Thermoelectric Temperature Controller Sensor Attachment with Notes on Thermocouples

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TE TECHNOLOGY, INC.

1590 Keane Drive
Traverse City, MI 49696-8257
http://www.tetech.com

Phone: (231) 929-3966
Fax: (231) 929-4163
e-mail: cool@tetech.com

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Overview

Good temperature measurement is required for good temperature control, so we will discuss attachment of the temperature sensors used on TE Technology's temperature controllers. Many people also use thermocouples for monitoring or verifying system performance, so we will briefly discuss thermocouples, too. Numerous photos are included to help guide you.

Proper sensor attachment is probably the most important thing you can do to make sure your temperature controller functions satisfactorily.

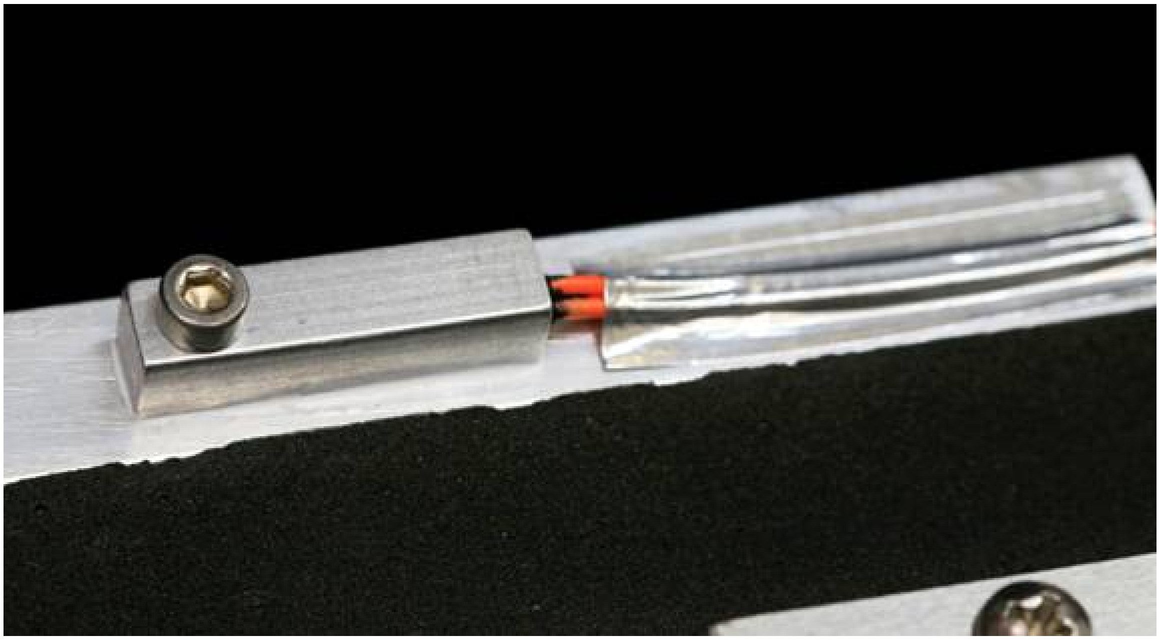
Remember: The temperature measured by the controller is the temperature of the SENSOR and not necessarily the temperature of the TE device! So, the key to good control is to make the temperature of the sensor equal (as much as possible) to that of the TE device or object you are cooling.

How do you do this?

1. Sensor placement: The time lag time between when the TE device changes temperature and when you measure that change with the sensor needs to be minimized. This usually means placing the sensor as close to the thermoelectric module as possible.
2. Proper thermal attachment: Make certain that the temperature sensor has the best possible thermal connection to the object you wish to measure.
3. Removal of external influences: External influences such as Infra Red (IR) radiation and heat conducted by the sensor wires to the measurement point need to be minimized.

Attaching Sensors used for Thermoelectric Controllers

Cold Plates, Part 1



MP-3193 Sensor on a cold plate

This picture shows one suggested method of attaching a sensor to a cold plate. The sensor is placed along the side of the cold plate, so there is a relatively little time lag between when the modules change temperature and the sensor detects this change.

