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Applications of the TC62X Solid-State Temperature Sensors

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INTRODUCTION

Sensing temperature and comparing that temperature to preset limits is the basis for a variety of problems that designers face in system design and process control. Conventional temperature sensing solutions, such as thermocouples and RTDs, require additional electronic components to linearize and amplify their low-level outputs. Since electronic components are already in the circuit, semiconductor manufacturers have begun adding temperature sensing functions to their amplifier and reference circuits. The result has been a new generation of small, easy-to-use temperature sensing products.

Electronic thermal sensors typically generate a voltage that is proportional to absolute temperature (PTAT). This voltage is then compared to a reference voltage to test the temperature limit. A new temperature sensor has been developed, however, that does not require a PTAT voltage. The new sensor provides two set points plus a control flip-flop with only three components. The same technique has also produced a single-set point sensor in a 3-pin package.

Figure 1 is a block diagram of the dual set point TC620 from Microchip Technology. This device combines a temperature-dependent element, voltage reference, two comparators, control flip-flop and push-pull digital outputs in a single CMOS integrated circuit. Set point temperatures are selected with external resistors. The temperature-dependent element is a Positive Temperature Coefficient (PTC) resistor.

The circuit does not generate a PTAT voltage. Instead, a reference amplifier forces 1.2V across the on-chip PTC. As temperature increases, the PTC resistance increases while the current decreases. The PTC current is compared to current flowing through the external set point resistors. If the PTC current falls below a set point current, that set point output will go to a logic-high state. Two comparators provide low and high set points in a single 8-pin DIP or Small Outline (SO) surface mount package.

The control flip-flop is set when the temperature exceeds the high limit and reset when the temperature goes below the low limit (Figure 2). The control output is available with two polarity options: a ‘C’, or Cool, option (i.e. to turn on a fan at the high limit) and an ‘H’, or Heat, option (i.e. to keep a heater on until the high limit is reached).

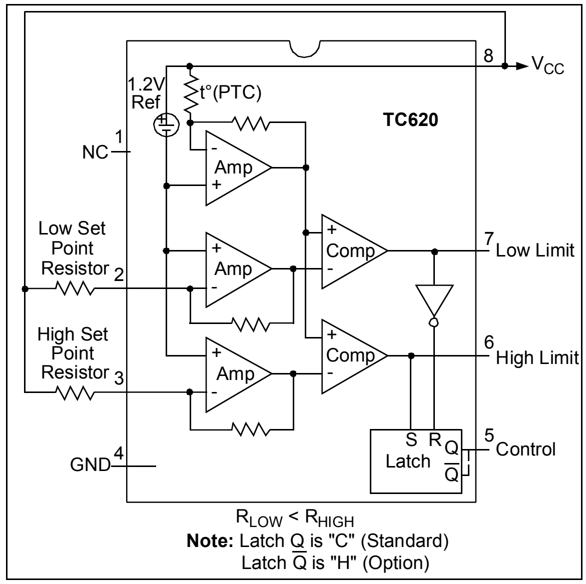

FIGURE 1: *Block Diagram of the TC620 Temperature Sensor.*

TC620 set point resistors are selected from a graph (Figure 3) or calculated from the equation:

EQUATION

$$R = 0.5997 \times T^{2.1312}$$

Where: R is in Ohms and T is in Kelvin

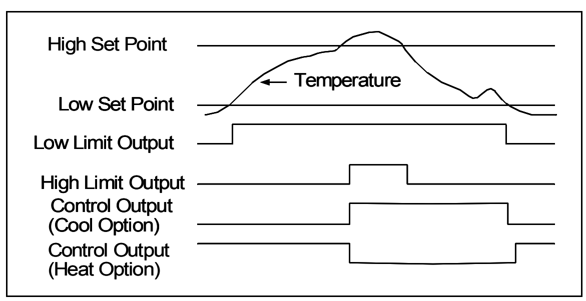

FIGURE 2: *TC620 Temperature vs. Output Logic.*

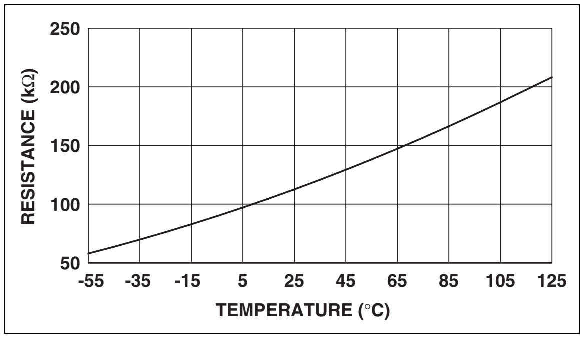

FIGURE 3: TC620 Sense Resistance vs. Temperature.

