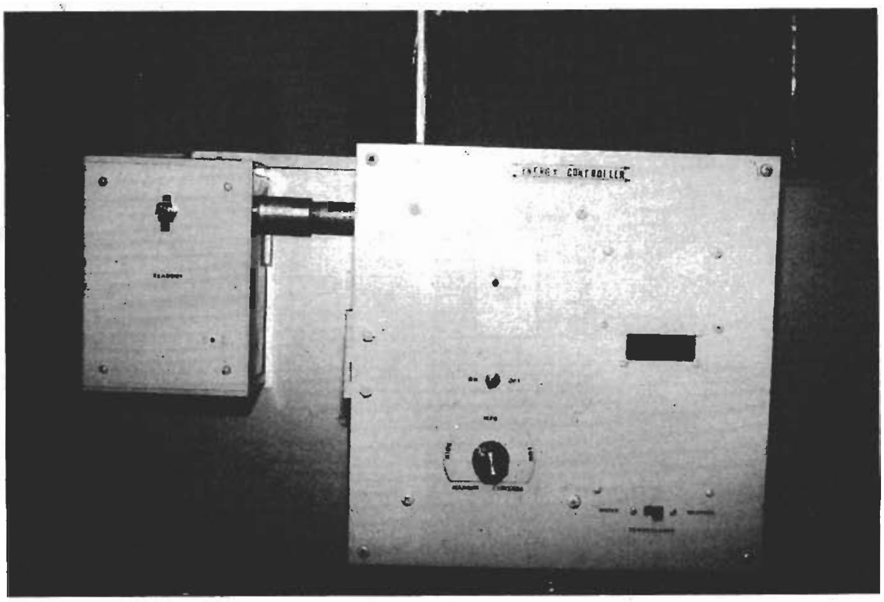

ENERGY MISER FOR YOUR FURNACE

Cut fuel costs and increase the efficiency of your home heating system with this easy-to-build energy controller.

ROLAND GIBSON

EVEN IN THESE TIMES OF UNCERTAIN FUEL costs, there is one fact that you can be sure of—if less fuel is consumed, the cost of energy will be lowered. That is the purpose of this project—it is an energy "controller" designed to minimize the amount of oil used by a hot-water heating system.

Oil hot-water heating systems use an aquastat to control the system's water temperature. That aquastat has adjustable settings for hot-water temperature and circulator control. Before installing this controller, our fuel-oil supplier had recommended that the hot-water temperature be set at 180°F during the winter, and 160°F for the summer; the corresponding recommended circulator settings were 160°F and 140°F respectively. However, I did some tests and found that, except during periods of very cold weather, those settings were excessive and it should therefore be possible to reduce fuel-oil consumption if the circulator were set at 120°F and the water temperature were varied inversely with the outside temperature. From that idea grew the controller.

An energy controller

In the AUTOMATIC mode, the controller monitors the atmospheric temperature and compares that with the temperature of the water in the heating system's boiler. Based on that comparison, the circuit either turns on or turns off the boiler's burner, maintaining the water temperature at a level that is no higher than needed for heating.

In addition, in the MANUAL mode, provision has been made so that the water temperature can be set by hand and then maintained at any level between 100°F. That is intended for use during periods when heat is not required.

The circuit design is relatively simple, supplementing but not eliminating any of the oil-burner's control circuit. When the controller is switched OFF, oil-burner operation returns to normal.

The controller has a "fail-safe" design. But that we mean that if it fails during an "on" cycle, the oil burner will operate using the preset oil-burner controls. If a failure occurs during the "off" cycle, the burner will shut off and stay off until the controller switch is placed in the OFF position, returning the burner operation to the preset burner controls.

The components used in this project are readily available. Construction is straightforward and any technique can be used. A PC board can be used if desired, and will certainly make things a bit neater, but it is not *required*—none was used in building the prototype described here.

How it works

The controller's schematic is shown in Fig. 1. The power supply for the circuit is shown in Fig. 2-a; the power supply for the temperature readout is shown in Fig. 2-b. The two temperature sensors, IC5 and IC6, are AD590's from Analog Devices. They have an output of 1 microamp-per-degree Kelvin. Accuracy is 0.5°.

