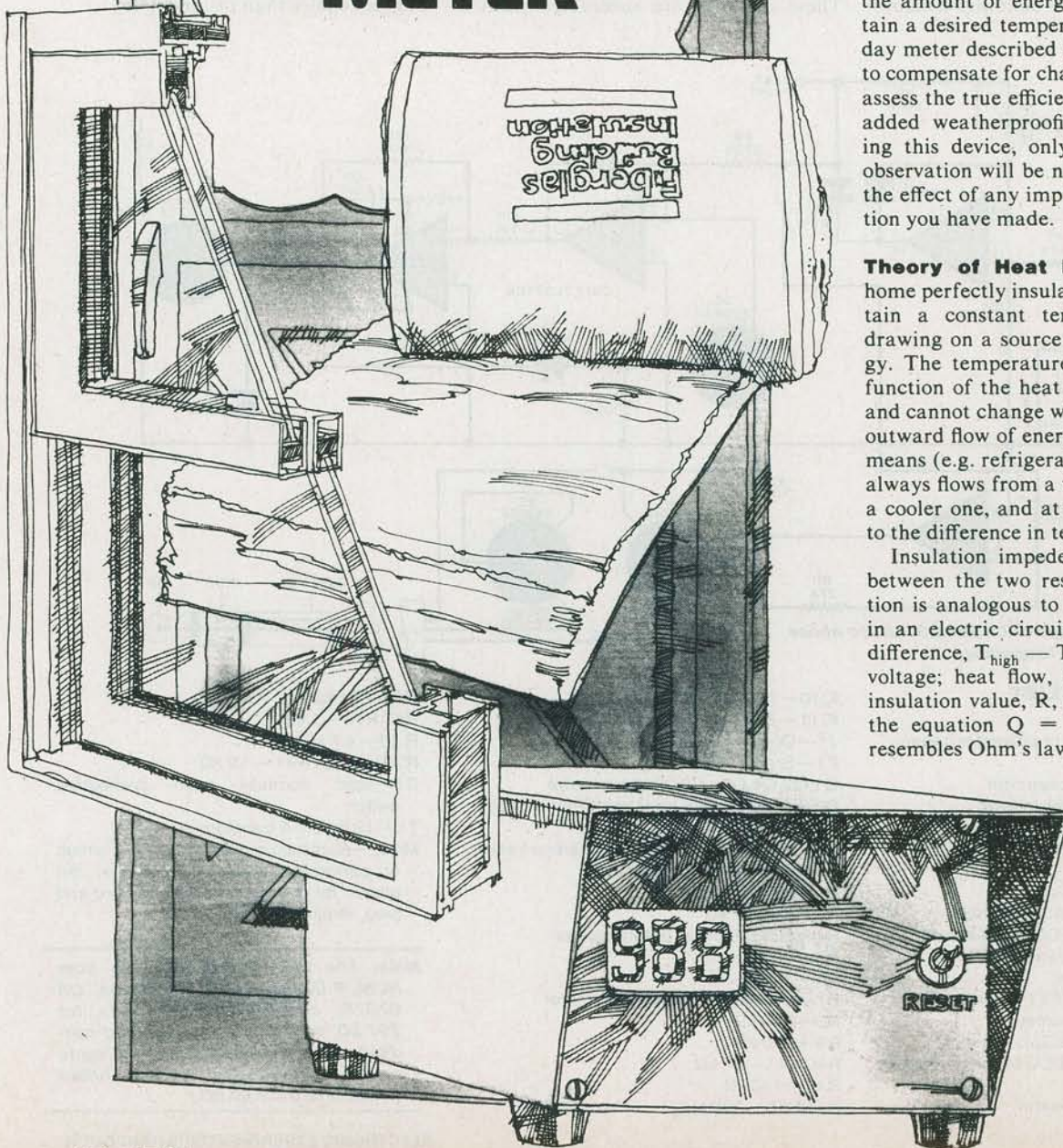


BY RUSH W. HOOD

CHECK YOUR HEAT LOSS WITH A DEGREE-DAY METER



Find out how well your weatherproofing and insulation work

Large amounts of money are being spent by homeowners today on insulation, storm windows and other means of reducing energy use and cost for heating homes. Gauging the effectiveness of these improvements, however, often requires months or even years of tabulations. Data garnered from supplier bills are often misleading owing to changing weather conditions that directly affect the amount of energy needed to maintain a desired temperature. The degree-day meter described here will allow you to compensate for changing weather and assess the true efficiency of your home's added weatherproofing. Moreover, using this device, only a day or two of observation will be needed to determine the effect of any improvement in insulation you have made.

