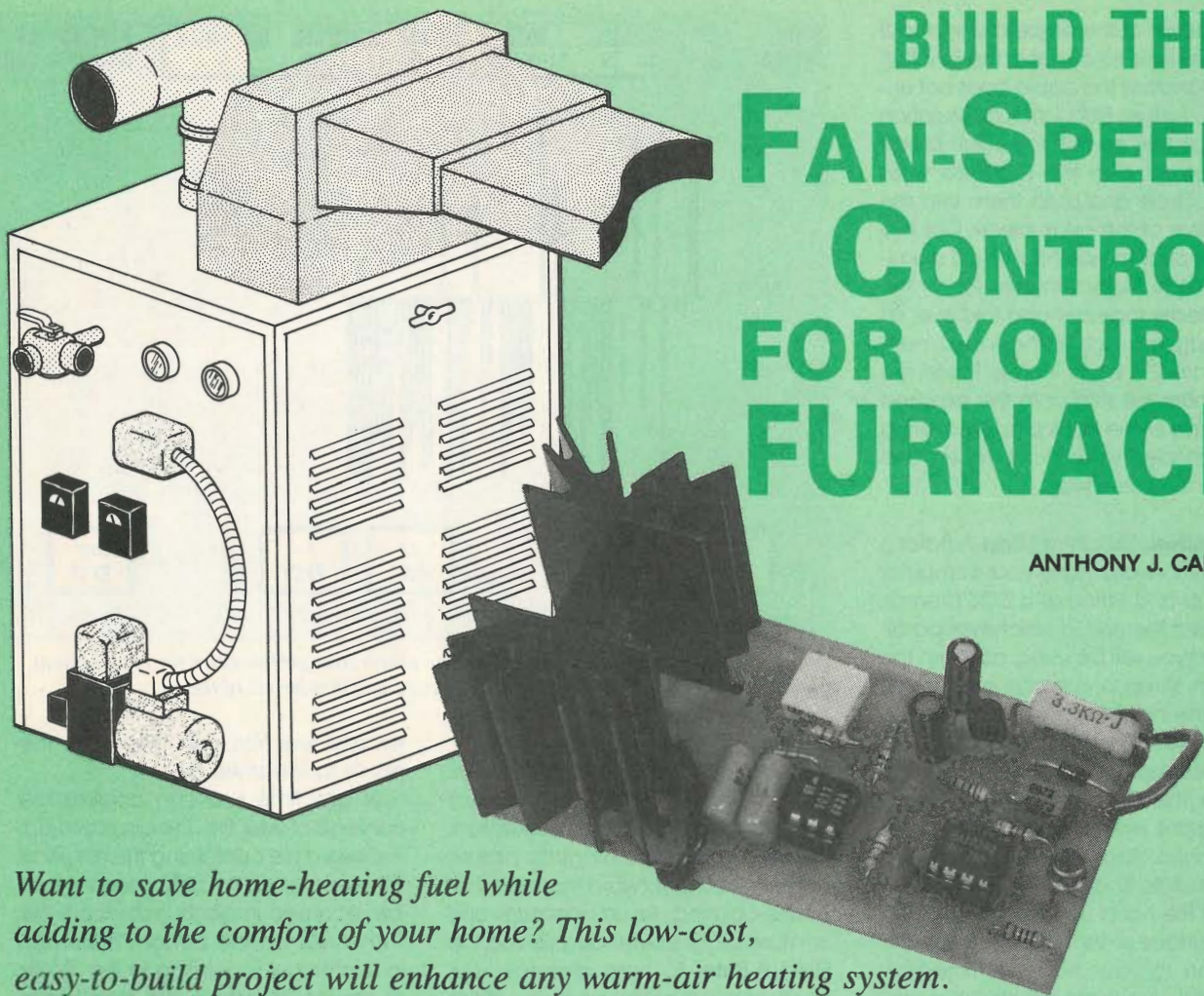


# BUILD THIS FAN-SPEED CONTROL FOR YOUR FURNACE

ANTHONY J. CARISTI



*Want to save home-heating fuel while adding to the comfort of your home? This low-cost, easy-to-build project will enhance any warm-air heating system.*

Unless the warm-air furnace which heats your home is one of the very latest, most highly sophisticated units available today, it suffers from one drawback: its constant blower speed. Most 80% AFUE (annual fuel utilization efficiency) warm-air furnaces manufactured today use a fixed-speed blower, which is set to work best during the coldest, most severe weather conditions. Most of the time such conditions do not exist, so the blower speed is too great for maximum comfort. It cools the furnace's main warm-air distribution duct (the plenum) too fast, shuts down, and deprives you of a very important feature of a properly designed warm air heating system—Continuous Air Circulation, or CAC.