Thermally conductive paste (such as TE Technology TP-1) is used to improve the thermal connection between the sensor and the cold pate. Place the thermal paste on the flat surface of the sensor where it contacts the cold plate. We haven’t found it necessary to put thermal paste along the wire. The use of a surface mount sensor with a large contact area will help minimize these effects, and we strongly suggest using this design where possible. For example, the MP-3193 has a large flat surface which provides a good thermal link to the plate surface.

Finally, the sensor wires are taped to the side of the cold plate using aluminum tape. This tape can be purchased at hardware stores, and is commonly used in the heating and ventilation industries. The aluminum tape conducts heat around the top of the wire and helps the wire assume the same temperature as the cold plate. In doing so it minimizes the temperature difference between the wires and the sensor head, and this in turn minimizes the amount of heat that is added or removed from the sensor head by the wires.

It is important not to underestimate the amount of error that can be caused by not following these simple steps. In experimentation we were able to create a test case where an MP-2996 thermistor was attached to an aluminum plate. The sensor wires were leading to a nearby temperature controller at a typical room temperature and were not taped along the plate. When the plate was heated to 100 °C the sensor only indicated an 80 °C temperature. This error was virtually eliminated by the addition of thermal paste and aluminum tape!

Cold Plates, Part 2

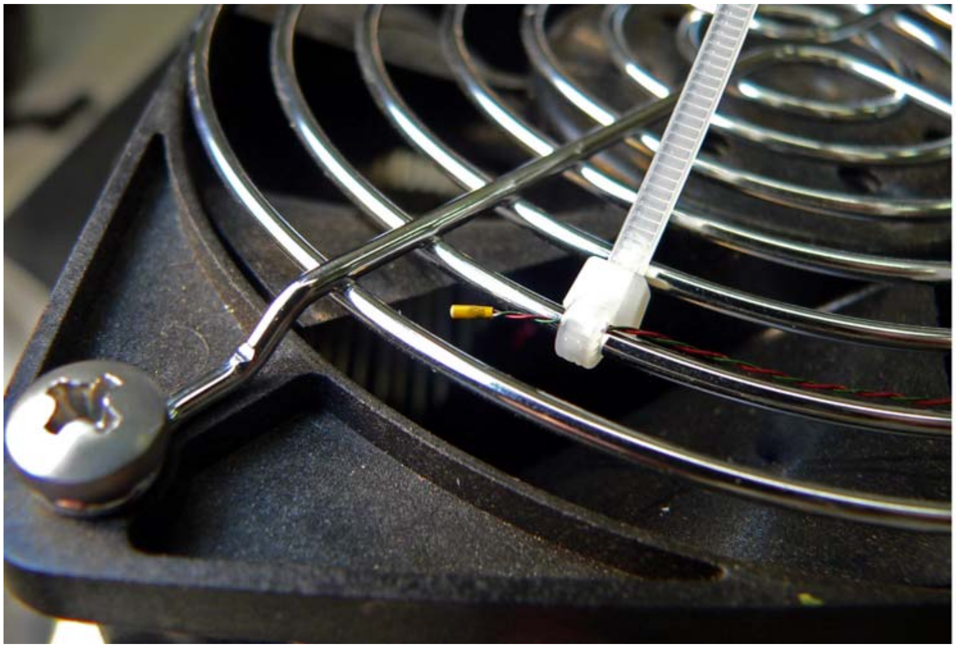
You can also drill a hole in a cold plate and epoxy a temperature sensor in the hole using a thermally conductive, electrically insulative epoxy. This can yield the fastest sensor response time of all approaches. The sensor can be placed in the center of the plate directly above a thermoelectric (Peltier) module, and if the hole is deep enough the epoxy pre-cools (or pre-heats) the wire before the sensor.

