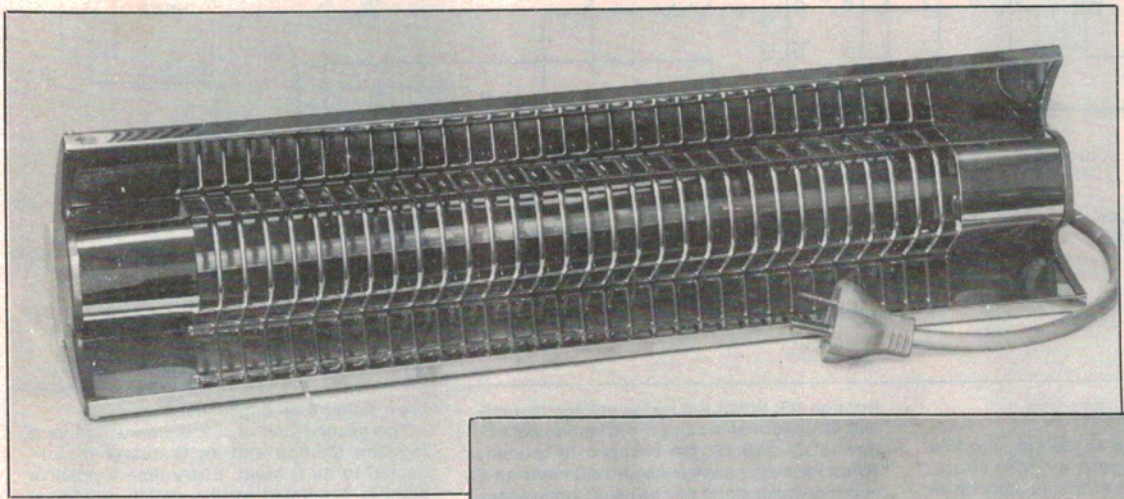
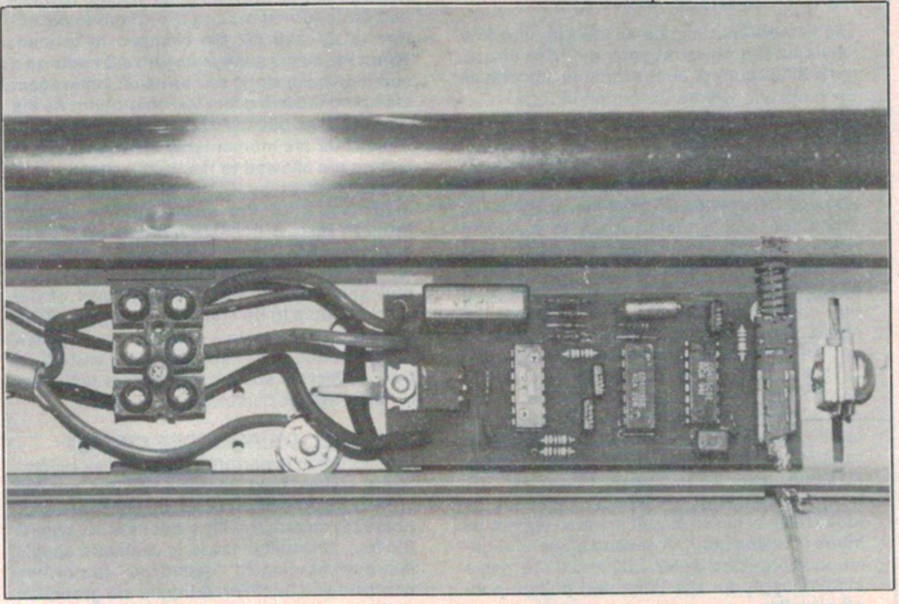
Bathroom strip heater time-out

Ian Thomas





Ever left your bathroom strip heater on all day! Sure boosts the electricity bill! This simple project automatically turns off the heater after allowing you enough time for morning ablutions. Just pull the switch cord when you walk in the bathroom of a morning and the project does the rest. No bathroom strip heater? — no worries, this shows you how to build one in a commonly available model.