An ideal situation is where blower motor speed is set by the temperature of the furnace plenum. At relatively low temperatures, the blower runs slowly; it increases in speed as the plenum gets warmer. Not only does

that provide increased comfort, but the noise level of the blower system is greatly reduced most of the time, and less electrical power is used to drive the motor.

Chances are your warm-air heating system does not have a two-speed blower control. However, you can easily modify your system by installing our low-cost Blower Speed Control. It will enhance your comfort during the heating season, and might allow you to set your thermostat a couple of degrees lower, letting you save precious and expensive fuel.

**Design Overview.** The Automatic Blower Speed Control sets the blower motor RPM to either of two speeds, low or high, as required by the heating load on the heating system. Low speed will operate most of the time when the furnace plenum is at a relatively cool 110° Fahrenheit or less. That will keep air circulating throughout the home and help eliminate that

cold feeling that sometimes occurs when the blower shuts down.

When heating demand increases from either colder outside temperatures or by setting the thermostat higher, the increase in plenum temperature is sensed by the Speed Control, which automatically switches the blower motor to high speed. Air flow is boosted to the maximum possible volume, transferring as much heat as it can from the furnace heat exchanger to the living area of the home.

Once the thermostat is satisfied and the plenum cools down below about 110°F the blower automatically returns to low speed. You'll benefit from continuous air circulation and enhanced comfort, all while saving fuel.

**About the Circuit.** The heart of the blower speed control is the phase-controlled Triac circuit illustrated in Fig. 1. During each AC half-cycle, capacitor  $C_A$  is charged through adjustable

resistor  $R_A$ . The voltage on  $C_A$  is applied to a diac, which acts like a bi-directional Zener diode. The diac will trigger and conduct current when its switching voltage is reached. That

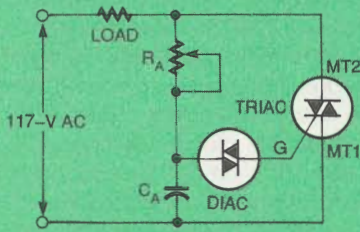


Fig. 1. A typical phase-control Triac circuit. Adjusting the resistance of  $R_A$  changes the time it takes to charge up  $C_A$ , and fire the diac.

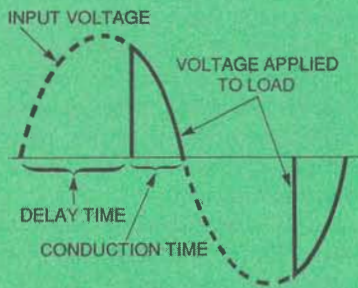


Fig. 2. If the Triac's trigger pulse is delayed, this waveform is the result. Delaying the trigger applies less energy to the load.

current is in turn applied to the gate terminal of the Triac, which will switch on and let current flow through the load. The Triac will continue to conduct until the end of the AC half-cycle, when it switches off and waits for the next trigger input.

The amount of resistance  $R_A$  is set to controls how fast  $C_A$  charges up to the trigger voltage of the diac. The greater the resistance, the longer it will take. That delay controls how much current the load sees. A longer delay in triggering the Triac allows less time in the half-cycle for the Triac to conduct, so less electrical energy is applied to the load. Figure 2 is an example of that type of waveform. When the load being driven is a permanent split-capacitor (PSC) induction motor, the reduced amount of available electrical energy slows the motor down. By adjusting the value of  $R_A$ , we can control the motor's speed.

Let's look at Fig. 3, the schematic diagram of the blower-control circuit. The basic variable-motor-speed circuit described above is composed of Triac TR1 along with phase-control network D4, R8, R9, and C5. Those components form the low-speed circuit, with R8 adjusted for the desired low-speed operation of the blower

motor. That network is always in place, so the motor cannot rotate at a speed that is less than the desired minimum.

A second RC network composed of R7, C4, and diac D3, forms a duplicate phase-control network that is connected, through optoisolator IC3, in parallel with the first network. In effect, either phase-control network can be used to control motor speed. In the second phase-control network, the value of R7 is low enough to provide a minimal delay, essentially delivering full line power to the motor. That results in high-speed blower operation. Note that when the high speed phase-control network controls the Triac, the low-speed circuit has no effect on motor performance since the Triac will have been triggered earlier in the half-cycle.