Thermistors epoxied into aluminum cold plates

TE Technology's standard air coolers, cold plates, and liquid coolers (except for the cold side of the liquid cooler) on both the external heat sink base and the cold plate/internal heat sink base allow you to use either mounting option. That is, the sensor hole is drilled to a 25 mm depth so you could mount a small diameter sensor like the MP-2444, but it is also tapped with M3 threading 9.7 mm deep for mounting the MP-3193.

Air Coolers

This picture shows a small sensor attached to the finger guard on an air cooler. The small sensor size reduces the time lag, or response time of the sensor. Because the sensor and a large amount of its wire are directly in the cooler's air intake, the sensor provides a good indication of the air temperature. If there is good air circulation within the enclosure the sensor temperature will approximate the enclosure's internal temperature. The fans usually suck air in, and the air is then cooled, so this will likely be the warmest point in the system.



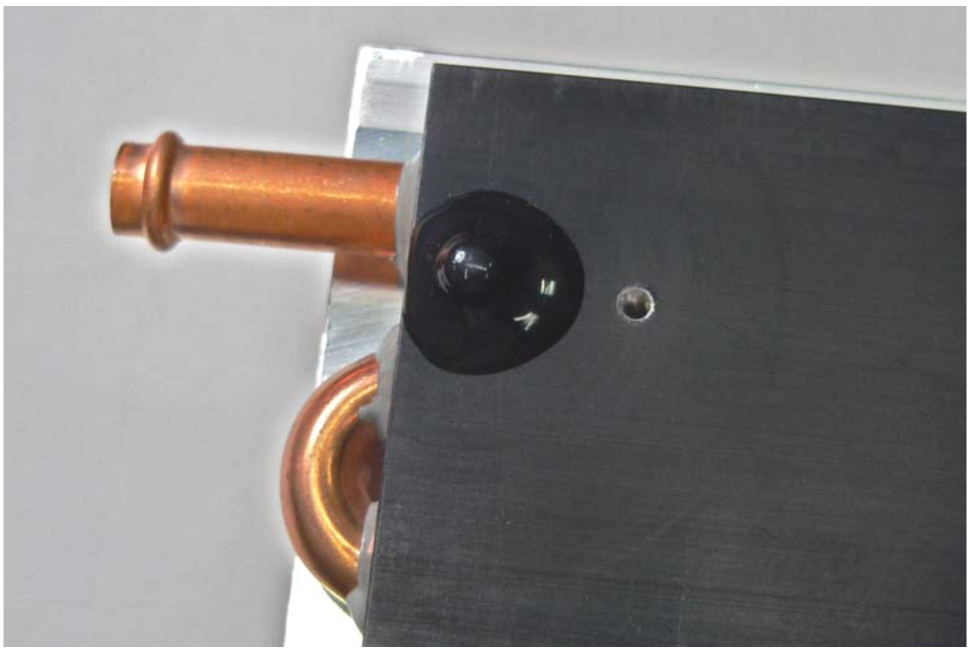
Small sensor on the finger guard of a fan in an area of high air flow

BE CAREFUL!: In the preceding air cooler example, if the fan fails or its air flow through the fins is restricted, the sensor temperature is no longer representative of the temperature of the enclosure temperature. The air cooler could then become excessively cold or excessively hot (if the system is capable of heating). There can also be a significant temperature difference between the temperature of the heat sink and the sensor if there is a high heat flow. For these reasons, when using an air temperature sensor we recommend that a second sensor be used for alarm and emergency shut down purposes. This second sensor is attached to the base plate of the heat sink or cold sink using the same method as in the cold plate example. Of course, additional sensors can be placed anywhere a potentially harmful condition could exist.

Sensor monitoring the base plate temperature of a finned heat sink

Liquid Coolers

When attaching a sensor to a liquid exchanger follow the same procedure as if you were attaching it to a cold plate. TE Technology's standard liquid coolers (LC-XXX series) have a small sensor hole drilled and tapped near one of the inlet/outlet tubes. You can use a sensor in this location to monitor the liquid exchanger's temperature and prevent freezing and/or overheating. Usually the fluid flow is directed so that the exchanger fitting closest to the sensor becomes the fluid outlet. That way the exchanger's temperature at the sensor location will more closely match the fluid outlet temperature.