IT IS PROBABLY not everyone's misfortune to return from six week's holiday in Bhutan or Tenerife to find the bathroom strip heater has been left on, but even a one day lapse of memory can cost about 50c. Even more important though, is the risk of fire due to an unattended heater. A nice answer to this problem seemed to be to incorporate some form of simple timer into the pull-on/pull-off switch used to control the heater.

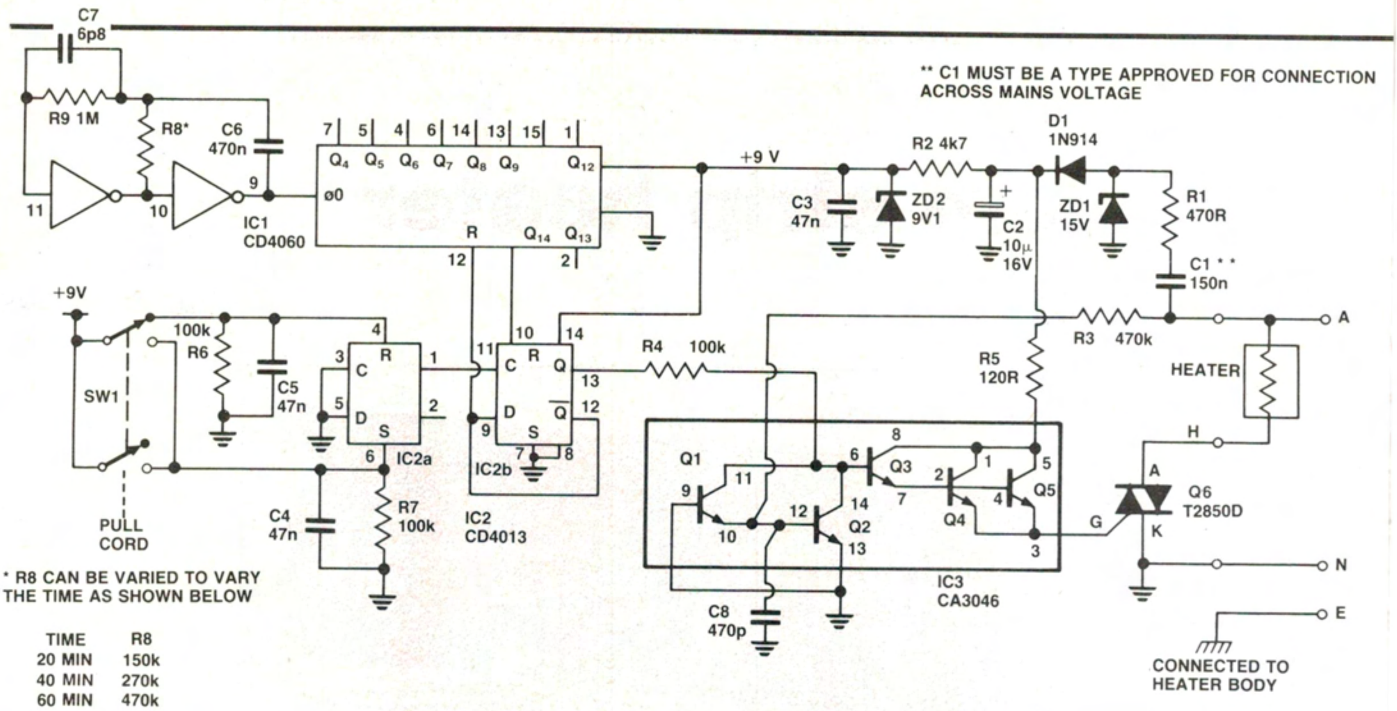
Giving the matter a little thought it seemed that the switch pull cord should work exactly as normal, except that whenever the heater was turned on a timer was started which would shut it off again after 30 to 40 minutes (and if anyone was in the bathroom for longer than that then the heater turning off would be a timely reminder). Also, if the timer needed to be restarted then simply turning the heater off then on again would do the trick.