Theory of Heat Flow. Were your home perfectly insulated, it would maintain a constant temperature without drawing on a source of additional energy. The temperature of an object is a function of the heat energy it contains, and cannot change without an inward or outward flow of energy. Unless artificial means (e.g. refrigeration) are used, heat always flows from a warmer reservoir to a cooler one, and at a rate proportional to the difference in temperature.

Insulation impedes the flow of heat between the two reservoirs. The situation is analogous to the flow of current in an electric circuit. The temperature difference, $T_{\text{high}} - T_{\text{low}}$, is equivalent to voltage; heat flow, Q , to current; and insulation value, R , to resistance. Thus, the equation $Q = (T_{\text{high}} - T_{\text{low}}) / R$ resembles Ohm's law.

Degree-Day Meter

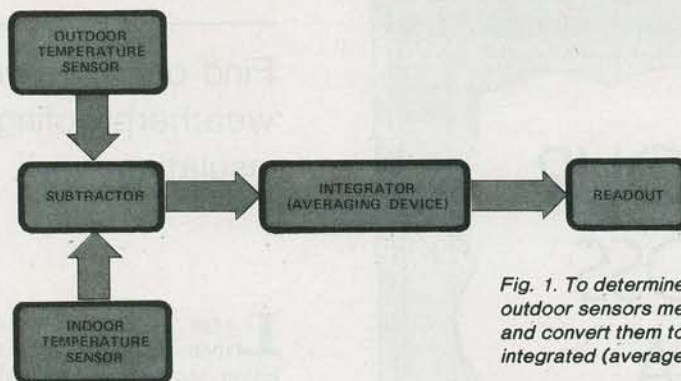


Fig. 1. To determine degree-days, the indoor and outdoor sensors measure temperatures and convert them to voltages, which are subtracted, integrated (averaged) and applied to readout.

If the temperatures inside and outside your home were constant for a long period of time, you could simply measure the temperature difference and the rate of energy use by reading the gas or electric meter and calculate the average insulation value of your building. Because

the temperature of the outside air changes too rapidly to allow such procedure, the degree-day was devised.

A degree-day is computed from temperature readings taken at frequent, regular intervals throughout the day. These readings are subtracted from a

reference temperature, usually 68°F, and the differences are averaged over one day. If a day is reported to have had 15 degree-days, for example, the energy needed to heat your home would have been the same as if outside had been 15 degrees cooler than inside all day.