Sensor hole near fluid outlet

However, to accurately measure the temperature of the fluid the sensor would ideally be placed directly in the fluid stream. Typically, the sensor is positioned just past the exchanger's fluid outlet. This minimizes the lag time between the when the fluid is cooled or heated and the sensor senses this change in temperature. Of course, this can impose logistical problems that may or may not be worth the effort. None of our sensors are specifically rated for submersion in liquids. In such cases, the sensor could be placed into a special fitting that is inserted into a T-fitting, which is then installed in-line with the fluid outlet.

Precautions when Selecting and Using Thermistors

Do not use a sensor that shows signs of damage or exhibits other signs of failure.

Do not let the sensors get wet unless they are specifically rated for operation in wet and condensing environments. Unless specifically noted in TE Technology's product literature the sensors sold by TE Technology (including those sold as part of a standard temperature controller) are not rated for use in wet or condensing environments.

Do not exceed the sensor's maximum sensing temperature during operation or processing, such as when attaching wires. Protect against overheating when soldering wires to the sensor by heat sinking the sensor head or the wires leading to the sensor head before soldering.

Do not allow the wires to become shorted to external metal components and do not allow one sensor wire to become shorted to the other sensor wire. This can happen if the insulation on the wire is breached and the exposed metal is shorted through some conductive medium such as metal or water. Sensors using the single stranded magnet wire (MP-2444 and MP-3176, for example) have thin varnish insulation and this may be easily abraded and breached. Other sensors may not have insulated wires. Protect and insulate wires as required with heat shrinkable tubing or other method as necessary. Specific caution should be paid to wires as they exit the sensor holes in metal plates, etc. Sharp bends in the wire as it enters the sensor hole can breach the wire insulation at the edge of the sensor well.

Mechanical stress can damage the sensor head. The thermistors sold by TE Technology do not have intrinsic strain relief mechanisms. Do not pull on the sensor wires or put stress on the temperature sensing head. Unless there is a mounting hole built into the sensor head the sensor should not be subjected to any compression forces or mechanical stresses. If a mounting hole is included in a sensor head then only compression mounting forces should be applied, and those forces should only be applied in the direct area of the sensor mounting hole (as would normally be covered by the head of a mounting screw). So, for example in the case of the sensors that are made from an aluminum tube with a flattened end for a mounting surface, the compression forces for mounting should only be applied to the flattened surface and not the other portions of the aluminum tube.

When mounting a sensor in a sensor well (hole), drill the hole big enough and use a compliant thermal epoxy or other material so that thermal stresses associated with the expansion and contraction of the dissimilar materials do not crack the sensor head. A tight hole and/or rigid adhesive can cause excessive stress to be placed on the sensor head, causing mechanical damage to the sensor as the components are thermally cycled.

If you do not find a temperature sensor offered by TE Technology that is suitable for the application we suggest that you contact one of the many third party sensor manufacturers for assistance in sourcing a suitable product. NTC thermistors are common, and many companies such as Measurement Specialties offer ready made sensor probes that can be used with TE Technology's controllers.

Failure Mechanisms:

Temperature sensors can and do fail. When designing a thermal control system, we strongly recommend that independent protection devices, such as over/under-temperature thermostats, electrical fuses, etcetera, or other such protection devices be utilized to eliminate hazards and potential damage to the coolers, controllers, and associated equipment in case of a sensor failure or malfunction. The use of independent protection devices means that failure in a single point of the system such as a temperature sensor will not cause hazardous conditions for the user and or equipment.

The user must test and verify the performance and reliability of the selected sensor in the actual application. It is impossible for TE Technology to access the reliability of a thermistor in the myriad of applications that exist. However, to assist the user in understanding some of the failure modes and common symptoms TE Technology has generated the following table listing some ways in which thermistors can be damaged and the symptoms associated with such damage. This is not an exhaustive list of either failure modes or symptoms, but is intended only to give the user some guidance in avoiding and diagnosing failures.