Design

A quick survey of bathroom strip heaters available from electrical supply houses showed a considerable variety available with power ratings of between 750 and 2400 Watts. As I wished to be warmed rather than crisped, I chose a 'Rayflow' model 22/13 (750 Watts) and a model 22/15 (1100 Watts) to construct prototypes. Both are bare wall mounted single bar heaters with no power cord or switch and hence nothing to have to throw away when I started modifying.

Once the power rating of the heaters was chosen, a suitable triac was selected to handle the necessary current (3.1 A for the smaller heater and 4.6 A for the larger). The RCA T2850 series of triacs seemed to fill the bill exactly as they can handle up to 8 A RMS, given adequate heat sinking, and are reasonably cheap. Another great advantage is that the T2850 comes in a standard T0-220 outline with the mounting tab electrically isolated from the power. This makes things a lot safer as the heater electronics is switching lethal voltages; a fact which must *NEVER* be forgotten. The 'D' version of the triac range can block up to 400 V and is the one to use for 240 Vac applications.

From the data sheets, the gate current needed to turn the triac on reliably is about 60 mA under all conditions, or say 100 mA to be safe. This made the control power ▶



HOW IT WORKS — ETI-275

The heater-timer can be divided up into four sections: the power supply, the triac circuit, the pull-on:pull-off circuit and the timer itself. Each section will be described in turn.

THE POWER SUPPLY:

DC power for the electronics is provided from the mains input through capacitor C1, diodes ZD1 and D1, and the electrolytic capacitor C2. When the active mains input is swinging negative diode, D1 is reverse biased and ZD1 is turned on. Capacitor C1 is therefore charged up to the peak negative voltage of the mains (about −315 volts). When the mains start to swing positive ZD1 turns off and D1 turns on pumping the charge stored in C1 into C2. During this part of the cycle C1 and C2 act as a potential divider to reduce the mains down to a safe level. When C2 has enough charge zener diode ZD1 breaks down to dump any excess charge to ground. R1 is in series with C1 to protect the zener ZD1 from any transients on the mains input as C1 looks like a short circuit to any spikes or steps in mains input. A second stage of regulation is provided by R2, ZD3 and C3 to give a stable supply for the timer and pull-on:pull-off circuits.

THE TRIAC DRIVE CIRCUIT

As described in the design section the triac Q6 requires a short pulse of about 100 mA just after the mains voltage passes through zero volts. This function is performed by transistors Q1 and Q2 which are part of the IC transistor array IC3. Mains voltage is applied to the emitter of Q1 and the base of Q2 through R3. When the mains voltage is positive Q2 is turned on and the common collectors of Q1 and Q2 are clamped to ground. When the mains swings negative Q1 acts as a common base stage and turns on, once again clamping the two collectors to ground. As the input voltage passes through zero volts both Q1 and Q2 are momentarily off and their collectors are allowed to rise to the control voltage determined by IC2b. If pin 1 of IC2 is high then, just after the mains voltage passes through zero, a positive pulse is applied to the base of Q3 which acts as an emitter follower. Transistors Q4 and Q5 give more current gain and R5 sets the final level of the current pulse to be applied to the gate of the triac. If, however, pin 1 of IC2 is low it makes no difference what happens to Q1 and Q2 as their collectors always stay at zero volts and no triac trigger pulses are produced.

THE PULL-ON:PULL-OFF CIRCUIT

This function is performed by a break-before-make switch (see construction for details) where two sets of contacts are used for better reliability together with a dual CMOS type D flip flop. One half of the IC is used as a simple set-reset flip-flop to "debounce" the switch contacts and its D and C inputs are grounded and not used. The Set and Reset inputs (pins 4 and 6) both are grounded through 100k and 47nF and are connected to the switch changeover contacts. The switch common is connected to the positive rail so that when the switch is operated only one positive edge appears at the Q output pin 13. The capacitors C4 and C5 serve to suppress any transients that may be coupled over from the mains side of the system as the pull-downs are a rather high impedance.

The second half of IC2 is connected as a toggling flip-flop and its Q output is connected to its D input. Every time a positive edge is generated by the switch debounce flip-flop it changes the state of the control flip-flop and enables the triac or shuts it off. At the same time the Q output also enables or disables the timer.