While the TC621 is similar to the TC620, it senses temperature via an external Negative Temperature Coefficient (NTC) thermistor instead of an on-chip sensor. Thermistors are available in a wide variety of package options for special design requirements, such as chips for rapid thermal response and metal sheaths for corrosion resistance.

For high volume applications, a single set point device is available. The trip point of the TC622 and TC624 is set by a single external resistor.

Hysteresis is very important for controlling chatter, or “motorboating”, in control systems. Semiconductor sensors provide low, repeatable hysteresis when compared with bimetallic thermal switches. The TC620 control output provides programmable hysteresis, which is equal to the difference between the high and low set points. There is also about 2°C of hysteresis at each set point. The single set point of the TC622 and TC624 has fixed hysteresis of 2°C.

The push-pull outputs of the TC62X series sensors connect directly to digital logic or microcontroller inputs (see Figure 4). Output current is limited to 1 mA for the TC620 so that self-heating will not introduce unwanted hysteresis. Output current is easily boosted to drive larger loads. Examples of driving DC and AC loads are shown in Figure 5A, Figure 5B and Figure 5C.

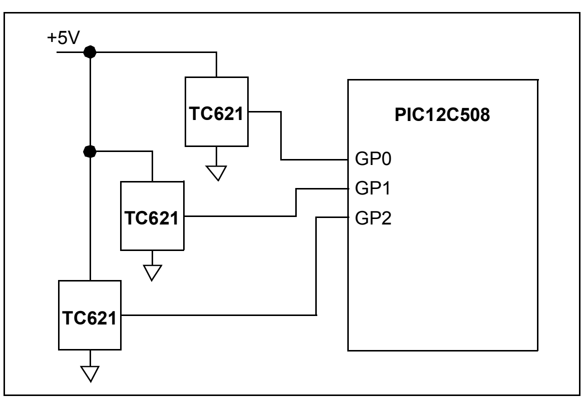

FIGURE 4: Direct Interface to a Microcontroller.

Three state outputs (low, high and off) are useful for minimizing wiring costs in control applications. The TC620 can be combined with an external CMOS buffer to provide three output states on a single line (Figure 6). Below the low set point temperature, the output will be in the high-impedance (off) state. When the low limit is exceeded, the output will switch to a low-impedance state and force a logic low. The output goes high if the high limit is exceeded.

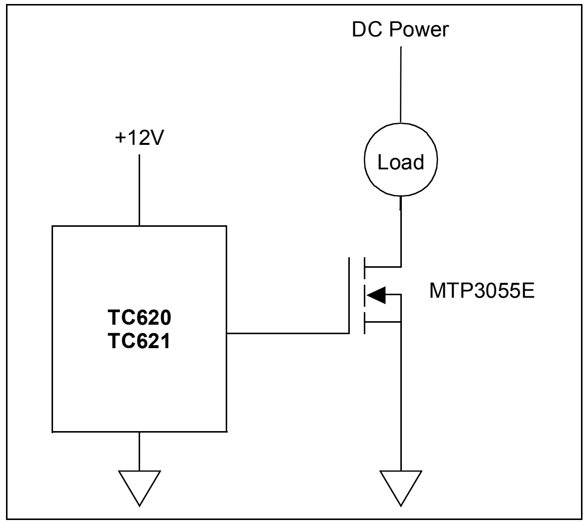

FIGURE 5A: Boosting Output Drive Current.

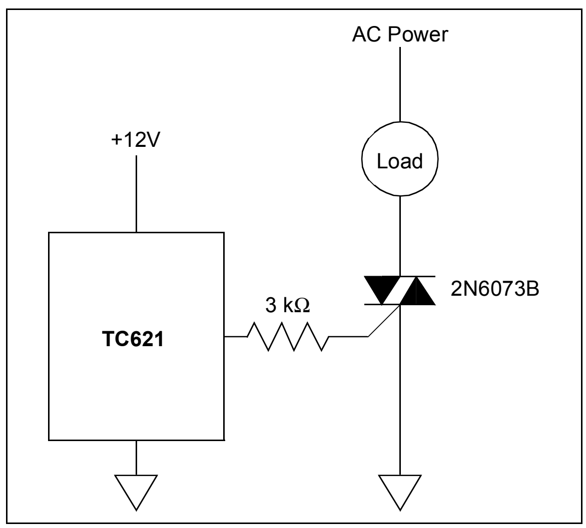

FIGURE 5B: Boosting Output Drive Current.