Remember, when properly functioning an NTC thermistor's resistance will decrease as its temperature becomes warmer. Likewise, a failure that results in a lowering of the sensor's resistance will in turn generate a warmer temperature reading, and conversely a failure that causes an increase in the sensor's resistance will generate a cooler temperature reading.

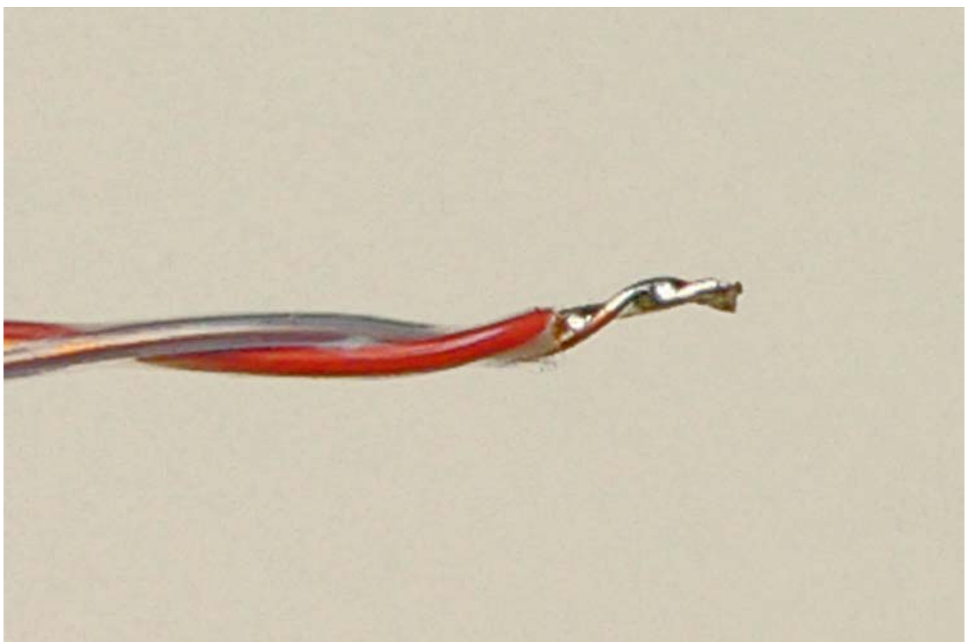
Damage Mechanism:	Associated Symptoms:
Shorted Wires	Sensor resistance is approximately zero ohms. Can be caused by sensor wire's insulation being breached against a metallic surface such as a sensor well. Can also be caused by individual strands of a stranded wire shorting to a neighboring terminal on a temperature controller.
Mechanical Damage	High resistance if wires, internal contacts or sensor bead is cracked, low resistance if sensor wires or internal leads are shorted. Common causes can be internal wires broken (wires pulled after sensor head is secured in place) or an oversized screw head crushing a sensor in a flattened tube thermistor such as the MP-2996.
Moisture Intrusion	Resistance reads lower than normal, may be partially or completely reversible when sensor is baked in an oven to remove moisture.
Overheating	Resistance of sensor drifts from initial resistance at any given temperature.
Thermal cycling failure	High resistance if internal contacts or sensor bead become cracked, this failure mechanism is actually a form of mechanical failure.

Thermocouples

Thermocouples and Cold Plates

You may want to measure the temperature of an object using a secondary temperature measurement device, such as a thermocouple temperature meter. We usually buy a spool of fine gauge thermocouple wire from a company such as Omega Engineering and make our own thermocouples. 0.25 mm diameter wire (0.010 inch) is a good size. It is a compromise between having a wire that is big enough to work with and yet small enough to minimize any heat being conducted by the wire itself to the temperature measurement junction.