Optoisolator IC3 is used to switch in the high-speed phase-control network. That permits the low-voltage part of the circuit to be electrically isolated from the motor wiring.

When plenum temperature is below 110°F IC3 is off, allowing the low-speed phase-control network to run the motor. Above 110°F IC3 is activated. That turns the second phase-control network on, which runs the motor at high speed.

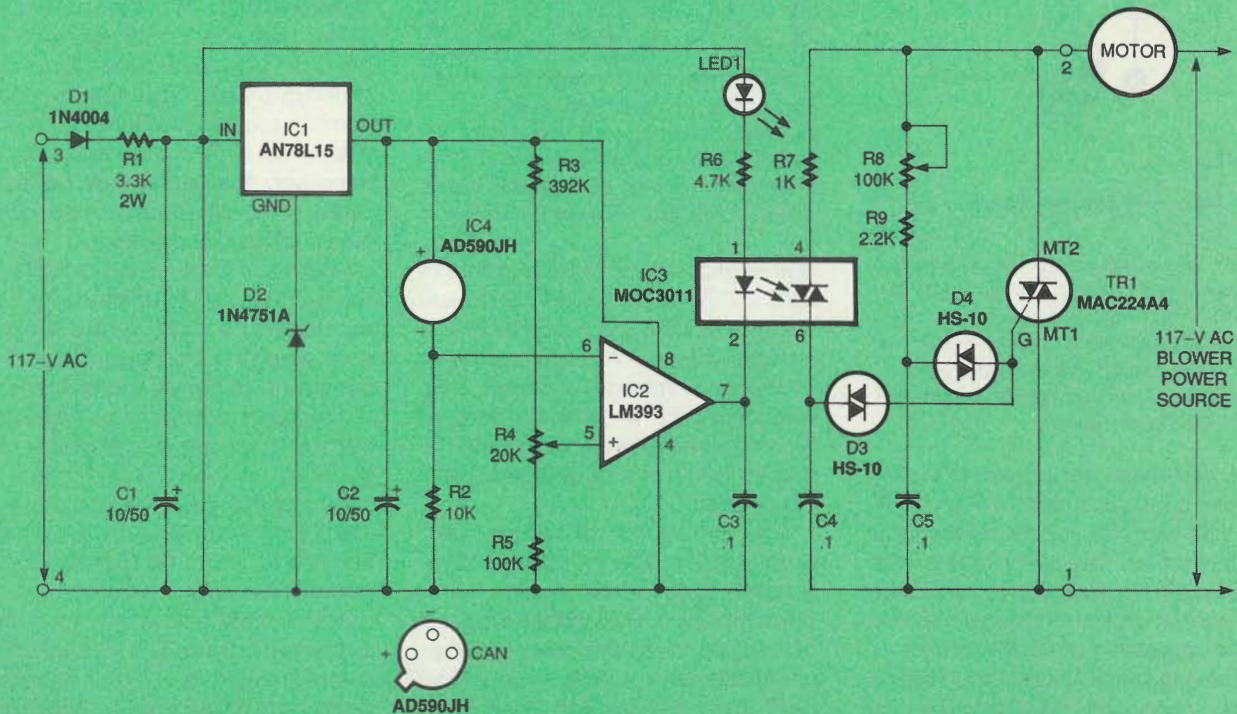


Fig. 3. Here is the schematic of the Automatic Blower Speed Control. An optoisolator protects IC2 from the destructive voltages of the blower motor. It's a good idea to use two different-colored wires for the temperature sensor's "+" and "-" terminals. The sensor terminal marked "CAN" is not used.