THE TIMER CIRCUIT

The timing function is performed by a CMOS oscillator-timer IC1 which is a CD4060. This IC consists of an inhibitable oscillator circuit which only needs a few external resistors and capacitors, together with a 2^{14} divider circuit. This means the oscillator must produce 2^{13} or 8192 pulses before the last stage, Q14, goes positive. If we want about a 30 minute delay then the oscillator output period should be 30X60/8192 or about 0.22 seconds. This period is set by R8 and C6 which together have a time constant of about 0.13 second (the oscillator gives an output pulse roughly every two time constants). R9 serves to limit the input current to the CMOS input pin 11 and C7 acts as a speed-up capacitor. When the reset pin 12 is taken high the oscillator circuit is inhibited and all fourteen divider stages are set low. Therefore when the control flip-flop Q output is low and the heater is off then the Q output is high and inhibits and resets the timer. As soon as the heater is turned on the timer is released and after about 35 minutes (measured) the timer Q14 goes positive and resets the control flip-flop. As soon as the control flip-flop is reset it resets the timer and the whole circuit returns to its idle state.

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needed to operate the triac quite appreciable by itself, ignoring any power needed to operate the timer circuitry. This brought me head on to the first difficulty. The heaters chosen (and in fact almost all wall mounted heaters) have quite narrow bodies which mount flush to the wall and there simply isn't enough room to mount any readily available power transformer capable of handling the gate power requirements. Problem!

However, all was not lost as triacs need only be pulsed on once every half cycle of the 50 Hz mains, or evey 10 milliseconds. Also, the pulses can be very short (10 µs is heaps), provided the pulse is applied at exactly the right time. This means our current needs are reduced by a factor of $10^{-6}/10^{-3}$, or 1000 times — much more reasonable! There are ICs available to do this pulse generation and timing (such as the RCA CA3058 or CA3079) but they are powered from the 240 V mains through a resistor which has to drop several watts itself. This amount of power in one component makes for hot, and therefore unreliable, electronics. (As an aside, the reliability of an electronic device is halved for about every 10° C temperature rise, so if our timer operates at 70° C rather than

25° C then it will probably fail 25 times sooner!)

Since the average total current drain of the timer and control circuitry can be reduced to below about 10 mA, then capacitive-divider type power supplies seem to be ideal. These use two capacitors as a potential divider to give a (comparatively) low impedance low voltage ac supply. When combined with a couple of diodes (see 'How It Works') you get a low voltage dc output. For low current applications this is a cheap, compact and safe dc source provided the smaller (higher impedance) capacitor is connected to the *active* mains input and is a type approved for continuous connection across the 240 Vac supply (see 'Parts List'). This combination of triac pulse triggering and the use of low power CMOS timing circuits solved the transformer problem but left me with the problem of generating the trigger pulses for the triac without wasting power.

As we have a triac whose gate must be taken positive with regard to terminal 2 to turn it on, then what is needed is a series of positive-going pulses about 10 µs long just after the mains voltage has gone through zero volts. If all the effects of triac holding current are allowed for then the pulse should be present until about 30 µs after the mains passes zero volts to ensure the triac stays on.