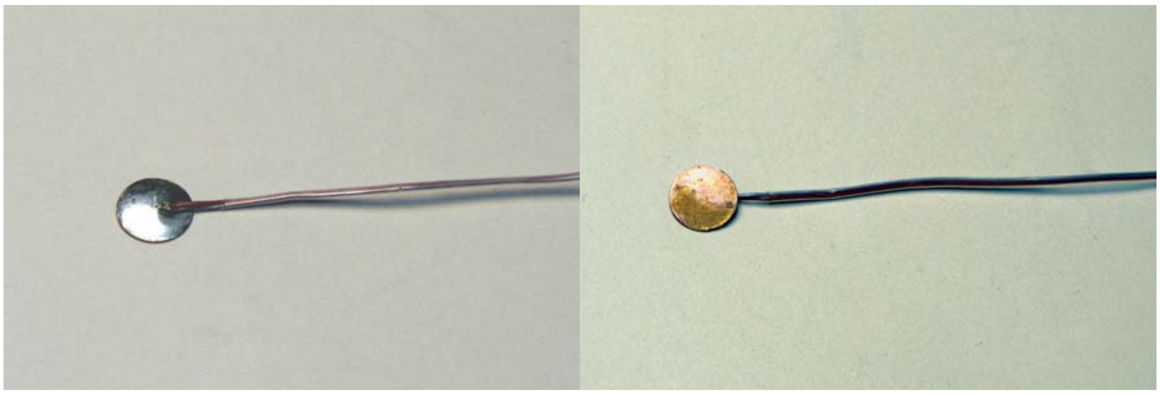
To make a thermocouple junction we simply strip the insulation off of the end of thermocouple wires, twist in a few tight turns with a pair of pliers, and then solder the twisted junction together. Once soldered, cut off any excess twists of soldered wire. You only want roughly one twist to pinpoint the area of temperature measurement. As of this writing we are using 63/37 tin/lead solder, but other alloys should work. You just don't want the solder to melt when taking measurements.



Thermocouple junction before being soldered to copper button

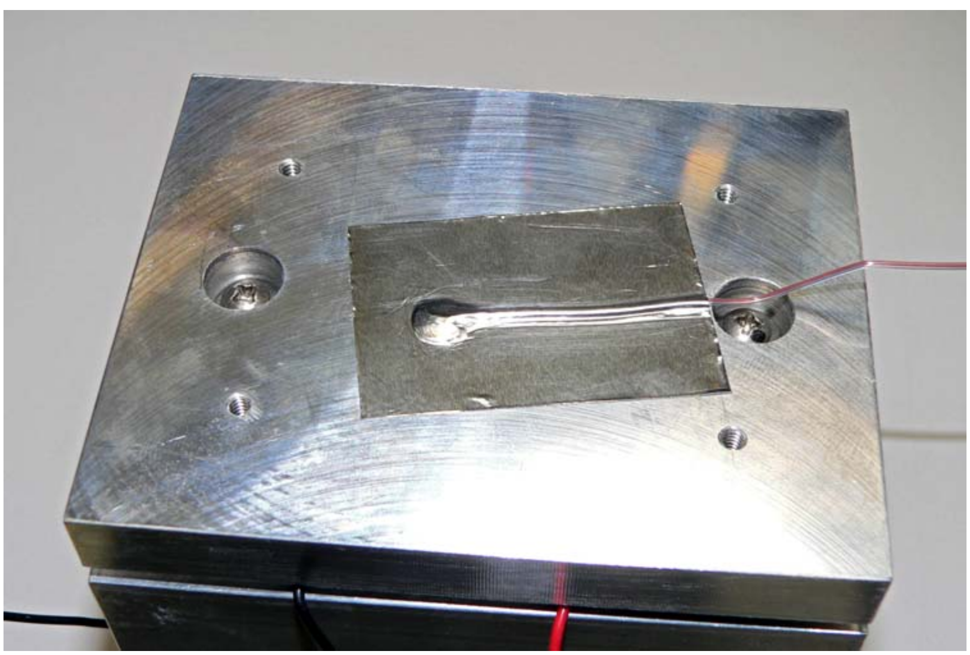
If you are NOT using battery powered thermocouple meters you may want to conformal coat (or otherwise electrically insulate) any exposed electrical conductor on a thermocouple probe. We have seen ground loops created between two different thermocouples when using AC powered measurement equipment. Temperature changes are measured in microvolts, so even a tiny ground loop can really offset a measurement. They are most frustrating when the temperature differences they induce are small enough to make the data seem plausible, thus going unnoticed and secretly distorting the data.

