Assembling temperature sensors:

thermocouples and resistance temperature detectors RTD (Pt100)

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DEPARTMENT OF CIVIL ENGINEERING
AALBORG UNIVERSITY

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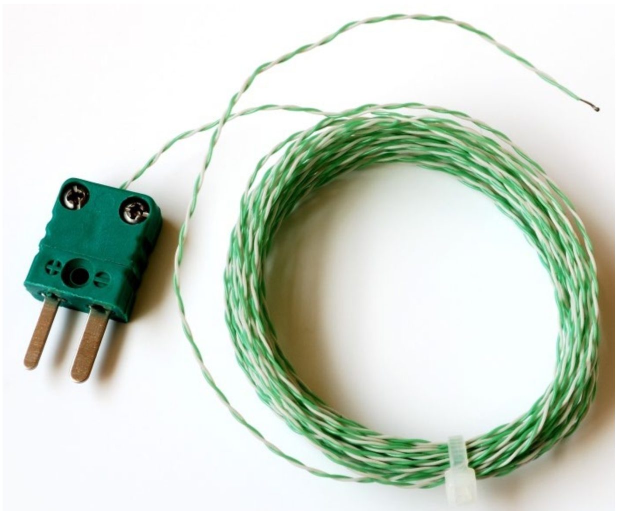

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by

Hicham Johra

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1. Foreword

Temperature is one of the most common physical quantities (measurand) to be measured in experimental investigations, monitoring and control of building indoor environment, thermal comfort and building energy performance.

The most common temperature sensors are the thermocouples and the resistance temperature detectors (RTDs). These analog sensors are cheap, accurate, durable and easy to replace or to repair. The cable of these sensors can easily be shortened or extended. These sensors have a simple, monotonic and stable correlation between the sensor's temperature and their resistance/voltage output, which makes them ideal for temperature measurement with electronic logging equipment.

This technical report aims at providing clear guidelines about how to assemble and mount type-K thermocouples and Pt100 RTDs. These are the most common temperature sensors used in the Laboratory of Building Energy and Indoor Environment at the Department of the Built Environment of Aalborg University [1].

2. Type-K thermocouples

2.1 Introduction

Thermocouples are pairs of metal wires covered with a protective plastic tube. The pair of wires are insulated from each other everywhere except at the sensing junction (the junction which actually measures the temperature). Each wire is made of a different metal alloy. When the two ends of the thermocouple's wires are connected together, an electrical potential difference (voltage) is generated as a function of the temperature difference between these two ends (Seebeck-Peltier effect, see *Figure 1*) [2]. It should be noted that thermocouple measurement equipment requires a "cold-junction compensation" (CJC), which is usually an ice-point reference or an RTD Pt 100.

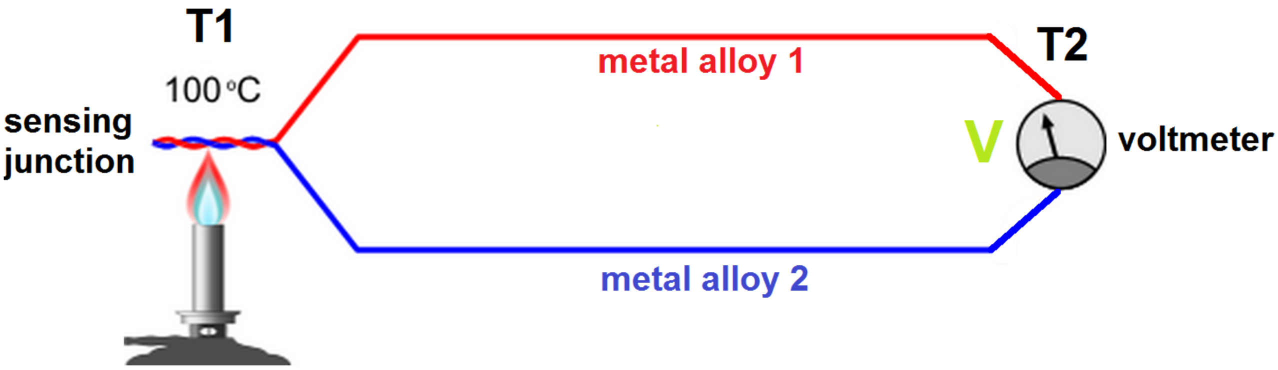

Figure 1: *Junction of two dissimilar metal alloys (thermocouple) inducing thermoelectric effect: Seebeck-Peltier effect.*

Thermocouples are very cheap temperature sensors. They can be cut and re-sized at will without any problem. Thermocouples are also very durable and can resist aggressive environments such as corrosive fluids, nuclear radiations and high temperatures. There are different types of thermocouples for different applications with different pairings of metal alloys. For building applications, the type-K thermocouples (Chromel-NiCr and Alumel-NiAl alloys) are commonly used.