As most oil-burner controls in the U.S. are calibrated in degrees Fahrenheit, for convenience it would be desirable to scale the sensor output to those units; 10 millivolts-per-degree Fahrenheit was the output we chose. Let's see how that scaling is done. To keep things simple, we'll only discuss the scaling for the water-temperature sensor, IC6; the procedure, and values used, are identical for the air-temperature sensor, IC5. To convert from Kelvin to Fahrenheit, the following equation is used:

$$\text{Temp (in °F)} = \text{Temp (in °K)} - 459.67$$

Remembering that we are scaling the output to 10 millivolts-per-degree Fahrenheit, the total resistance of R1 and R2 becomes:

$$1.8 \times \frac{10^{-2}}{10^{-6}} = 18000 \text{ ohms}$$

To create that resistance, a 16K resistor and a 5K pot are connected in series; the pot is used to trim the total resistance until it is the precise value needed. When that is done, the voltage drop across R1 and R2 will be equal to 10-millivolts-per-degree-Fahrenheit, plus 4.5967 volts. To complete

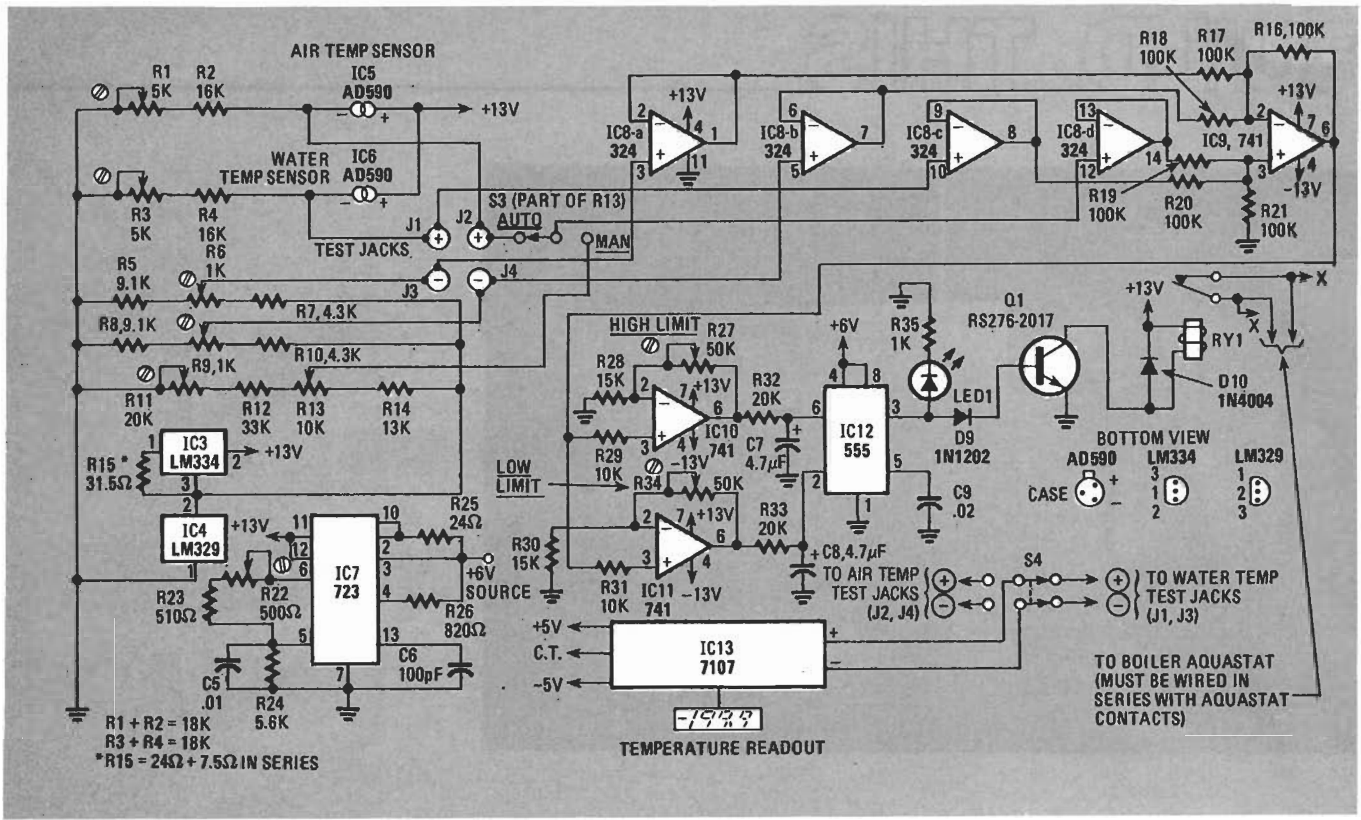

FIG. 1—SCHEMATIC DIAGRAM of the energy controller. Relay RY1's contacts must be wired in series with the oil burner aquastat's contacts.

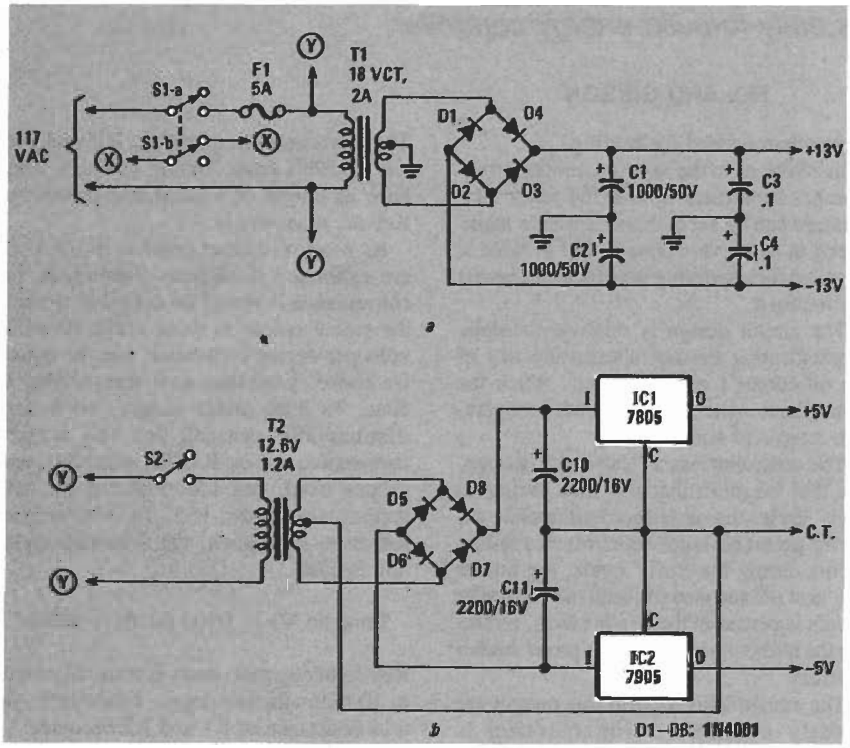

FIG. 2—POWER SUPPLY for the energy controller is shown in *a*; the power supply for the readout is shown in *b*.

that conversion, a 4.6-volt reference voltage is needed. That is done by generating a precise 6.9 volts using the combination of IC3, an LM334 constant-current source; IC4, an LM329 6.9-volt voltage reference, and R15. That voltage is then placed across a voltage divider network consisting of R8, R9, and R10. Trimpot R9 is used to balance the divider, and the 4.6 volts is taken from its wiper.

In the manual mode, a resistor network, R11-R14, is used in place of the air-temperature sensor. With the values shown, R11 is adjusted so that the voltage at the junction of R12 and R13 is 4.6 volts. The output, taken from the wiper of R13, can be adjusted so that is simulates an air-temperature of between 0°F and 100°F.