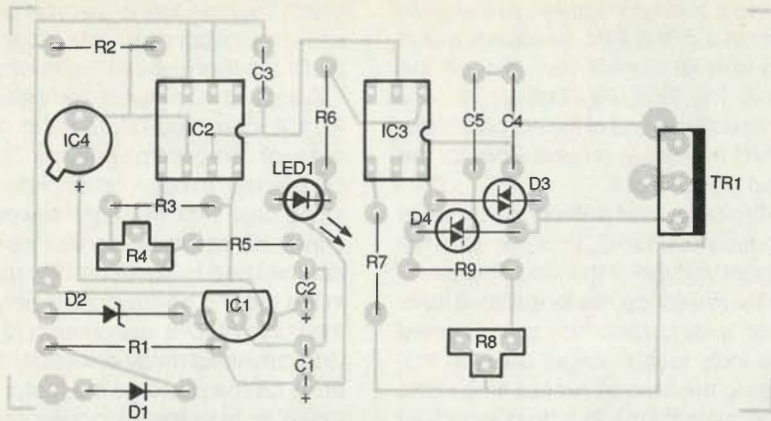
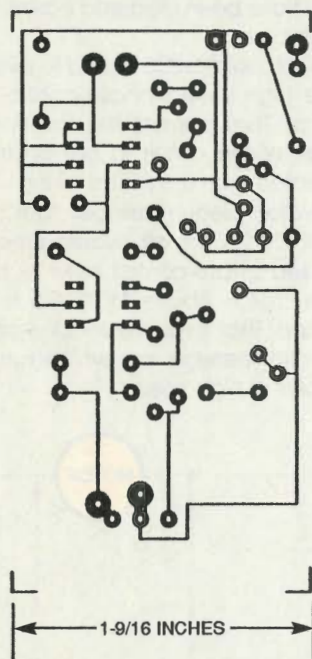


Fig. 4. Component layout of the Blower Speed Control is simple and straightforward. Take care that all polarized parts, such as ICs, capacitors, and diodes are inserted with the proper orientation or they could be damaged.



Here's the foil pattern for the Automatic Blower Speed Control. The design of the Controller is simple enough to use a single-sided printed circuit board. If you don't want to drill and etch your own board, the Controller can be hand wired on a piece of perfboard.

A half-wave Zener-regulated DC power supply formed by R1, D1, D2, and C1 feeds 30-volts DC to the input of IC1, a fixed 15-volt linear regulator. The regulator supplies temperature sensor IC4 and a voltage divider network composed of R3, R4, and R5.

The output of IC4 is designed to provide a current of 1 microampere-per-degree Kelvin in response to the ambient temperature surrounding it. Its output current is passed through R2 to produce a known temperature/volt-

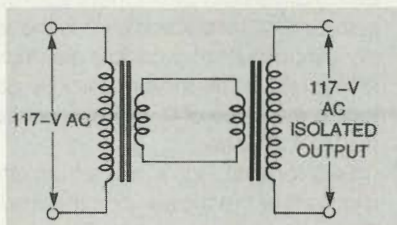


Fig. 5. If you have to troubleshoot the high-voltage section of the Blower Speed Control, it's a good idea to use an isolation transformer for additional safety. You can wire two transformers back-to-back for reasonable isolation.

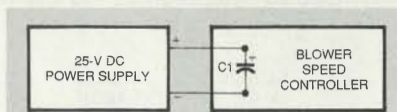


Fig. 6. When you're ready to do preliminary testing of the low-voltage side of the Blower Speed Control, temporarily hook up a 25-volt DC power supply in this way to power the circuit.

age relationship. At a temperature of 25°C (77°F), the equivalent Kelvin temperature is  $25 + 273.2$ , or 298.2° K. A sensor current of 298.2 microamperes produces a voltage of about 2.98-volts across R2. In order to measure the temperature of the warm air, IC4 is placed inside, or in close contact with, the plenum.

Only one section of voltage comparator IC2 is used. A voltage comparator, as its name implies, compares the level of two input voltages. It acts like an op-amp that has no external feedback, resulting in very high gain. The output voltage of the comparator is either 15-volts or 0, depending on which of the two voltages present at the input terminals is higher than the other.

The negative input terminal of the comparator is the voltage across R2, accurately representing the plenum temperature. The positive input of the comparator is connected to a voltage level set by potentiometer R4. That level is set to about 3.16 volts during calibration of the circuit. That is the voltage that appears across R2 when the furnace plenum is at about 110°F.

When the plenum temperature is below 110°F, the comparator's output terminal is high. That leaves the LED in IC3 dark. As a result, the high-speed phase-control network is disconnected, and the motor runs at low speed when the plenum switch calls for blower operation.

When plenum temperature exceeds 110°F, the output of IC2 goes low, and its open-collector NPN output transistor sinks current through the internal LED of IC3. That activates the high-speed phase-control network, causing the blower motor to run at maximum speed.

An LED indicator is connected in series with the input circuit of IC3 to provide visual indication of high speed motor operation. That feature is useful when testing the Blower Speed Control.

**Construction.** The blower speed-control circuit is contained on a single-sided printed-circuit board. A drilled and etched board is available from the source given in the Parts List if you do not wish to etch your own. Alternatively, the circuit may be hand wired on a perfboard using good construction techniques.