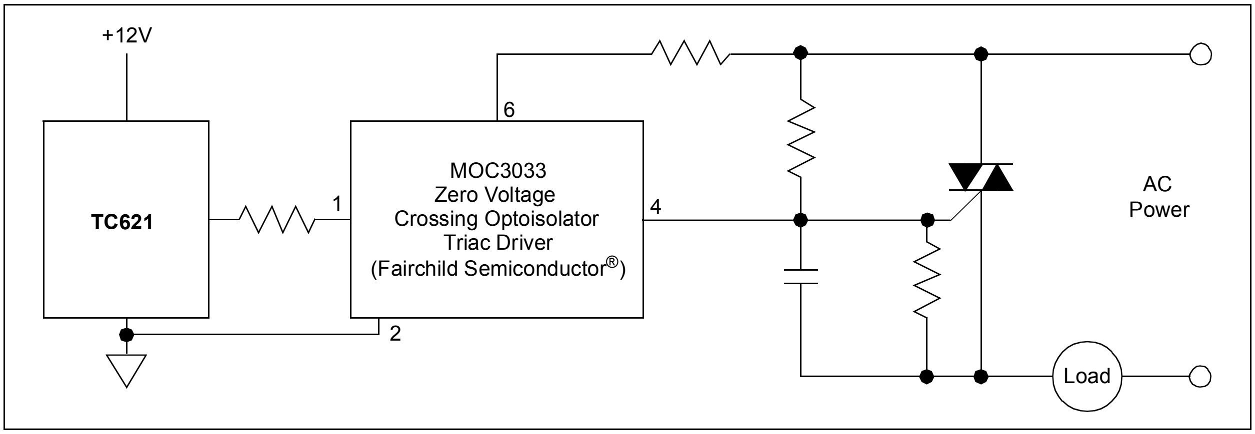

FIGURE 5C: Boosting Output Drive Current.

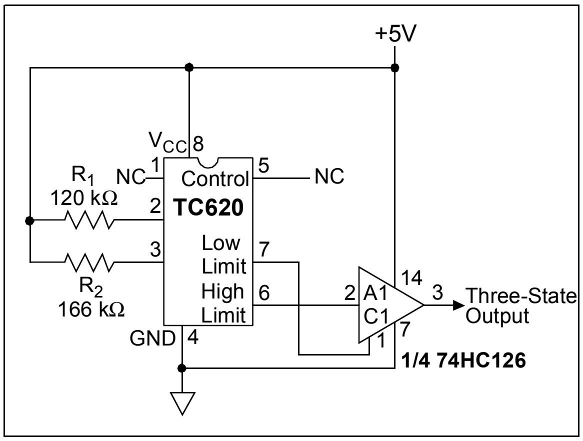

FIGURE 6: Boosting Output Drive Current.

PROTECTING ELECTRONIC COMPONENTS AND SYSTEMS

Thermal protection of sensitive components becomes critical as system designers are asked to pack more functions, operating at higher speeds, into smaller packages. For example, the Intel® Pentium® processor dissipates up to 16 watts at 66 MHz and will be damaged if the cooling system fails. High ambient temperatures can also degrade performance or damage components in communications systems, file servers, power supplies, motor drives and other applications where heat is generated. These components and systems are easily protected with semiconductor temperature sensors because the sensor operating characteristics and packaging are compatible with the components being protected.

Proper mounting of the temperature sensor in relationship to the heat source is critical to ensure correct results. Therefore, it is important to select the correct package for a particular task. For example, protecting a microprocessor, such as Intel's Pentium, is simplified when a TC620 in SO package is mounted underneath the microprocessor's pin grid array (PGA) package (Figure 7). The two set points let designers offer a 'graceful' shut down procedure: if the low set point temperature is exceeded, unnecessary peripherals can be shut down, files backed up, and a system warning generated. If the high set point is exceeded the system is shut down to prevent damage to the CPU.