The outputs from the temperature sensors and reference voltages are buffered by IC8-a–IC8-d, a 324 quad op-amp. The op-amp outputs are connected to IC9, a 741 op-amp. That IC adds the two 4.60-volt reference voltages and subtracts them from the sum of the two temperature-sensor output voltages. The output of IC9 equals the sum of 10 millivolts-per-°F of outside temperature plus 10 millivolts-per-°F of water temperature.

The controller's operation is a function of the sum of the air temperature and the water temperature. Take a look at Fig. 3. You'll note that irrespective of whether water-temperature scale A or B is used, the sum of the air and water temperatures is the same. That is, using scale A, at an air temperature of 0°F, the water temperature is 180°F, for a total of 180°F; at an air temperature of 30°F, the water temperature is 150°F, for a total of 180°F, and so on. That works the same way for scale B, and would for any other scale, as long as that relationship was maintained.

To conserve fuel, we want to turn off the boiler's oil burner when the combined sensor readings equal that critical value. When that is done, the higher the air temperature, the lower the water temperature maintained by the boiler. For the rest of this discussion, let's assume that we've chosen 180°F for that value. Remembering our scaling factor of 10 millivolts per degree Fahrenheit, we are going to want to open the relay when IC9's output reaches 1.8 volts. That output is connected to IC10 and IC11, two additional 741 op-amps; those IC's are used here

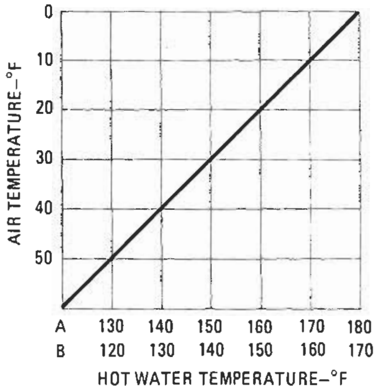

FIG. 3—WATER TEMPERATURE versus air temperature. At every point along this line, the sum of the air and water temperatures is the same.

PARTS LIST

All resistors ¼-watt, 5%
R1, R3—5000-ohm potentiometer, lienar taper
R2, R4—16,000 ohms
R5, R8—9100 ohms
R6, R9—1000-ohm potentiometer, linear taper
R7, R10—4300 ohms
R11—20,000-ohm potentiometer, linear taper
R12—33,000 ohms
R13—10,000-ohm potentiometer, linear taper
R14—13,000 ohms
R15—31.5 ohms (see text)
R16-R21—100,000 ohms
R22—500-ohm potentiometer, linear taper
R23—510 ohms
R24—5600 ohms
R25—24 ohms
R26—820 ohms
R27, R34—50,000-ohm potentiometer, linear taper
R28, R30—15,000 ohms
R29, R31—10,000 ohms
R32, R33—20,000 ohms
R35—1000 ohms

Capacitors
C1-C4—1000 µF, 50 volts or better, electrolytic
C5—.014 µF, ceramic disc
C6—100 pF, ceramic disc
C7, C8—4.7 µF, 25 volts or better, electrolytic
C9—.01 µF, ceramic disc
C10, C11—2200 µF, 1600 volts or better, electrolytic

Semiconductors
IC1—LM7805 5-volt positive voltage regulator (National)
IC2—LM7905 5-volt negative voltage regulator (National)
IC3—LM334 constant-current source (National)
IC4—LM329 6.9-volt reference voltage, temperature stabilized (National)
IC5, IC6—AD590 temperature sensor (Analog Devices)
IC7—723 linear voltage-regulator (Intersil)
IC8—324 quad op-amp (National)
IC9-IC11—741 op-amp (National)
IC12—555 timer (National)
IC13—7107 evaluation kit (Intersil)
Q1—RS276-2017 NPN transistor (Radio Shack), or equivalent
D1-D8—1N4001
D9—1N1202
D10—1N4004
LED1—jumbo red LED
J1-J4—banana jacks
RY1—DPDT relay, 12 VDC, 160 ohm coil, Radio Shack 275-218 or equivalent (see text)
S1—DPDT switch
S2—SPST switch
S3—SPDT switch (part of R13)
S4—DPDT switch
Miscellaneous: Perforated construction board, enclosures (see text), copper piping (see text), wire solder etc.

to control the operation of IC12, a 555 timer configured as a Schmitt trigger. A 723 precision voltage regulator, IC7, is used to provide V_{CC}, a regulated +6 volts, for IC12. The output of IC12 (pin 3) depends on the voltages at its pins 6 and 12. If the voltage at pin 6 is ⅔ V_{CC}, or 4 volts, IC12's output will go high. If the voltage at pin 2 is ⅓ V_{CC}, or 2 volts, IC12's output will go low.