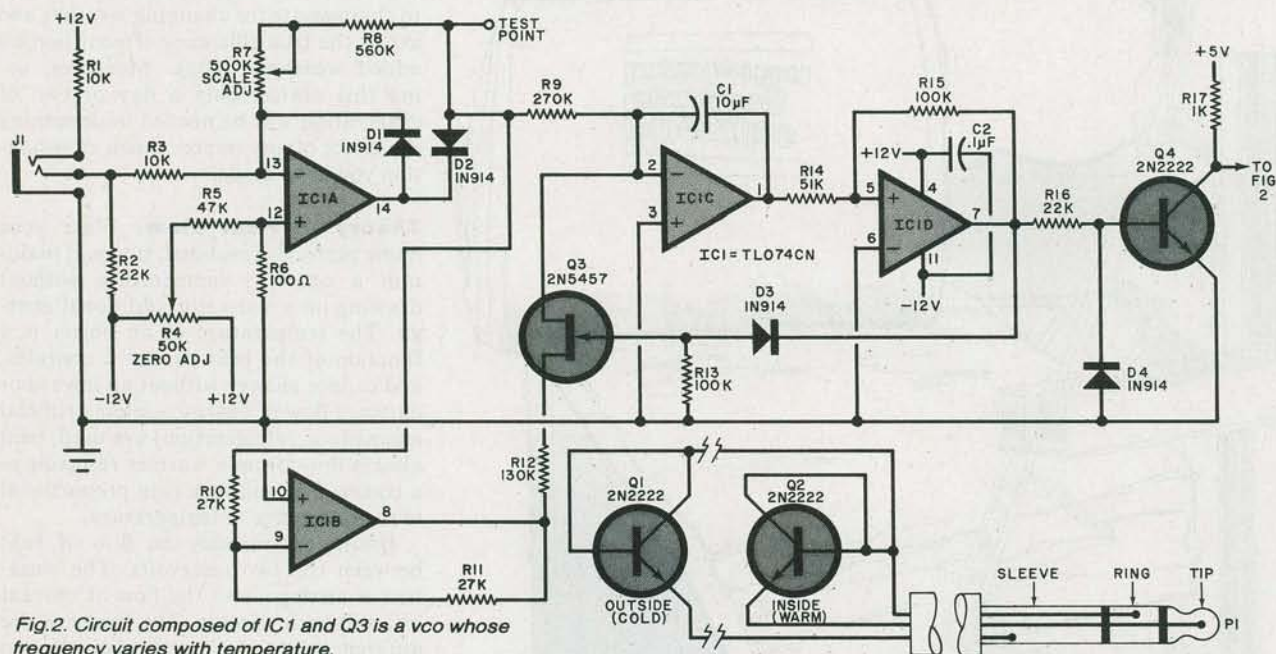


Fig. 2. Circuit composed of IC1 and Q3 is a vco whose frequency varies with temperature.

PARTS LIST

C1—10- μ F, 25-V Mylar or polyester capacitor
 C2—0.1- μ F ceramic capacitor
 C3—1000- μ F, 25-V electrolytic
 C4—100- μ F, 25-V electrolytic
 C5, C6—0.33- μ F, 25-V tantalum capacitor
 D1 through D4—1N914
 D5, D6—1N4001 1-A, 50-V rectifier
 DISP1, DISP2, DISP3—Common-anode display (MAN4610 or similar)
 F1—1-A, fast-blow fuse
 IC1—TL074CN quad BIFET op amp
 IC2—74LS93 binary counter
 IC3, IC4, IC5—74LS90 BCD counter
 IC6, IC7, IC8—74LS47 BCD-to-seven segment decoder
 IC9—7812 + 12-V regulator

IC10—7805 +5-V regulator
 IC11—7912 -12-V regulator
 J1—Open-circuit stereo phone jack
 P1—Stereo phone plug
 Q1, Q2, Q4, Q5—2N2222 transistor
 Q3—2N5457 FET transistor (Radio Shack 276-2028)
 The following are 1/4-W, 5% carbon resistors unless otherwise noted:
 R1, R3—10 k Ω
 R2, R16—22 k Ω
 R4—50 k Ω trimmer potentiometer
 R5—47 k Ω
 R6—100 Ω
 R7—500 k Ω trimmer potentiometer
 R8—560 k Ω
 R9—270 k Ω
 R10, R11—27 k Ω
 R12—130 k Ω
 R13, R15—100 k Ω

R14—51 k Ω
 R17, R18—1 k Ω
 R19—4.7 k Ω
 R20 through R41—1.2 k Ω
 S1—Spst normally open pushbutton switch
 T1—12.6-V, 1-A transformer
 Misc.—Aluminum enclosure, printed circuit or perforated board, IC sockets, red plastic for display window, line cord and plug, strain relief, etc.

Note: The following is available from HLW, P.O. Box 1026, Beaverton, OR 97075: complete kit of parts for \$97.50, plus \$3.50, postage and handling. Also available from the same source is an etched and drilled printed circuit board for \$9.00.