Protecting power transistors, diodes, etc. is easy when the TC622 in a TO-220 package is used (Figure 7). The tab of the TC622 package is internally connected to V_{CC}, so an insulating washer may be required, if the heat sink is at a voltage potential beyond the TC622's V_{CC} range of 4.5V to 18V.

Measuring the internal air temperature inside a system is accomplished using the DIP, small outline (SO) or TO-220 packages. Since the sensor is mounted in the same type of package as other ICs, and is at the PC board level, the sensor's output will accurately reflect the actual environment of components within the system. For measuring specific hot spots on sensitive components, the TC621 offers a wide variety of options when combined with an almost infinite selection of thermistor packaging types.

Sensing that a component is too hot is not sufficient protection, however. Further action, such as turning on a cooling fan, is required. The TC622 or TC624, combined with a switching transistor, will turn on a fan at the preprogrammed temperature (Figure 8). Keeping the fan turned off until cooling is required produces several advantages. Reliability is improved because the amount of time that the fan must run is reduced. In addition, efficiency is improved and noise is reduced.

Even turning on a cooling fan is not enough to ensure protection, however. For example, equipment can still be damaged if the fan fails or air intake vents are blocked. If additional protection is required, the TC620 will control a fan and provide a warning of thermal runaway (Figure 9). The circuit of Figure 9 will turn on the fan at +45°C and give an over-temperature warning at +85°C. The entire circuit operates from a single +5V power supply, so the over-temperature warning is

CMOS/TTL compatible. Also, supply current is only about 140 µA when the fan is off, which makes the circuit ideal for battery-powered equipment.

As previously mentioned, semiconductor thermal sensors offer low and repeatable hysteresis when compared with bimetallic devices. Low hysteresis is very important in protecting critical electronic systems that must be restarted as soon as possible, such as a file server. Since the system will normally attempt a restart operation as soon as the temperature returns to an acceptable level, minimum hysteresis equates to minimum time before the system can return to service.

HEATING/COOLING CONTROL

The control output of the TC620 or TC621, either by itself or combined with the low and high set points, forms a simple but flexible temperature controller for environmental and process control. Heating, cooling or combined heating/cooling options are available with one IC, which reduces design and prototyping time.

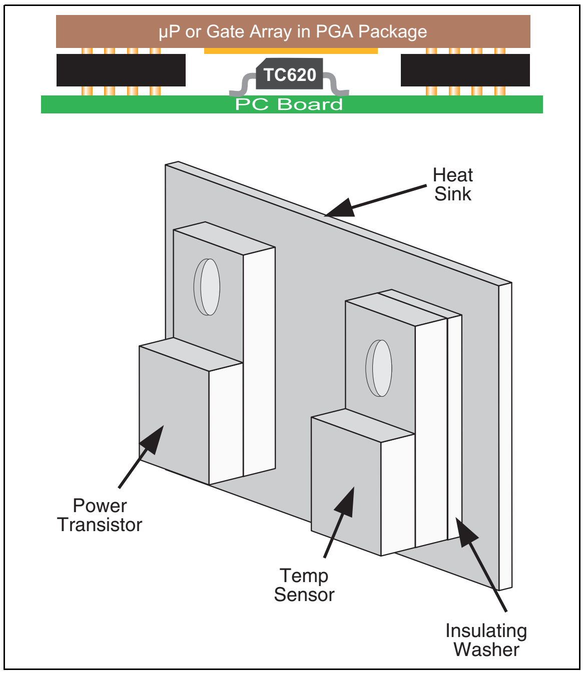

FIGURE 7: *Mounting the temperature sensor to protect sensitive components.*

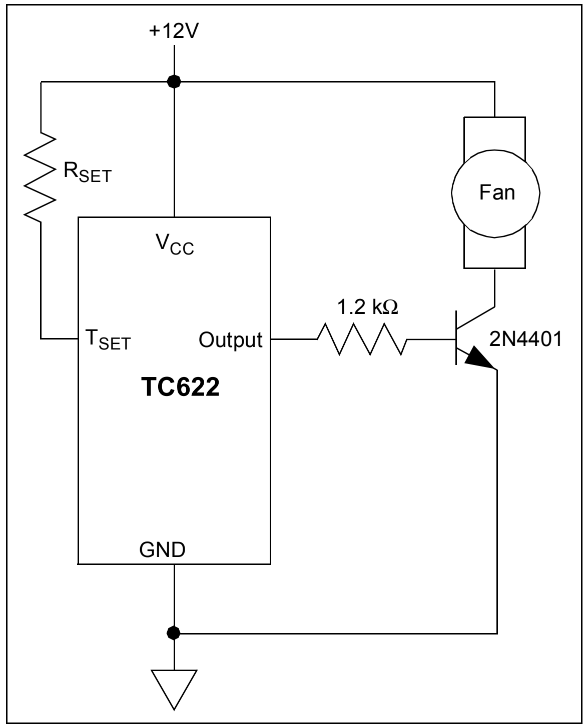

FIGURE 8: *Temperature Controlled Fan.*

Since temperatures are selected with external resistors, stocking one device provides the designer with temperature control over a range of –50°C to +120°C.