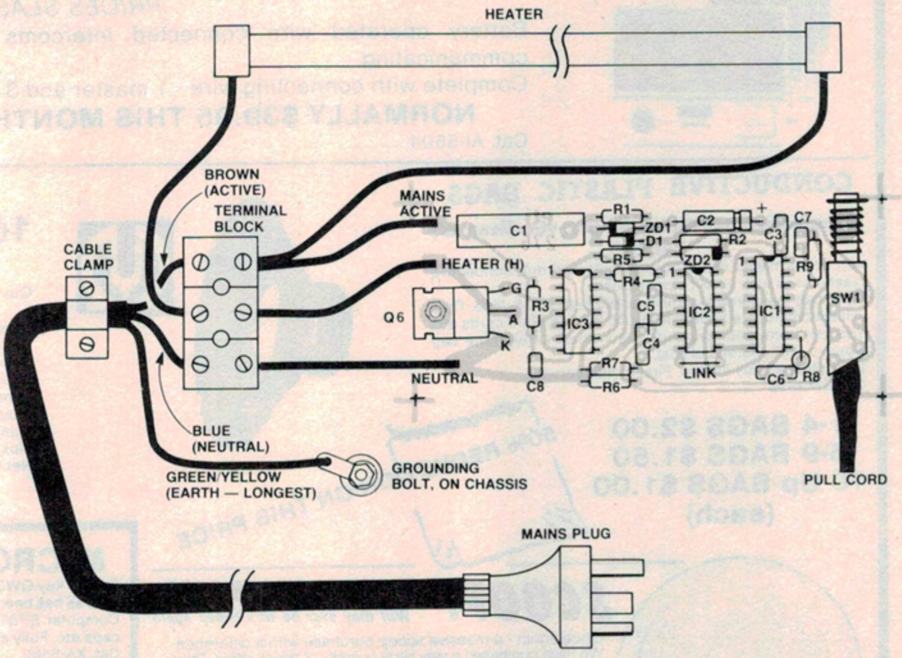
One very cheap integrated transistor array such as a CA3046 can be connected to achieve exactly the required functions, together with three resistors and one capacitor (once again, see 'How It Works'). The circuit also gives a high impedance control input to gate the trigger pulses. The toggling pull-on/pull-off operation with timer reset and control area are also described in detail in 'How It Works' and require only two cheap CMOS ICs to do everything needed.

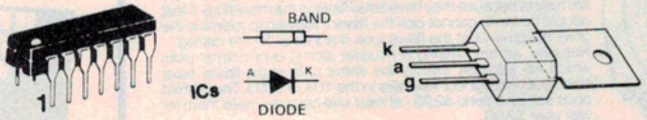
Construction

As the heater timer is controlling 240 V and the intended environment is often damp and steamy it is most strongly recommended that the timer be constructed on the printed circuit board designed for the project and available from several suppliers, or from a pc board made from the artwork reproduced elsewhere here.

A rough and ready approach with mains power will give spectacular and perhaps permanent results (and we need all the readers we can get!), so unless you really know what you're doing it's safer to stick exactly to the instructions. I built two prototypes using the Rayflow heaters mentioned in the design section as they had metal bodies where I mounted the electronics. This gives a nice, safe *earthed* box which is also used as a heatsink for the triac (which must drop between three and five Watts when the heater is on).

Before assembling the pc board, the first thing to do is use the blank board as a template to mark and drill the heater body. Carefully locate the board so that the end where the triac is mounted covers 8-10 mm of the centre reinforcing of the heater body (which acts as the triac heatsink). Make sure that the long axis of the blank board is exactly centred on the heater body axis and





COMPONENT PINOUTS

mark where the triac mounting hole is on the heater body.

Remove the blank board and centre-punch and drill a 9/64" (3.6 mm) hole through both the centre reinforcing and the front of the heater body. Be careful not to damage the reflector.

Next, enlarge the hole in the front of the heater body to ¼" (6.4 mm) using a larger drill. Insert a 3.5 mm (or if you still have some, a 4BA) by 12 mm machine screw through the larger hole in the heater body front so the free end of the screw protrudes through the centre reinforcing and tightens with a suitable nut. Make sure there are no burrs in the holes as the screw acts to carry away the excess heat from the triac and good thermal contact is essential.

The free end of the screw is the mounting post for the triac end of the pc board. Reinsert the blank pc board over its new mounting post and mark off the mounting hole for the other end of the board and the point where the switch cord will go through the bottom of heater body. Once again, make sure the long axis of the board is exactly parallel to the long axis of the heater body. Drill out the second mounting point to 9/64" (3.6 mm) also.

Cut a hole for the pull cord about 4 mm wide by 6 mm long to ensure the cord doesn't foul when the unit is finally assembled. This just about completes the tedious mechanical work and now the interesting electronics part can begin.