Figure 4 illustrates the parts placement of the board. Note that the Triac will require a heatsink since it will dissipate several watts, depending upon the size of the blower motor. The Parts List suggests one possible selection, but you may use any heatsink that provides sufficient cooling. Bear in mind that the metal tab of the Triac is electrically hot, so both it and the heatsink must not be shorted to any part of the circuit or furnace.

Before starting assembly, clean the copper side of the PC board with steel wool to remove any dirt or oxidation. Wash it with detergent and water, and dry thoroughly. Refer to Fig. 4 for proper location of all the parts. All polarized components, such as semiconductor devices and electrolytic ca-

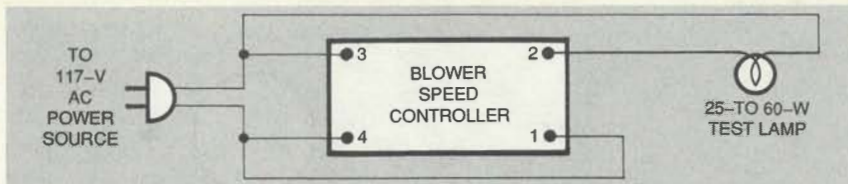


Fig. 7. Wire the Blower Speed Control in this way to test the high-voltage side. Use a 25- to 60-watt light bulb to simulate the blower motor. The Triac and its heatsink will be electrically live—don't touch them unless the Controller is unplugged from the wall socket.

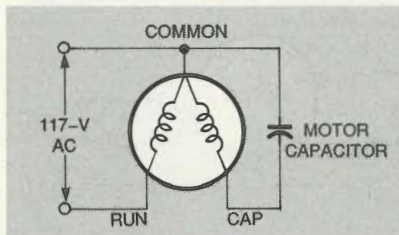


Fig. 8. This is how a typical permanent split capacitor (PSC) motor is wired. Sometimes both capacitor terminals are isolated.

capacitors, must be properly oriented. Just one part placed backwards in the board will prevent the circuit from working, and will probably cause damage to one or more components.

The integrated circuits should be soldered directly onto the printed circuit board for reliability, since the circuit might be exposed to vibrations from the furnace while the blower is operating. Before soldering, be absolutely sure that each IC is properly oriented as illustrated in Fig. 4. Be careful; it is difficult to remove an IC from the board once it has been soldered in place. The two diacs are bi-directional; they are placed into the circuit board without regard to polarity.

It is important to use metal-film resistors where specified in the Parts List to ensure proper calibration and stability of the temperature-switching point. Ordinary carbon resistors are not temperature stable, and should not be used where metal-film types have been specified.

Be very careful when handling the Triac. If the leads need to be bent slightly, be sure that the bends take place away from the plastic body of the Triac. That will avoid any possible damage to the Triac from mechanical stress. It is best if two long-nose pliers are used to perform the bending operation. Be absolutely certain that the orientation of the Triac is correct when inserting it into the printed circuit board. The Triac should be

mounted to the heat sink using suitable hardware and heat-sink compound. If necessary, use 16-gauge wire to connect the power leads of the Triac to the PC board. Refer to Fig. 4 to properly locate those connections. The heatsink should be securely mounted to prevent breaking the Triac's leads.

The temperature sensor will be mounted either in close contact, or inside the plenum of the furnace to sense plenum temperature. Refer to the schematic diagram (Fig. 3) before wiring the temperature sensor to the circuit board. Only two of its three terminals are used: positive and negative. The third terminal is connected to the sensor's metal case and is not used. It is mandatory to insulate the wiring and body of the sensor to prevent any possible short circuit to the sheet metal of the furnace. A short circuit here might destroy the sensor and other components.

Connections between the PC board and the sensor is made with 20-gauge stranded wire with insulation rated at 105°C (221°F). Any length will be satisfactory. Use different color wires if possible. That will make identifying the sensor leads easier. Measure and cut the required length of wire, noting the final location of the PC board and sensor.

When the printed-circuit board is completed and the Triac is securely mounted to its heatsink, examine the assembly very carefully for opens, short circuits, and bad solder connections, which might appear as dull blobs of solder. Any solder joint that is suspect should be redone by removing the old solder with desoldering braid, cleaning the joint, and carefully applying new solder. It is far easier to correct problems now rather than later if you find that the circuit does not work.

If the circuit board is to be mounted outside the furnace cabinet, it must be placed in a small covered plastic

## PARTS LIST FOR THE AUTOMATIC FAN-SPEED CONTROL

### RESISTORS

(All resistors are ¼-watt, 5% units, unless otherwise noted.)

