch the thermometer to sensor B (tank -top temperature) and see if it is adequately hot for your needs. If not, switch on the override switch for a couple of hours and check the temperature again. For doing dishes you need quite hot water (about 55°C or above). But you only need about 8 litres of it. It seems rather a waste to use the HWS to provide it, as you will be heating at least twenty times as much water as you need. Boil a kettle instead.

4. Be warned - you may become addicted to compulsively watching the dial on days when you are home! It is fascinating to see how the system performs in different weathers. During a sunny day, the average temperature may rise from 30°C to 50°C. However if you left the override switch on overnight by mistake and have the adjustable thermostat set at 50°C, the tank on a similar sunny day will go from 50°C to only 60°C. Obviously at higher temperatures the system is collecting only 50% of the solar energy. These are typical figures I have recorded on my system, and it has solar panels with a selective coating which is supposed to be quite efficient at high temperatures!

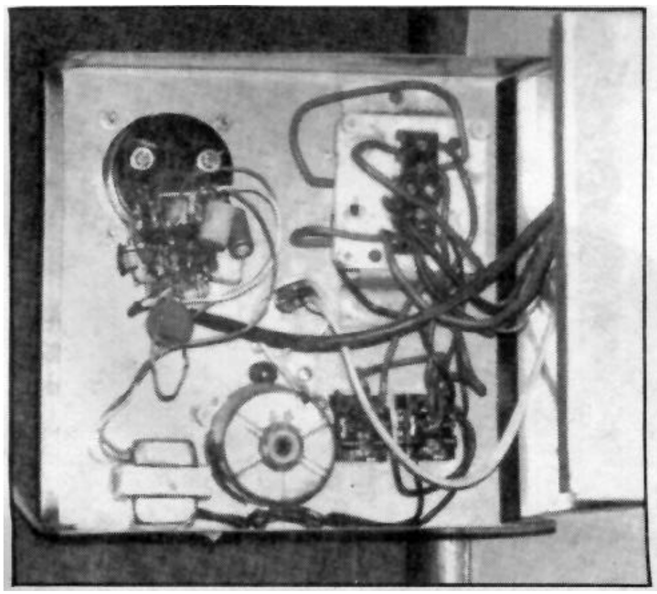


Fig. 2. Inside the black box-what a mess!!!

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me ??

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Another useful function of the average temperature sensor is to check for heat losses. Make a note of the temperature when you go to bed. Switch off the override and time switches until you plan to get up. Note the temperature next morning. It should have dropped by less than 5°C. If the previous few days have been very sunny, with little use of hot water, and the tank is very hot at night (say 60°C) you will probably find that the temperature drops by up to 10°C overnight.

This highlights the inefficiency of trying to keep the tank very hot all the time: the heat just leaks away.

If the average temperature plummets as soon as the sun goes off the panels in the afternoon, it means the system is suffering from reverse thermosyphon: hot water is flowing back into the solar panels and heating the evening sky.

This is especially bad if that heat energy happens to be electrical energy supplied via the booster element.

Black Box

Comparison of average and outlet temperatures

By switching from sensor A to sensor B and comparing the readings you can get a good idea of how well the water is flowing or being pumped through the panels. At the end of a sunny day, the average should be only a couple of degrees less than at the top. If they are the same, your pump is switching on for too long or stirring up the water in the tank too much by pumping too fast.

If there is a large temperature difference, there is probably a blockage somewhere, or the pipes between panels and tank are too small.

After using some water, the top temperature might be 45°C and the average temperature only 30°C. Assuming the inlet water is at 15°C, then you still have about half a tank of hot water.

There are probably many other uses I haven't even thought of yet. The sensors are quite cheap. With extra positions on the switch you could monitor temperatures at the inlet and outlet of the solar panels, air temperature, water inlet temperature, etc. If all the diodes are the same type, there should only be a need to calibrate one sensor. The lengths of wire between the sensors and the switch are not critical.