Start assembling the pc board with all the smaller components first. Make sure that the ICs are oriented correctly (to reverse is to destroy!) and most important of all, see that diodes D1 and D2 are correctly inserted. When assembling the triac be sure to

PARTS LIST — ETI-275

Resistors	all ¼W, 5%
R1	470R
R2	4k7
R3	470k
R5	120R
R4, 6, 7	100k
R8	(See circuit diagram)
R9	1M
Capacitors	
C1	150n/250 Vac (e.g: AEE type PME271 M or similar).
C2	10µ/16 V axial electro.
C3, 4, 5	47n ceramic or ploy.
C6	470n/63 V, 10% Wima, type PR-21 or similar.
C7	6p8
C8	470p
Semiconductors	
IC1	4060B
IC2	4013B
IC3	CA3046
Q6	T2850D
D1	1N914
ZD1	15 V/1 W zener
ZD2	9V1/400 mW zener
Miscellaneous	
SW1	4-pole changeover pushbutton switch (modified), Jeanrenaud type TJ (from STC-Cannon).
Heater	"Rayflow" model 22/13 (750 W) or model 22/15 (1100 W), either may be used (or similar type).

ETI-275 pc board; 3-way terminal block, mains-rated hookup wire (24 x 0.2 mm); nuts, bolts, etc.

Price estimate: $25-$28 (less heater)

bend the leads so the tab mounting hole falls exactly over the hole in the pc board. Do not at this stage attempt to assemble the switch as it has to be modified first.

Insert 240 volt insulated wires into the holes provided and marked (H is heater control out) observing the international colour coding for active (brown) and neutral (blue) as someone else may work on the heater later on and there is no future in building in nasty surprises (especially if the someone is an ETI staff member!)

The pull-on/pull-off switch presented special problems as I couldn't find anything suitable ready-made and had to specially modify a pc-mounting slide switch to do the job. The switch was a Jeanrenaud type TJ, four changeover, break-before-make (essential for contact debouncing), momentary contact switch with no mounting bracket or front pressbutton.

The first thing to do is to cut off the end of the slide that holds the front button. The cut should be made just before the circlip that holds the slide spring but leaves enough material to hold the spring securely. (See the accompanying photo.)

The next step is to *very carefully* cut away two of the four changeover contacts as shown here. The cuts should be made very slowly and carefully with a fine toothed hacksaw blade *AND ONLY THROUGH THE OUTER SWITCH BODY*. Do not cut the inner switch slide or the whole switch will be ruined!

Make four cuts around the four sides of the switch body then gently slide off the end of the outer body and discard it. Two tiny metal balls will drop out as the body is removed — these are the actual sliding contacts and can be thrown away also.

Next, drill a 3/32" (2.4 mm) diameter hole through the end of the switch slide that was exposed when the outer body was removed. The indentation that held the ball contact makes an ideal centre punch mark to start the drill.

The last step is to sew the pull cord through the hole you have just drilled. Don't even begin to think about the possibility of toying with the idea of using wire as the pull cord as a nylon cord gives excellent double insulation for the switch and once again there is mains voltage near the other end of the cord to your hand.

After the cord is attached then the switch is ready for assembly.

Before soldering the switch onto the pc board, screw a ⅜" 4 BA spacer onto the board near where the switch mounts. The screw used should be ¼" long and should have a lockwasher under its head. Then solder the switch in position so the cord is at the end away from the screw and the whole assembly is complete.

Once the switch has been modified and assembled with its mounting post then the heater is ready for final assembly, wiring and test. Thread the pull cord through its hole and mount the assembled pc board on its triac mounting screw and switch spacer. Tighten a nut down firmly over the triac mounting tab as this nut forms part of the triac heatsink. Make sure the pull cord operates freely and doesn't foul the sides of its hole (a little trimming with a small rat-tail file may be needed here). When all the mechanics are finished wiring can begin.

Cut a sufficient length of three-core flex to reach from the power point you intend to use to the terminal block in the heater when it is mounted where you want it. Attach a three-pin plug to one end. Strip back the other end outer insulation for about 100 mm and bare about 40 mm of the earth lead. Pass the flex through one of the knock-outs provided and clamp the end of the outer insulation in the cable clamp provided.

Use all the bared earth conductor to make a really solid connection to the earth terminal on the heater body. This connection is the most important in the whole project so take care! Then cut the active and neutral leads to length and terminate them in the mounting block that comes with the heater.