For measuring the temperature of flat surfaces we usually make what we call a “button” thermocouple. Here we take a thin sheet of copper (0.5 mm) and use a paper puncher to punch small copper “buttons”, or disks. Then, we solder the thermocouple junction to the copper button. If the copper button becomes warped during the punching process press it flat before soldering to it. The basic concept here is that the copper button improves the thermal link to the object it is connected to by increasing the junction surface area.



Button thermocouples: soldered side and object (measurement) side

Next, dab a little thermal paste on the copper button and attach the button thermocouple to the object with aluminum tape. Remember to cover about 25-50 mm of the thermocouple wires with the aluminum tape…

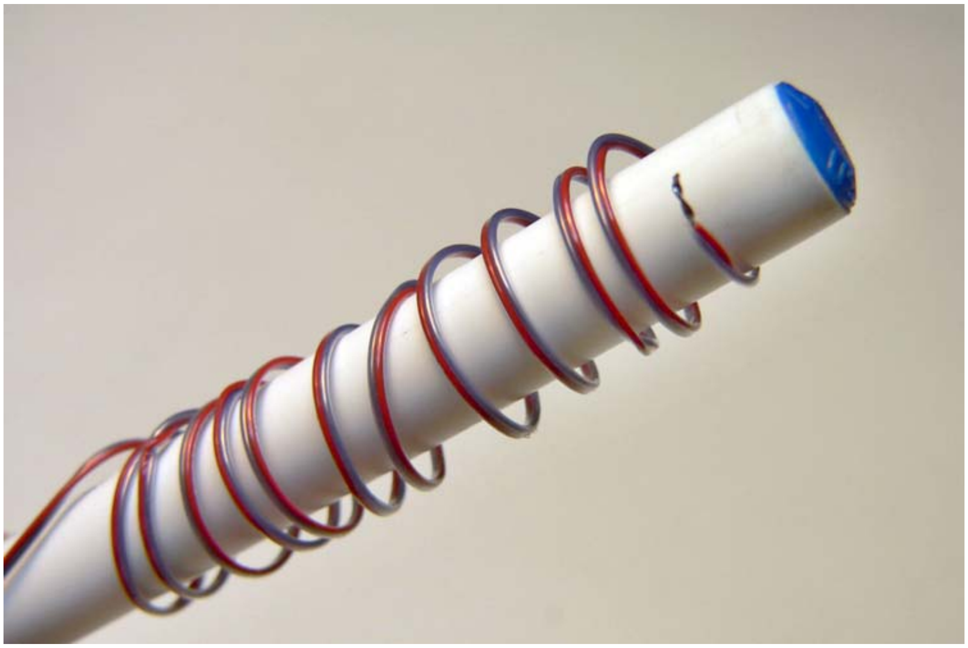


Button thermocouple attached to a cold plate and covered in aluminum tape

Thermocouples and Air Coolers

Air temperature measurements can be a little more difficult. The thermocouple temperature reading can be influenced by (1) attaching the wire to the enclosure wall, (2) by the heat being conducted to the tip of the thermocouple via the thermocouple wire, and (3) infrared radiation from heat sources.