- R1—3,300-ohm, 2 watt, metal-oxide
- R2—10,000-ohm, ¼ watt, 1%, metal-film
- R3—392,000-ohm, ¼ watt, 1%, metal-film
- R4—20,000-ohm, cermet potentiometer (Digi-Key 36C24 or similar)
- R5—100,000-ohm, ¼ watt, 1%, metal-film
- R6—4,700-ohm
- R7—1,000-ohm
- R8—100,000-ohm, ½ watt, cermet potentiometer (Digi-Key 3386P105 or similar)
- R9—2,200-ohm

### CAPACITORS

- C1, C2—10-µF, 50-WVDC, electrolytic
- C3—0.1-µF, ceramic disc
- C4, C5—0.1-µF, 250-WVDC, Mylar

### SEMICONDUCTORS

- IC1—78L15 regulator, integrated circuit
- IC2—LM393 dual comparator, integrated circuit
- IC3—MOC3011 optoisolator, integrated circuit
- IC4—AD590JH temperature sensor (Analog Devices)
- TR1—MAC224A4 Triac (Motorola)
- D1—1N4004 silicon diode
- D2—1N4751A Zener diode
- D3, D4—HS-10 diac (Teccor)
- LED1—Light-emitting diode, red

### ADDITIONAL PARTS AND MATERIALS

Heatsink (Mouser 532-529802B25 or similar), printed-circuit board, hardware, enclosure (optional, see text), hookup wire

**Note:** The following items are available from: A. Caristi, 69 White Pond Road, Waldwick, NJ 07463: Etched and drilled printed circuit board, \$12.95; TR1, \$4.75; IC1, \$2.75; IC2, \$3.25; IC3, \$3.25; D3, \$2.00; D4, \$2.00; IC4, \$9.75. Please add \$5.00 postage/handling. NJ residents must add appropriate sales tax.

enclosure to protect it from dirt and inadvertent short circuits; if mounted inside, the enclosure could be omitted. If an enclosure is used, remember that the heatsink will need some air flow to maintain Triac cooling. Drill holes in the sides of the enclosure for

air flow and the power input and output leads. It is best to use 16-gauge, 105°C insulated stranded wire for those connections. Use several different colors to help avoid miswiring.

Do not install the circuit board into its case or the sensor into the furnace at this time. The assembly must first be checked out to be sure it is operating properly.

**Preliminary Testing.** The preliminary test is divided into two parts. First, the primary side of the circuit is checked using a low-voltage DC power supply as the source of power. The second part consists of checking the AC power side of the circuit using an ordinary lamp bulb to simulate the blower motor of the furnace.

**CAUTION:** Since the circuit will be powered directly by the AC line during the AC power portion of the test procedure, it is mandatory that no contact be made to any part of the Triac circuit. If you have to troubleshoot that part of the circuit, an isolation transformer must be used to prevent electrical shock. Figure 5 shows how two identical step-down transformers might be connected back-to-back for line isolation.

Refer to Fig. 6 when setting up a DC power supply for the first half of the preliminary test. The supply voltage should be no more than about 25 volts. If the voltage breakdown rating of D2 (about 27 to 33 volts) is exceeded, D2 will burn out.

Connect the negative lead of the DC power supply to the negative side of C1, and connect the positive lead to the positive side of C1. Measure the voltage at the positive side of C2. A normal reading is between 14.75 and 15.25 volts. If you do not obtain that voltage, disconnect power and troubleshoot the circuit before proceeding. Check the orientation of D2, IC1, C1, and C2. Measure the resistance across C2 to be sure there is no short circuit on the 15-volt line. A normal reading is about 13,000 ohms. If that is not seen, examine the board thoroughly for shorts, opens, and bad solder joints. When the fault has been located and repaired, continue with the checkout procedure.