The output from IC12 drives Q1, which is used to control the operation of RY1, a normally closed relay. Ideally, RY1's contacts should be rated at 20 amps, but if such a relay is unavailable, a DPDT relay whose contacts are rated at 10 amps may be used; the contacts are tied together to double the rating. That's what was done here.

Relay RY1's contacts are wired in series with the aquastat water-temperature control contacts. Note that the aquastat's contact circuit will have to be broken for that to be done.

The 3½-digit temperature readout is an Intersil 7107 evaluation kit. That kit comes complete with all necessary components and a PC board, but not a power supply; an appropriate supply is shown in Fig. 2-b. As supplied, however, the meter's full-scale reading is 200 millivolts; it must be modified for this application so that the full-scale reading is 2.00 volts. That can be done by changing the value of three of the components in the evaluation kit. Those changes are C2 from 0.47 µF to .047 µF, R1 from 24K to 1.5K, and R2 from 47K to 470K.

Construction

Construction is straightforward and can be done using any technique. The prototype was built on perforated construction board, using point-to-point wiring with good results. Once the unit is built, but before it is housed or installed, it must be aligned.

To align the temperature sensors you'll need an accurate thermometer as well as a voltmeter. Making sure that the area that you are working in is not subject to sudden changes in temeprature (caused by drafts, etc.), place the thermometer and the sensors next to each other. Turn the controller on and place it in the AUTOMATIC mode. With the meter's positive lead connected to J1 and the negative lead to ground, adjust R6 until the meter reads exactly 4.6 volts. Next, connect the meter's positive lead to J4 and adjust R9 for 4.6 volts.

Once those adjustments have been made, connect the meter's positive lead to J1 and the negative lead to J3, and adjust R3 until the meter's reading agrees with the measured temperature. Remember—the voltage across those jacks has been scaled so that 10 millivolts equals 1°F. For example, an 80°F temperature would be read on the meter as 0.8 volts. After that has been done, connect the meter's positive lead to J2 and the negative one to J4, and adjust R1 until the meter reading agrees with the measured temperature. Finally, verify that the output of IC9 is twice the measured temperature. That is, if the measured temperature is 65°F, there should be 1.3 volts on pin 6 of IC9.

Next, we need to adjust the output of IC10 so that it is 4 volts when IC9's output is 1.8 volts. To do that, place the controller in the manual mode, and adjust R11 so that the voltage at the junction of R12 and R13 is 4.6 volts. Then adjust R13 so that you get a 1.8-volt output from IC9. Finally, adjust R27 for 4 volts at pin 6 of IC12.

The last adjustment to be made is to adjust the lower temperature-limit. Here we were interested in a temperature differential and selected a combined air- and water-temperature drop of 15°F. That differential is one that was convenient for our situation; any that works well for you can be used. In any event, the adjustment is made in the same manner. Adjust R13 until the IC9's output measures 1.65 volts (1.8 − .15). When that is done, simply adjust R34 until 2 volts is measured at pin 2 of IC12.

Final assembly and installation

With the exception of the readout's power supply, the unit was housed in a 12 × 12 × 4-inch recessed light-fixture box lined with asbestos. The readout's power supply was housed in a separate 5 × 7 × 3-inch metal case. Both units were mounted on the boiler using ⅝-inch standoffs. All external wiring, other than the sensor wires, must be enclosed in BX or conduit.