Figure 10 is an example of a swimming pool solar heating panel pump control. This circuit uses an external thermistor that is attached to the solar panel in a manner that will allow it to sense heat generated by direct exposure to the sun. A thermistor with a resistance of about 100 kΩ at 25°C should be selected. One such thermistor is the ACW-027 from Ketema®, which can be clamped around a pipe in the solar panel.

This circuit will energize the pump when the sun is heating the panels and turn off the pump when the sky is cloudy or the sun goes down. To prevent rapid cycling of the pump during partly cloudy conditions, the hysteresis is set for a relatively wide (20°F) span. Providing a low thermal impedance between the thermistor assembly and the solar panel will also prevent rapid pump cycling by adding the solar panel's thermal time constant to the hysteresis.

To select the set point resistors, consult the thermistor data sheet for the thermistor's value at the desired temperature. For example, assume that we want the pump to turn on (high set point) at 100°F and turn off (low set point) at 80°F. For the Ketema ACW-027, the resistance is 55.7 kΩ at +100°F and 91.1 kΩ at +80°F. These values are the high and low set point resistors, respectively.

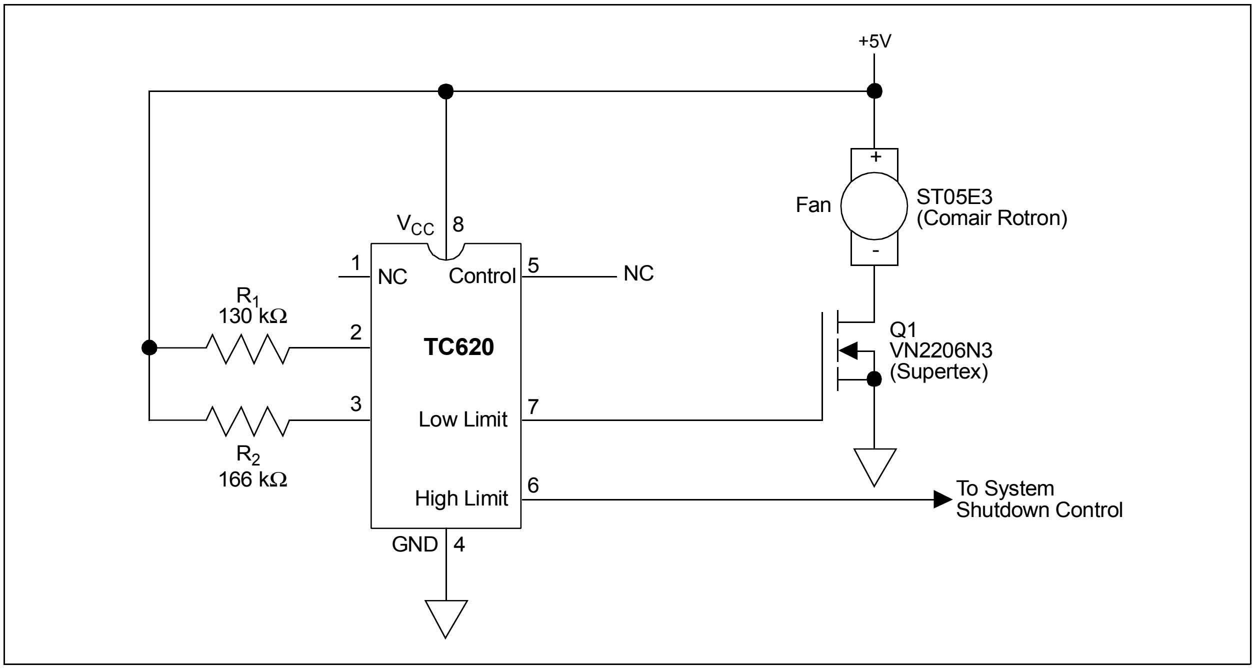

FIGURE 9: *Temperature-controlled fan with fail-safe warning.*

As the sun heats the solar panel and the thermistor assembly, the pump will turn on at +100°F. The pump will stay on until the temperature decreases to +80°F. This ensures that the solar panel has time to heat up before the pump is energized, and that the pump will turn off before the solar panel has cooled below the pool temperature.