Connect a DVM or VOM across R2 to monitor the sensor current. Apply 25-volts DC power to the circuit and note the voltage reading of the meter,

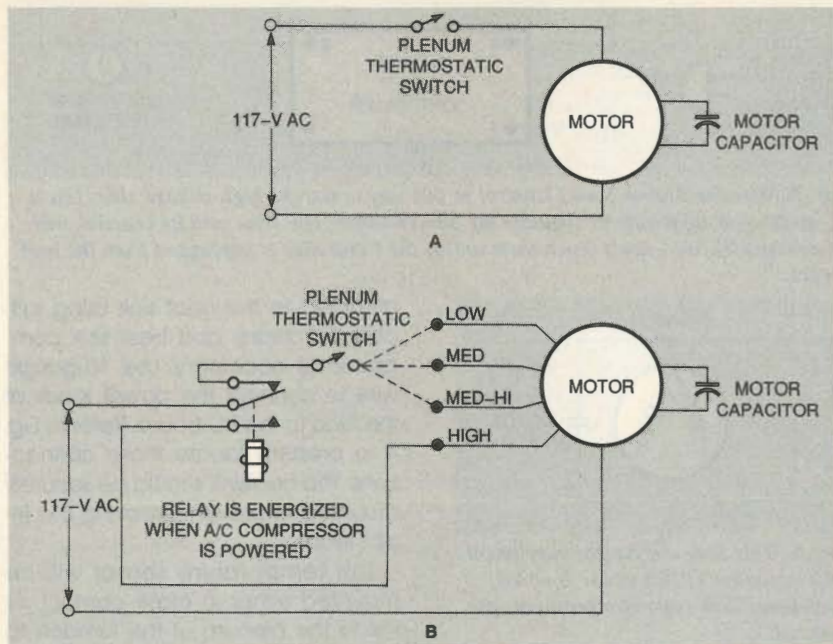


Fig. 9. Here are some typical blower motor wiring diagrams, showing a single-speed (A) and a four-speed (B) arrangement. The lower speeds in arrangement (B) are usually hard-wired to one choice, depending on the size of the house and the capacity of the furnace. The high speed is automatically selected by the air conditioner.

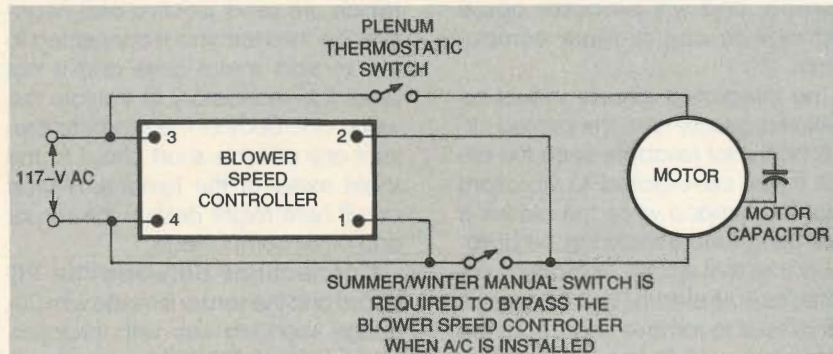


Fig. 10. The Blower Speed Control is connected to a single-speed motor system like this. If you also have air conditioning, you'll have to add the summer/winter bypass switch shown.

which should be about 3-volts DC, depending upon ambient temperature. If the reading is not correct, check the sensor's polarity.

With 25-volts DC applied, measure the voltage at pin 5 of IC2. Adjust R4 for a reading of 3.16 volts.

Assuming that the temperature sensor is at normal room temperature (much less than 110°F), LED1 should be off. Take a hand-held hair dryer and gently heat the sensor while monitoring the voltage across R2. Do not touch the sensor with the dryer. As the sensor heats up, the reading on the meter should begin to rise. When the voltage exceeds 3.16 volts, LED1 should come on. Remove the heat. When the voltage across R2 falls below 3.16 volts as the sensor cools back

down to room temperature, LED1 should turn off.

If LED1 does not light up, check its orientation. Check IC2 and IC3 to be sure they are inserted into the board as shown in Fig. 4. Try a new LED.

Disconnect the power supply. Refer to Fig. 7 and very carefully wire the circuit board, lamp, and AC power cord as shown. Double check the wiring before applying power, and be very careful not to touch any of the wiring or circuit board components.

Insert the line cord into an AC receptacle. Adjust R8, using an insulated screwdriver, over its range and note that it is possible to obtain anywhere from full to partial brightness of the lamp bulb. Set R8 so that the bulb is noticeably dim.