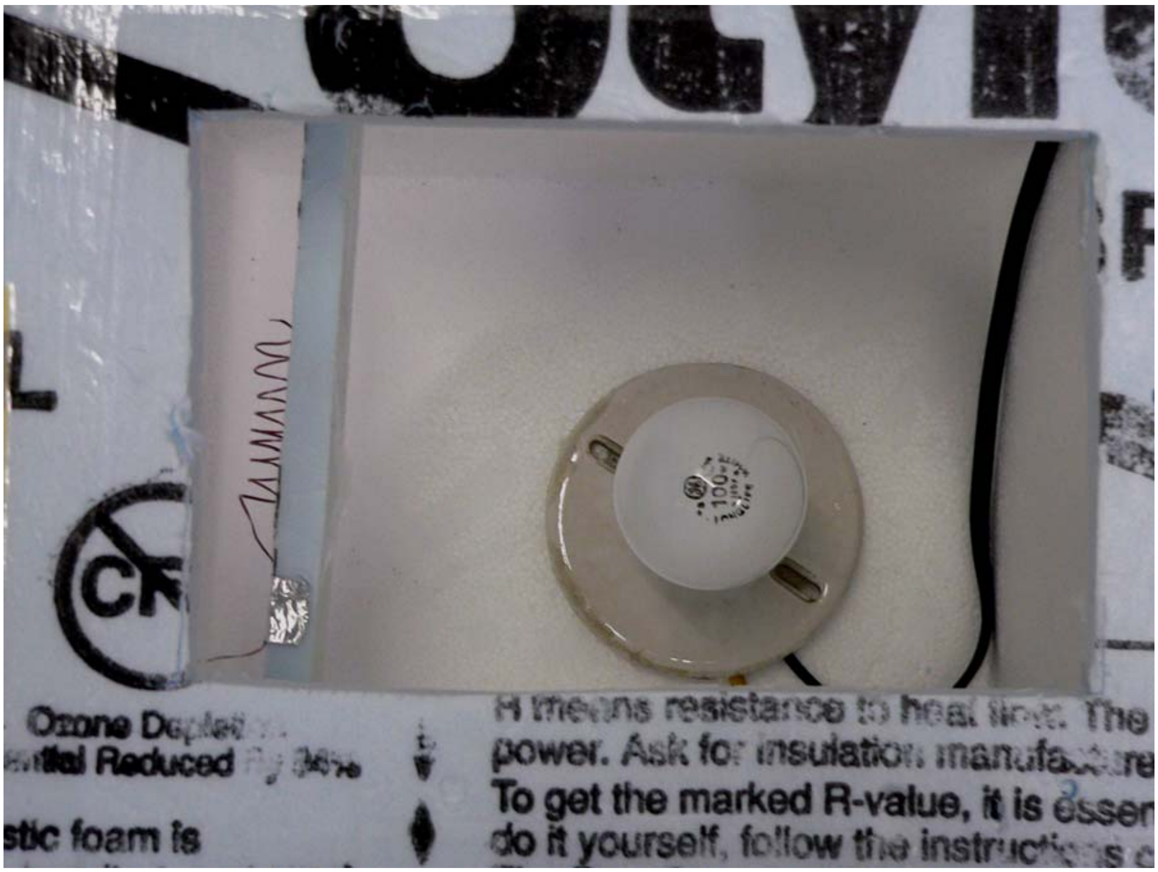
The wall temperature of an enclosure is usually different from the air temperature, and the wire will conduct heat from the enclosure wall to the tip of the sensor where the measurement is made. If you are testing a cooled enclosure and the thermocouple meter is outside the enclosure, it will be at a different temperature and also conduct heat from that end of the thermocouple wire into the enclosure. So, you will want to make the thermocouple wire length from any attachment point until the tip as long as possible. Winding the thermocouple wire around the end of a pen or pencil is a good way to get a lot of wire length in a short physical distance. This increases the wire's surface area and allows the temperature at the measurement tip to better equilibrate with the internal air temperature.



Thermocouple coiled around tip of pen to increase wire surface area and allow temperature equilibration

In this picture there is a view inside a simple foam box. A rectangular hole has been cut in the top to accept the cold side from an air cooler. Inside there is a light bulb which is being used as a dummy heat load.

Measuring the air temperature is the coiled thermocouple shown on the left side. Infrared radiation from the light bulb will affect the temperature reading, so there is a simple piece of foam insulation between the light bulb and the thermocouple as a radiation shield. A more proper radiation shield would encompass all sides of the thermocouple and block any radiation reflected back by the enclosure wall (but then you couldn't see the thermocouple in the picture…).



Styrofoam® enclosure with dummy heat load (light bulb) and a thermocouple for measuring the air temperature. An air cooler is to be inserted into the opening.