Many heating and cooling systems operate from a 24 VAC secondary voltage. Figure 11 is an example of a temperature control system that drives 24 VAC relays and operates from an internally-generated +15V power supply.

The controller is designed to regulate temperature over a +45°F to +85°F (+7°C to +29°C) range, with hysteresis of 5°F. Selection of the resistors is as follows:

The low limit is +7°C, so:

EQUATION

$$R_{LOTEMP} = .5997 \times (7 + 273.15)^{2.1312} = 98.6\ k\Omega$$

The high limit is +29°C, so:

EQUATION

$$R_{HITEMP} = .5997 \times (29 + 273.15)^{2.1312} = 115.8\ k\Omega$$

Temperature adjustment is controlled by potentiometer R_1. Since current flows through R_1 to both pins 2 and 3, the effect of a change in R_1 is twice as great as a change in R_{LOTEMP} or R_{HITEMP}.

Therefore, to provide an adjustment range of 40°F,

EQUATION

$$R_1 = \frac{(R_{HITEMP} - R_{LOTEMP})}{2} = \frac{(115.8 - 98.6)}{2} = 8.6k\Omega$$

The nearest standard-value component is a 10 kΩ potentiometer, so the high set point resistor will vary from R_{LOTEMP} (98.6 kΩ or 45°F) to $R_{LOTEMP} + 2 \bullet R_1$ (98.6 kΩ + 20 kΩ or 90°F).

Hysteresis is set by the difference between the high and low set points. The slope of the TC620's internal PTC resistor is about 430 Ω/°F, so 5°F of hysteresis occurs when the low set point resistor is about 2.15 kΩ less than the high set point resistor. Combining these values, and adjusting for standard 1% resistor values, we get:

EQUATION

$$R_{LOSET} = 98.6k\Omega - 2.15k\Omega = 96.45k\Omega = 95.3k\Omega$$
$$R_{HISET} = 98.6k\Omega = 97.6k\Omega$$

With R_1 attached to both programming resistors, the low set point resistor's 5°F hysteresis will track the high set point resistor as the user manually adjusts R_1 for different temperatures.