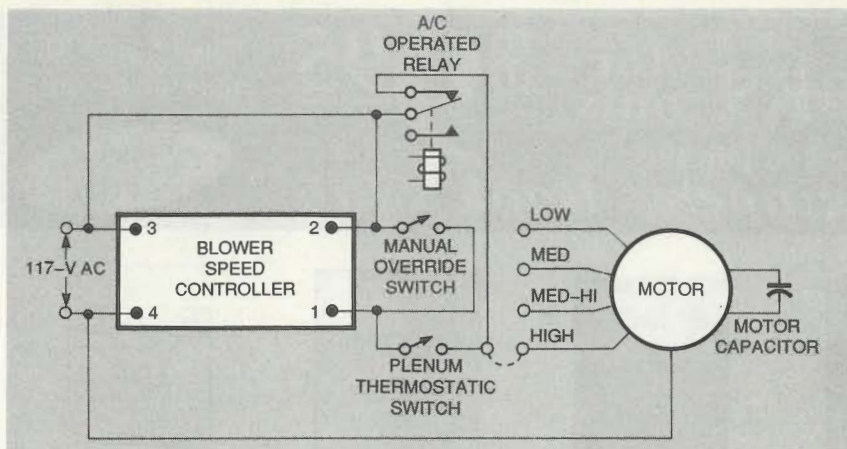


Fig. 11. The Blower Speed Control is connected to a multi-speed motor system like this. The air conditioning relay automatically bypasses the Controller during the summer. The lower speeds are no longer needed as the Controller will automatically set the blower motor's speed.

Gently heat up the temperature sensor as before, being very careful that the hair dryer does not touch the sensor. When LED1 comes on, the lamp should change to full brightness. If the lamp does not respond as described, check the orientation of the Triac. Check the circuit board for opens and shorts. If possible, try replacing IC2, IC3, D3, D4, or TR1 with new parts.

When the board is operational as described, it is ready to be installed into the furnace.

**Installation.** There may be literally hundreds of models of warm-air furnace in use today, so it is not possible to address each and every one. However, most furnaces will have either a single-speed or multi-speed permanent split-capacitor (PSC) blower motor (Fig. 8). Units designed to handle both air conditioning and heating will usually have a two-, three-, or four-speed motor that is automatically set to high speed for cooling and low speed for heating with a switching relay. Two such wiring diagrams are illustrated in Figs. 9-a and 9-b.

When installing the Blower Speed Control, the motor wiring should be such that it operates at maximum speed when its two input leads are powered by 117-volts AC. The phase-controlled Triac in the circuit will take over setting optimum motor speed.

Figures 10 and 11 illustrate typical wiring diagrams for single speed and multi-speed blower motors. Note that for systems that include central air conditioning, a manual summer/

winter switch or an A/C-operated relay must be included as shown to provide maximum motor speed during A/C compressor operation.

Before starting any wiring, disconnect power from the furnace by throwing the circuit breaker and emergency switch off. Then locate the 117-volt input wires to the motor and disconnect them from the furnace wiring. Rewire the circuit as shown in Fig. 10 or 11, depending on which type of system you have. Connect a pair of wires from the 117-volt AC power source at the furnace emergency switch to the 117-volt AC input terminals of the Controller.

As described earlier, the temperature sensor must be placed inside, or in close contact with, the plenum of the furnace where it can respond to temperature rise. Remember, the sensor cannot short out to any metal part of the furnace. Insulate and secure the sensor at the desired location.

**Final Test.** If you can, obtain a narrow stem thermometer that can be placed inside the plenum to measure the plenum air temperature. Otherwise, your hand placed on the sheet metal provides a fair measure of temperature.

Set the room thermostat down as far as it will go. Turn the furnace power on. Initially, the blower should be off. Locate the blower's plenum thermostatic switch, which turns the blower on and off. Set that switch to its minimum temperature setting. The blower motor should turn on. If the plenum is too cold, operate the

burner for a minute or two to warm it so that the blower will operate at the minimum temperature setting.

Using an insulated screwdriver, adjust R8 for the desired minimum blower speed. Do not set the speed too slow; check to be sure the motor is self-starting when power is applied. Once low speed has been set, you'll find the noise level in the living area is virtually non-existent.

Now turn the thermostat up so the burner operates. Monitor the temperature of the plenum. When the plenum becomes slightly warm (about 110°F) and LED1 glows, the blower should switch to high speed.

Turn the thermostat down to shut the burner off, and wait for the plenum to cool. The blower should switch back to low speed.

The final adjustment is the switching temperature of the plenum thermostat. For optimum heating efficiency, the blower motor should run when the plenum reaches about 95- to 100°F. The motor will operate at low speed, wringing every possible BTU out of the furnace plenum.

When the system has been set up as described, you will find that the furnace fan operates almost all of the time (continuous air circulation), is quiet, and provides a significant increase in your comfort level.

After operating the system through several variations in weather conditions, you may wish to fine tune the blower switching temperature (R4) and low speed adjustment (R8) to suit your individual preference. Ω



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