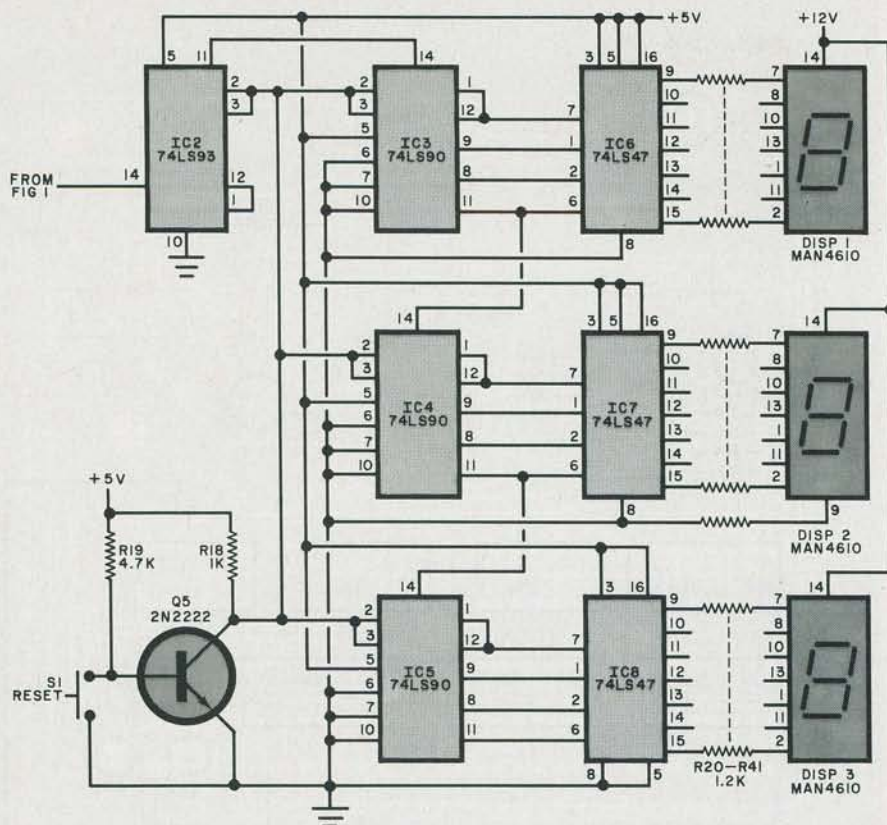


Fig. 3. Other than the divide-by-16 counter (IC2), digital circuit is conventional 3-digit counter, decoder and display.

Degree-days reported by your local weather service can be useful, but they may not be sufficiently accurate for critical measurements. Your inside temperature may not be the standard 68 degrees, and may vary through a 24-hour period. This degree-day meter project calculates the degree-days from the temperatures inside and outside your particular home.

How it Works. The meter continuously senses the indoor and outdoor temperatures, subtracts them and integrates the difference. Analog and digital circuit techniques are used to maintain the integration accuracy over long periods of time and to provide a numerical read-out. The block diagram in Fig. 1 summarizes, in an easy-to-follow method, the device's operation.

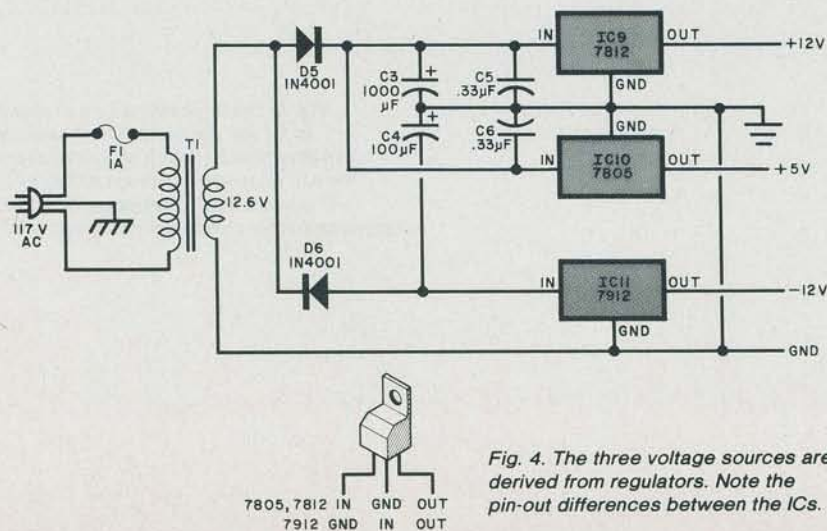


Fig. 4. The three voltage sources are derived from regulators. Note the pin-out differences between the ICs.

Circuit Design. The subtracting and integrating circuits are shown in Fig. 2. Indoor and outdoor temperatures are sensed by silicon transistors $Q1$ and $Q2$, which are connected as diodes. A constant current passing through a silicon diode junction develops a voltage drop that varies approximately linearly with temperature at a rate of $1.2 \text{ mV}/^\circ\text{F}$. The two sensors are connected in series opposition, so that the voltages across them are subtracted. The difference voltage taken from the junction of the two transistors is proportional to the difference between the two temperatures.