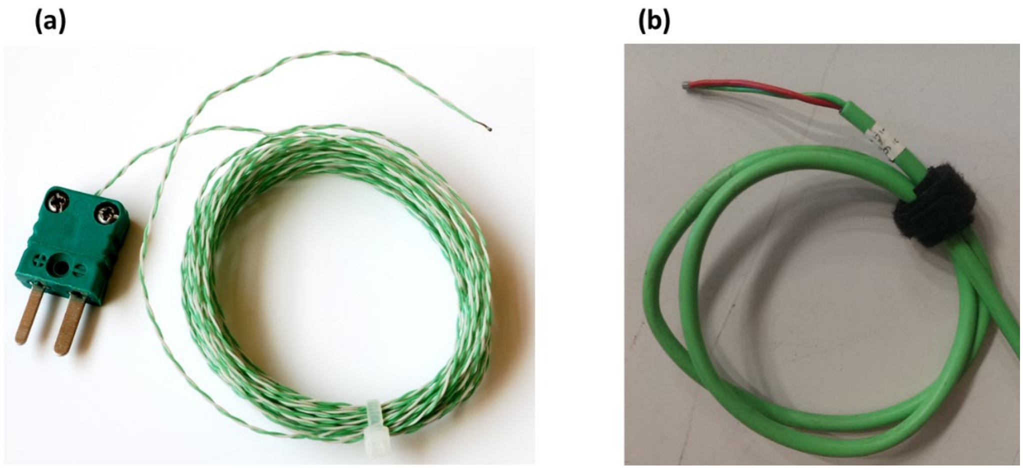

Figure 2: *Examples of type-K thermocouples used in the Laboratory of Building Energy and Indoor Environment: (a) thin type-K thermocouple with a standard type-K connector; (b) thick type-K thermocouple.*

2.2 Mounting simple exposed assembly of thin type-K thermocouples

For transient temperature measurement of surface, air or fluid requiring a small response time (short time constant), the thin thermocouples without protection or encapsulation (exposed thermocouples) are prefered. The thin thermocouples are more fragile and the measuring junction can easily be broken in case of shocks or debris in a high-speed fluid. In addition, direct contact between the thermocouple metal junction and another metal element can cause wrong measurement (more susceptible to electrical interference) and short-circuiting. If the thermocouple measuring junction has to be protected, read the section “Alternative robust assembly options for type K thermocouples”. If not, follow the instructions below for assembling a simple exposed junction of a thin type-K thermocouple.

To form the sensing/measurement junction with a thin type-K thermocouple, remove the plastic insulation of the 2 wires on about 2 cm (see *Figure 3 (a)*); twist tightly the 2 metal wires together (see *Figure 3 (b)*); cut the sensing/measurement junction tip to the desired length: usually between 5 mm and 10 mm (see *Figure 3 (c)*); the thermocouple sensing/measurement junction is formed and ready to be used (see *Figure 3 (d)*).