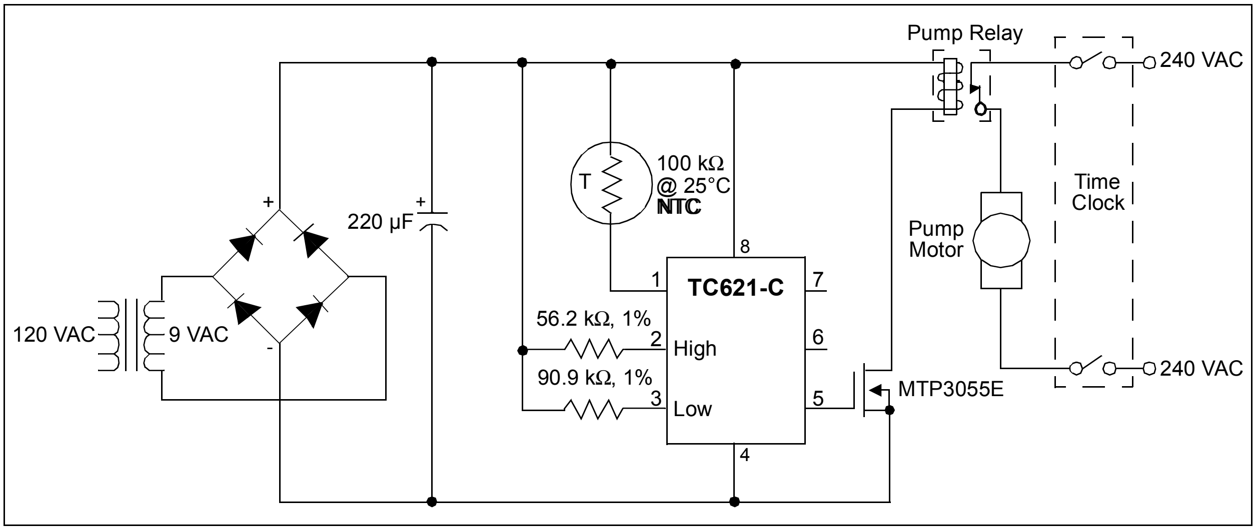

FIGURE 10: *Swimming Pool Solar Heat Control.*

The circuit of Figure 11 uses a TC4469 quad CMOS driver to add logic functions to the TC620 outputs. The first driver is used to drive an LED indicator. Depending on the position of the Heat/Cool selector switch, either the Heat or Cool LED will be lit. The second driver controls the "Comfort Zone" LED indicator. When the temperature is between the two set points (i.e. in the 5°F hysteresis zone) this indicator is turned on.

The third driver controls the heating contactor. It is enabled when the Heat/Cool selector switch is in the Heat mode (i.e. open) and the control output is low. When the Heat/Cool switch is closed, the third driver is disabled and the fourth driver is enabled to control the cooling contactor. This driver turns on the cooling contactor when the TC620's control output is high. The logic function of the TC4469 is used to prevent the heating and cooling contactors from operating simultaneously.

Power for the control system is derived from the 24 VAC supply. The TC620 and TC4469 are both CMOS products, so supply current (except for the LED current) is very low. Using triac switches to energize the relays keeps component costs to a minimum while maintaining high reliability.

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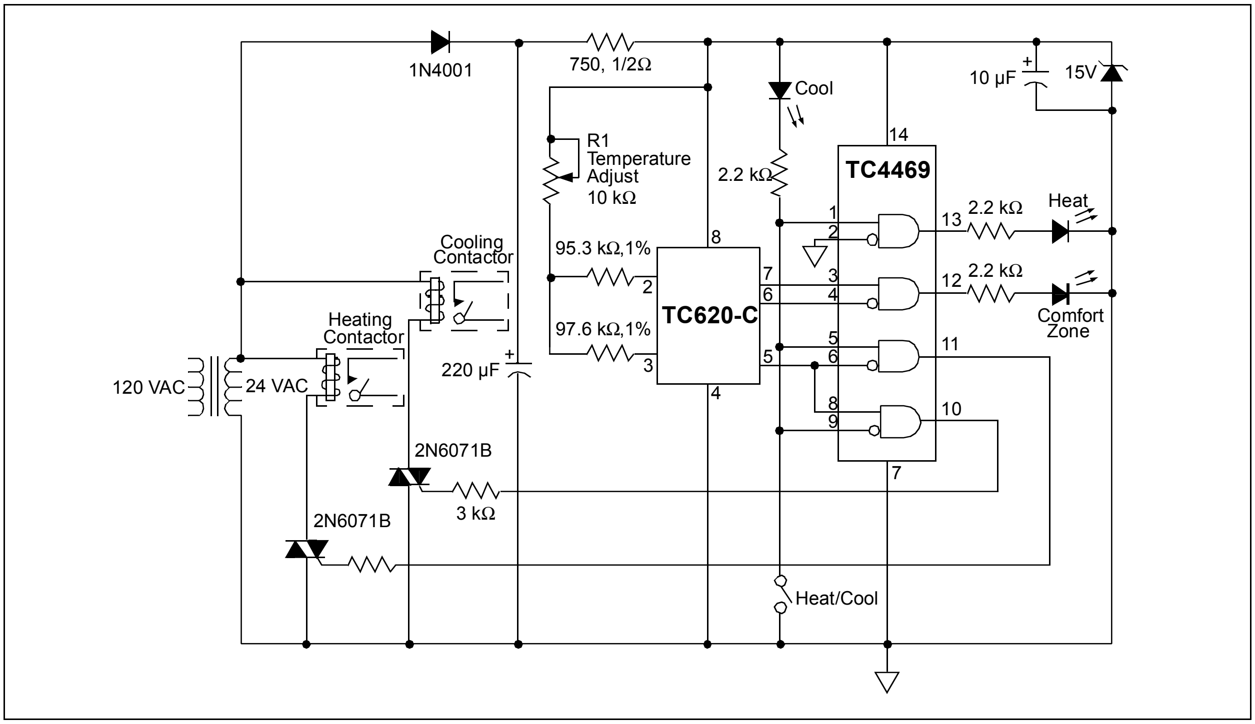

FIGURE 11: *Swimming Pool Solar Heat Control.*

NOTES:

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