Integrated circuit $IC1A$ supplies enough gain to boost the difference signal so that it varies at a rate of $100 \text{ mV}/^\circ\text{F}$. It also acts as a half-wave rectifier, making the meter insensitive to situations in which the outside temperature exceeds the inside temperature, which could happen on sunny days. Sections, B, C, and D of $IC1$ and FET $Q3$ with its associated components form a voltage-controlled oscillator (VCO) whose average output frequency is 160 cycles per degree-day. The output of $IC1A$ is coupled to the inverting ($-$) input of integrator $IC1C$ (which averages the signal) via $R9$ and to inverter $IC1B$ through $R10$. The output of $IC1B$ is coupled through $R12$ and FET switch $Q3$ directly to the inverting input of $IC1C$. When $Q3$ is turned on, its drain-to-source channel resistance, coupled with $R12$, is one-half the value of $R9$ and the $IC1B$ signal to $IC1C$ is twice that from $R9$ and is of the opposite polarity. Thus, the integrator is fed with either a plus or minus $100\text{-mV}/^\circ\text{F}$ signal depending on the state of switch $Q3$. A negative voltage applied to the gate of $Q3$ turns the transistor off.

The integrator output is coupled to comparator $IC1D$, which has a hysteresis of 10 volts. The output of $IC1D$ at pin 7 is either $+10 \text{ V}$ or -10 V depending on the polarity of the input signal with respect to ground. This output is coupled to the gate of $Q3$ through diode $D3$. Assume that the integrator is developing a positive-going ramp at its output. When this reaches the trigger voltage of the comparator, the latter rapidly switches to its maximum positive output, which reverse biases $D3$. This turns $Q3$ on and routes the inverted signal to the integrator, which now develops a negative-going ramp until the comparator switches to its maximum negative output. This turns off $Q3$, and the cycle is repeated.

The output of comparator $IC1D$ is converted into a TTL-level signal by $Q4$. Diode $D4$ is used to limit the negative-going signal to the base of $Q4$, while $R16$ is the base-current limiting resistor.

Degree-Day Meter

The TTL signal is used to drive the conventional 3-digit counter, decoder and display shown in Fig. 3.

The 160 cycles per degree day output from $Q4$ is divided by 16 in $IC2$ to provide a square wave having one cycle per tenth of a degree day. This signal is coupled to pin 14 of LSB counter $IC3$. Zero set is provided by depressing RESET pushbutton $S1$ which places a ground on pins 2 and 3 (reset to zero) of the four counting ICs. Note that $DISP2$ has its decimal point (pin 9) permanently activated by a resistor to ground.

The power supply, shown in Fig. 4, provides +5 volts for the TTL logic, ± 12 volts for the analog circuit, and +12 volts for the seven-segment common-anode readouts. Be sure to observe the pin-out difference between the regulator ICs.

Construction. The meter can be constructed using the foil pattern shown in Fig. 5, or perforated board and Wire-Wrap techniques. If you design your own layout, arrange it so that the digital portion—especially $IC6$, $IC7$ and $IC8$ —are along one long edge. In this way, the three-digit display can be mounted on a separate small board that uses the display current-limiting resistors for electrical and mechanical interconnection.

Select an enclosure large enough to accommodate the circuit board and $T1$. A rectangular front-panel cutout (covered by a red filter) should be made for the three-digit display. RESET switch $S1$ is also mounted on the front panel. Jack $J1$, the fuseholder and an insulating grommet for the line cord can be mounted on the rear apron. The 5-volt regulator $IC10$ and +12-volt regulator $IC9$, which handle appreciable power, should be mounted to the rear apron to allow this wall to act as a heat sink. Capacitors $C5$ and $C6$ can be soldered directly to the respective pins on their regulators.

The sensor circuit (Fig. 2) is made by soldering the base and collector of each transistor together to form one lead. Select a length of slender two-conductor zipcord having sufficient length to reach the meter from each selected location. At one end, separate the leads for an inch or so. Remove about 1/4-inch of insulation and slip a short length of narrow heat-shrinkable tubing on each lead, solder one to the base-collector lead and the other to the emitter lead. Slide the heat-shrinkable tubing down over the soldered connection and shrink it. The outdoor sensor ($Q1$) can be encapsulated in epoxy if it is not mounted in a weatherproof location. After both sensors are fabricated, connect the far ends of both pairs to the stereo-type phone plug.