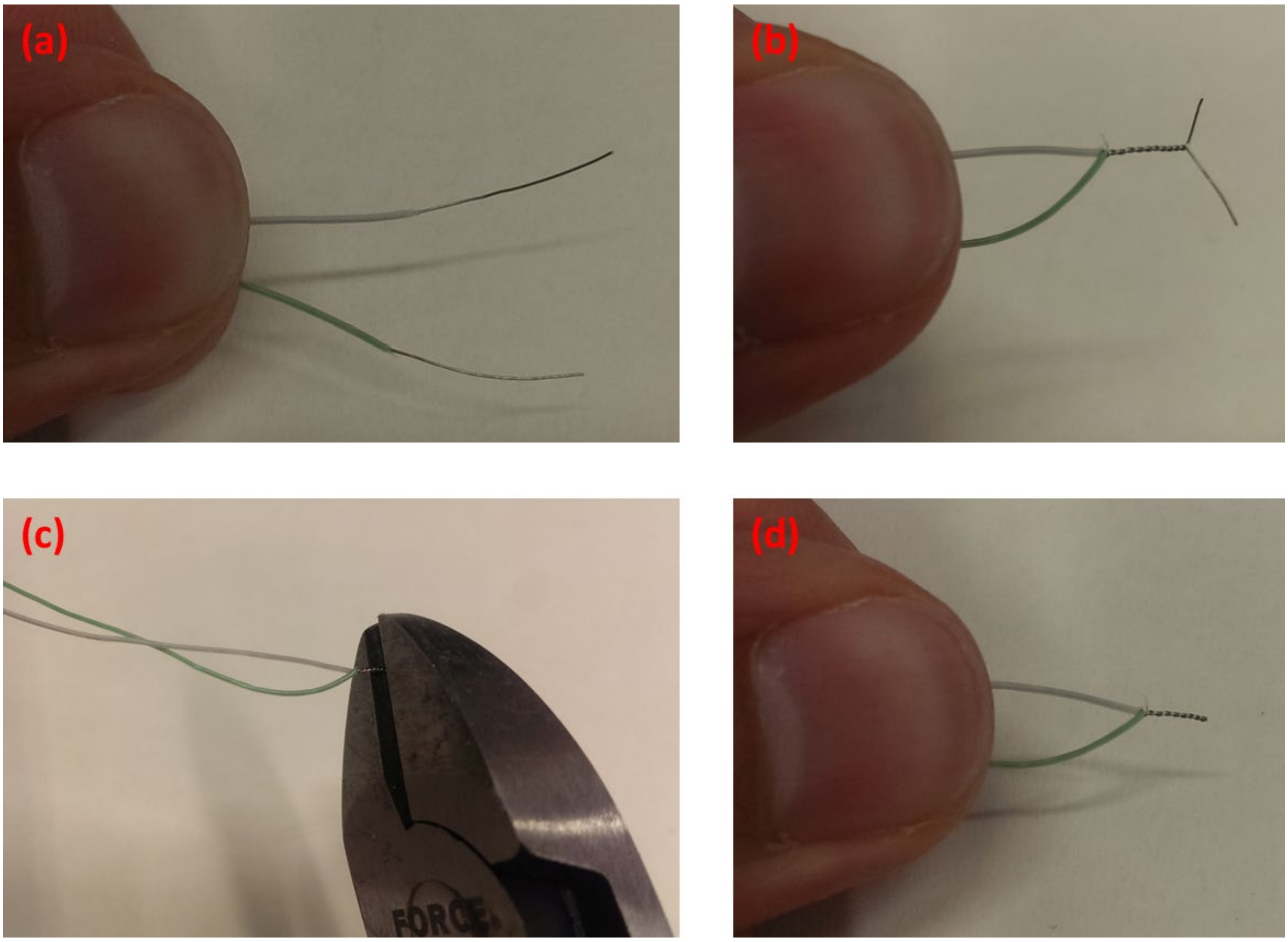

Figure 3: ***(a)*** *remove plastic insulation;* ***(b)*** *twist metal wires;* ***(c)*** *cut the tip;* ***(d)*** *the thermocouple sensing/measurement junction is formed.*

2.3 Mounting simple exposed single-point-of-contact assembly of thin type-K thermocouples

For certain applications, it is necessary to have a very thing thermocouple junction: for example, minimum fluid flow disturbance in a narrow cavity. In that situation, it is possible to weld thermocouples together with a electrical welding tool (see *Figure 4*) to form a thin single-point-of-contact thermocouple junction (see *Figure 5*). It should be noted that those single-point-of-contact junctions are very fragile and can easily break. They are thus not recommended for application in flow with debris, shocks, tensions or vibrations.