At this stage it is wise to make sure that the active and neutral leads have not been reversed somewhere. With nothing connected to the terminal block except the mains flex you have just connected (disconnect the two heater element leads) insert the three pin plug into the power outlet you intend to finally use and turn it on.

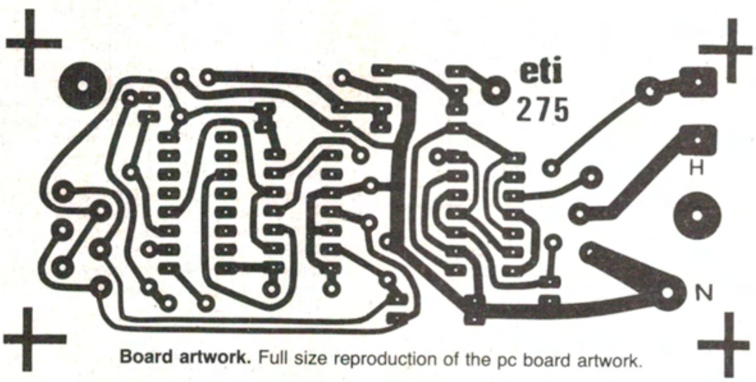
Using an ac voltmeter set to 300 V or 1000 V full-scale, measure the voltage between the active terminal and the earth post. It should be 240 V give or take a bit. The voltage between the neutral and earth should only be a few volts. If the neutral has 240 V then the active and neutral have been reversed somewhere. This problem must be sorted out before the controller is wired in. It may be you wired up the three-pin plug incorrectly or that the electrician wired up the three-pin plug incorrectly or that the electrician wired up the power outlet in error (not unheard of) but the neutral for the electronics *must* go to the supply neutral.

Once you are satisfied as to which is active and which is neutral, wire up the terminal block as shown in the photograph. Mains active is connected to electronics active and one side of the heater element (it doesn't matter which side). The control output from the electronics is connected to the other side of the element using the spare terminal block and you are ready for test.

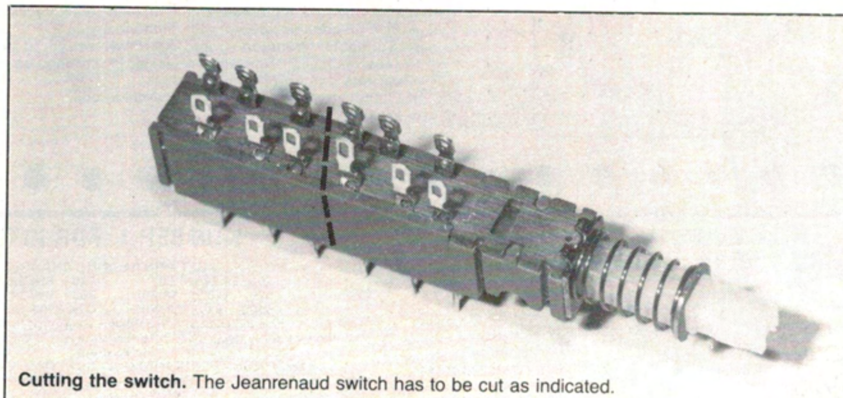
A few quick tests before the heater is wall mounted will make sure that all is well. Plug the heater in and turn it on at the power outlet. *Don't* leave the heater element face down on your bench unless you like fires. Try the pull-on/pull-off switch cord and make sure the heater turns on and off (when the heater element is powered you can usually hear a faint buzz as it warms).

A check on the timer is to turn on the heater element with the pull cord and check the voltage on pin 7 of IC1. It should change between ground and +9 V every few seconds as pin 7 is Q4 of the timer divider chain. Higher order divider outputs can also be checked by referring to the circuit diagram. Each higher order output should change state at half the frequency of the one before. When the pull cord turns the heater off, all the Q outputs should be at 0 volts.

After that, mount your new power saving heater on the wall and make sure that it does shut off after the set time; then watch your power savings grow! ●



Board artwork. Full size reproduction of the pc board artwork.



Cutting the switch. The Jeanrenaud switch has to be cut as indicated.