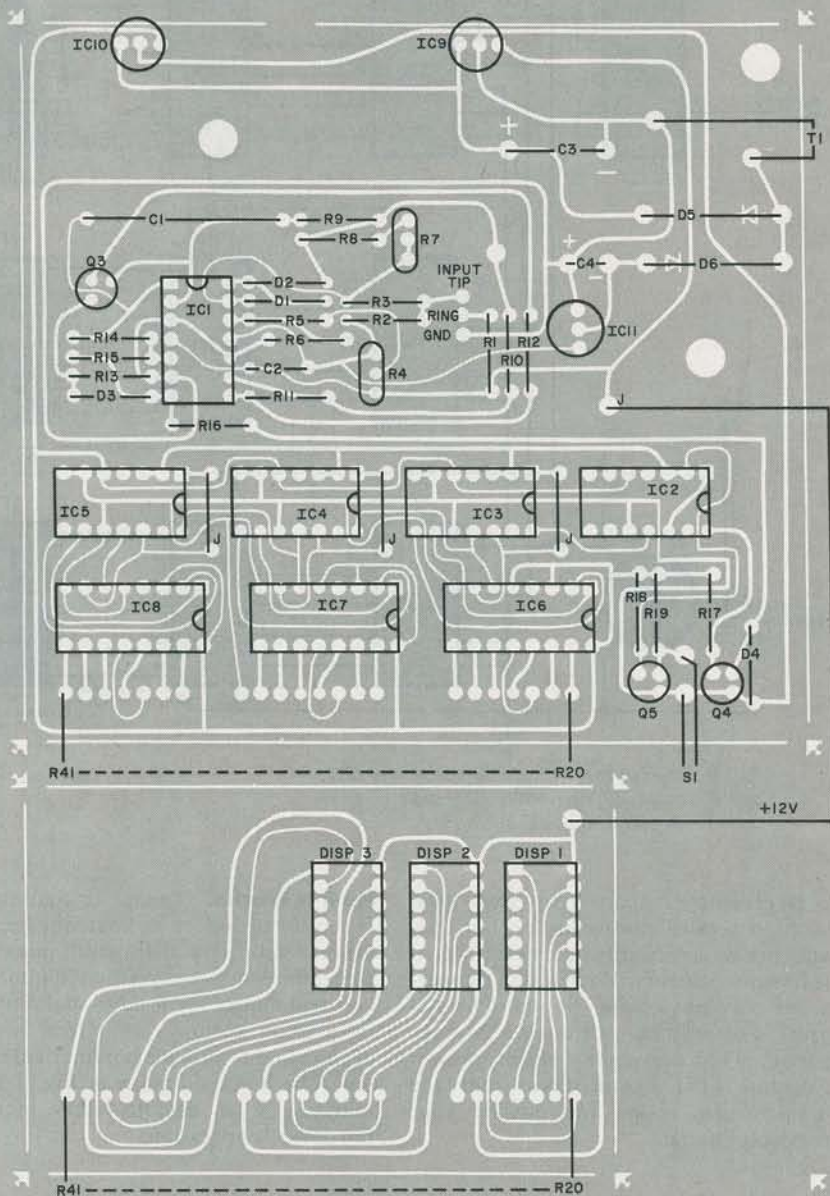
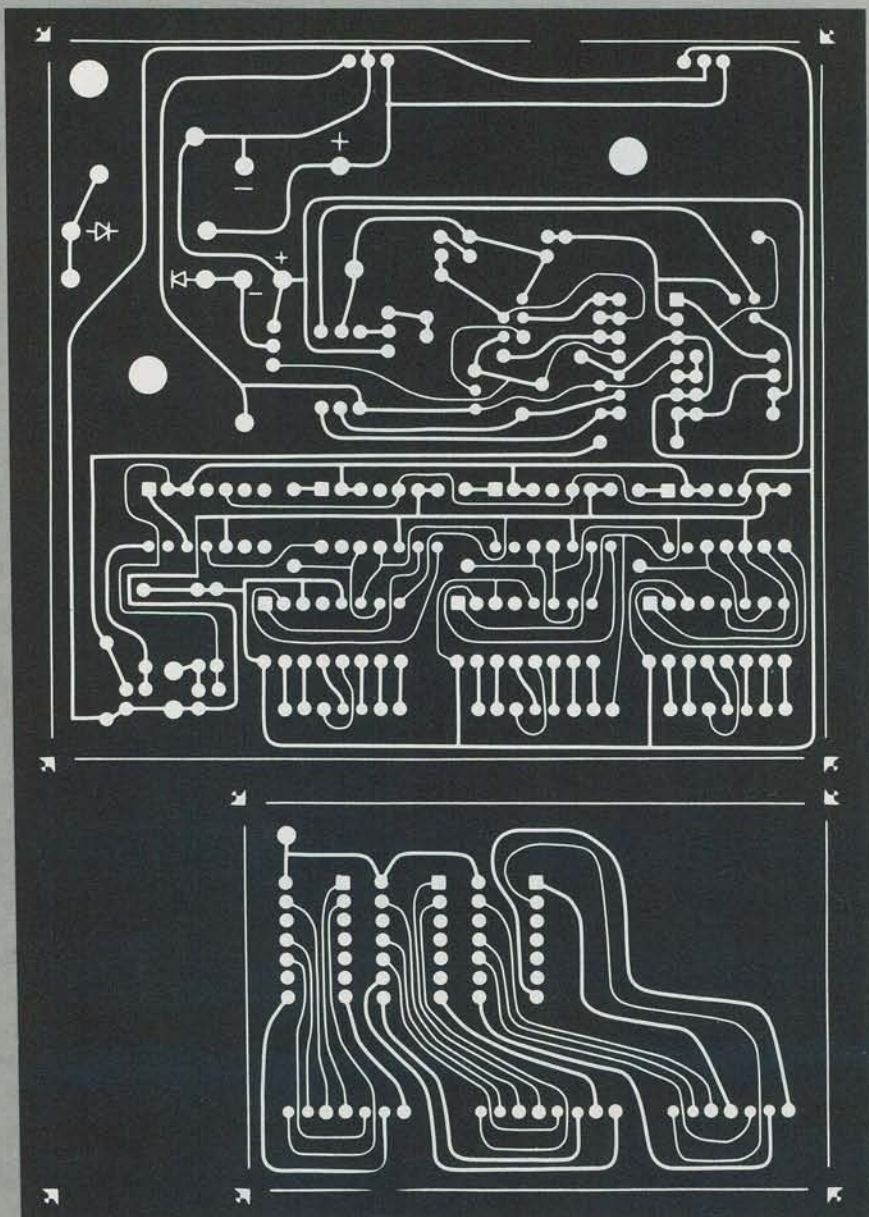