The outside air-temperature sensor was enclosed in a 3 × 2 × 1-inch case, such as the one shown in Fig. 4. A 5/32-inch hole was drilled in the bottom so that air could reach the sensor. A small hole was also drilled in the top for the cable. The sensor's cable should fit snugly through the hole, and any spaces sealed against leaks. Connections inside the case, of course, were soldered and insulated. The unit was fastened under a windowsill on the north side of the house.

Placement of the water-temperature sensor was not that simple. It would have been ideal if the sensor could have been placed in the same well as the aquastat, or if the temperature could be measured at the boiler's case. However, neither approach was feasible: the first due to insufficient space and the second due to temperature lag.

Figure 5 shows an acceptable solution.

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ENERGY MISER

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An offset connector was made by soldering together a ½-inch elbow, a short length of ½-inch pipe, and a ½-inch T-connector. Then a ½-inch copper end cap was drilled to accommodate a length of ⅜-inch (O.D.) copper pipe. The pipe was passed through the hole as shown, and soldered. Finally, a copper plug was soldered at the bottom of the ⅜-inch pipe. To place the sensor, the water supply to the boiler was shut off and the expansion tank drained. With the expansion tank drained and the boiler indicating zero pressure, the boiler was also drained to about one half of its capacity. The expansion tank's ½-inch copper feed-pipe was cut at about four inches above the boiler's outside metal enclosure. The ⅜-inch pipe was then inserted into the boiler through the bottom half of the expansion tank's pipe, and the top half of the expansion pipe was fitted into the open end of the elbow. After soldering the top half of the expansion tank's pipe to the elbow, and the bottom half to the open end of the "T", the drain valves were closed and the boiler's water supply valve reopened. The boiler was then started and the radiators bled to release air pockets.

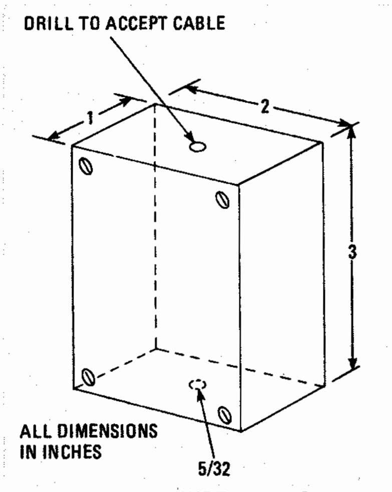

FIG. 4—THE AIR TEMPERATURE sensor is mounted in a box with these dimensions and mounted outdoors.

The water-temperature sensor was connected to the controller, using No. 22 gauge high-temperature insulated wire. Connections to the sensors were soldered and insulated. The sensor was inserted into the ⅜-inch pipe and the correct depth of insertion was determined by setting the aquastat's upper temperature limit at 150°F and moving the sensor up and down inside the pipe until the temperature readout agreed with the aquastat setting at the instant of boiler shut off.

For most installations, the aquastat circulator control should be set at 120°F; where you set the aquastat's high temperature limit depends on location and other factors. In our house, we found that a water tempera-

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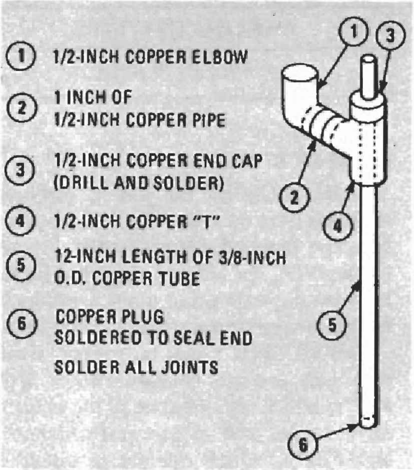

FIG. 5—USE THIS SETUP to place the water-temperature sensor. With it, temperature readings will be accurate, and normal boiler operation will be maintained.

ture of 150°F was sufficient for heating even in zero-degree weather. With that arrangement, the controller automatically controls the water temperature at outside temperatures of 20°F and higher. When the outside temperature drops below 20°F, the boiler maintains the water temperature at 150°F. That setup allowed for an 18-percent reduction in fuel use over the last year. In that time, there have been no problems or malfunctions with the system other than a defective toggle switch. **R-E**