Fig. 5. The large foil pattern (opposite) is for the electronic circuit, while the smaller board below it is for the display. The two boards are interconnected by the current limiting resistors. Installation of these and other components is shown above.



Operation. To calibrate the degree-day meter, all you will need is a dc voltmeter and an ordinary thermometer. Then proceed as follows: Connect the voltmeter between the test point shown in Fig. 2 and ground. Set the voltmeter for its most sensitive dc voltage range, and place the sensors close to each other. Turn on the degree-day meter, allow it to stabilize for 10 to 15 minutes, and then adjust *R4* for exactly zero volts on the dc voltmeter. Then place the outdoor sensor in a cool place (outdoors or in the refrigerator), and adjust *R7* until the voltmeter indicates -0.1 volt for every degree of difference in the temperatures between the sensors. For example, if the inside temperature is 70°F and the outside sensor is at 40°F , adjust *R7* for $(70-40) \times -0.1$ or -3.0 volts at the test point. Install the sensors where desired and you're ready to measure degree-days. The outside sensor should be mounted in a shaded location away from the house and protected from the weather. The inside sensor should be mounted in a central location away from heat sources.

To start a measurement, depress RESET push button *S1*. The display should be "00.0" and should be observed to increment through the day if the outside sensor is cooler than the inside sensor. The greater the temperature difference between outside and inside, the faster the display will increment.

To measure actual energy efficiency of your home, you must measure the energy used over the same time interval that you measure degree-days. Your utility company can tell you how to read your gas or electric meter, or an elapsed-time meter may be connected to measure the total length of time the furnace is heating. Simply divide the energy (therms, BTUs, or kilowatt hours) by the degree-days to obtain a figure in energy per degree-day. This number should be nearly constant from day to day, and any improvement you make in your building's heat retention will lower this factor.

The degree-day meter can also be used to check your home's heat gain while air-conditioning is in use. Simply reverse locations of the inside and outside sensors. It is suggested that regular records be kept throughout the season to encourage conservation. It will be obvious from the efficiency determinations when real improvements are made in the weatherization of your home. (Note that frequent opening and closing of doors is tantamount to a reduction in insulation efficiency.)

Use of the degree-day meter can help a homeowner accurately estimate the payback period on money spent weather-proofing his building. \diamond