Figure 4: *Welding toop for thermocouples.*

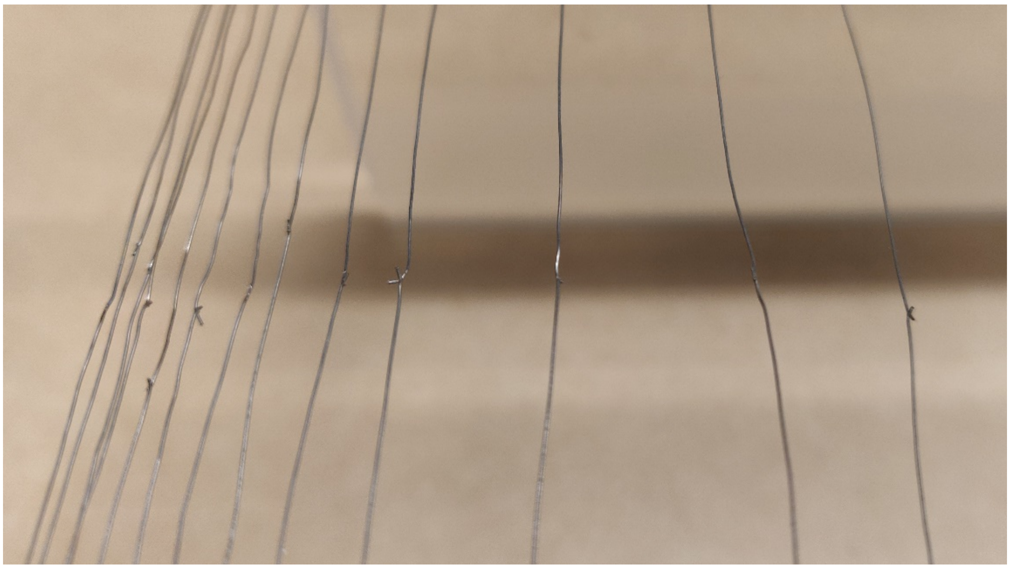

Figure 5: *Example of single-point-of-contact thermocouple junctions.*

To form the thermocouple junction, place the two thermocouple wires together in a single point of contact, and press then in between the plate and the gun of the electrical welding tool (see *Figure 6*). Do not forget to wear protective goggles, and do not touch the metallic elements of the tool when welding. Regulate the intensity of the current of the welding tool to not destroy the thermocouple wire. Cut the remaining thermocouple wires that extend from the single-point junction after the welding has been performed.

Figure 6: *Welding a thermocouple as a single-point-of-contact junction with an electrical welding tool.*

2.4 Mounting simple exposed assembly of thick type-K thermocouples

Thick type-K thermocouples are much more robust than thin thermocouples. They can be used in environments with high risks of mechanical damage such as in fluid with debris or under outdoor conditions. The thick thermocouple wires are much thicker and are therefore not easy to twist to form a tight measurement junction like for thin thermocouples. It is therefore recommended to use pressure connectors (crimping junction) for connecting the positive and negative wire of the thermocouple (see *Figure 7*). Thick thermocouples have larger thermal inertia than thin thermocouples and have therefore a larger sensor time constant. Similarly to the previous section, the instructions presented hereafter are describing the assembly of a simple exposed assembly of a thick thermocouple, which might be more sensitive to electrical interference (especially if in direct contact with metallic elements) and corrosion. If the thermocouple measuring junction has to be protected, read the section "Alternative robust assembly options for type K thermocouples".

Figure 7: *Pressure connectors (crimping junction) for assembling thick type-K thermocouples.*

To form the sensing/measurement junction of a thick type-K thermocouple, remove the plastic insulation of the 2 wires on about 1 cm (see *Figure 8 (a)*) and place the 2 wires inside the pressure connector (see *Figure 8 (b)*). Adjust the position of the wires so that the plastic insulation goes into contact with the pressure connector.

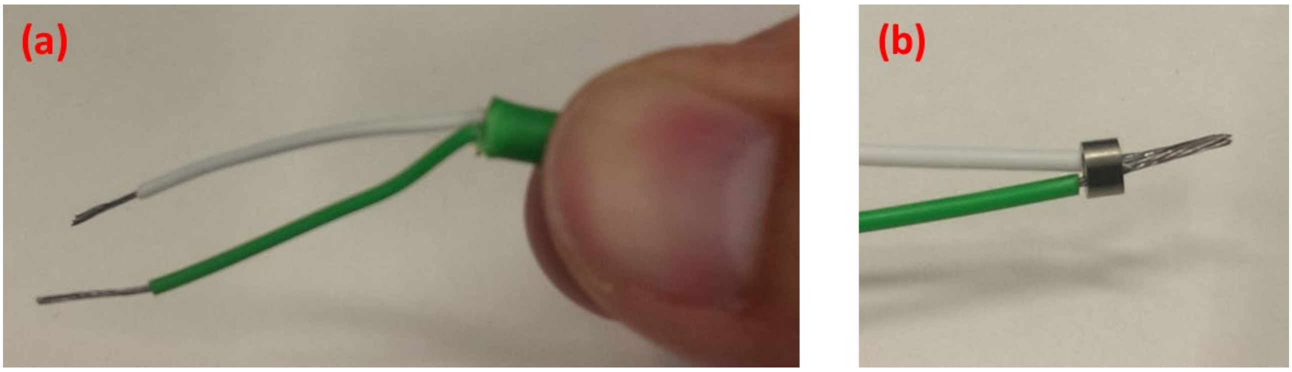

Figure 8: ***(a)*** *remove plastic insulation;* ***(b)*** *place the pressure connector.*

Use a dedicated plier (crimping tool) (see *Figure 9*) to press the pressure connector and lock it on the thermocouple wires (see *Figure 10*).

Figure 9: *Crimping tool for type-K thermocouple pressure connectors.*

Figure 10: *Pressing the pressure connector on the type-K thermocouple to form the sensing/measurement junction.*

Cut the wires on the other side of the pressure connector as short as possible so that they cannot touch each other and so that no dirt or debris can get stuck into it (see *Figure 11*).

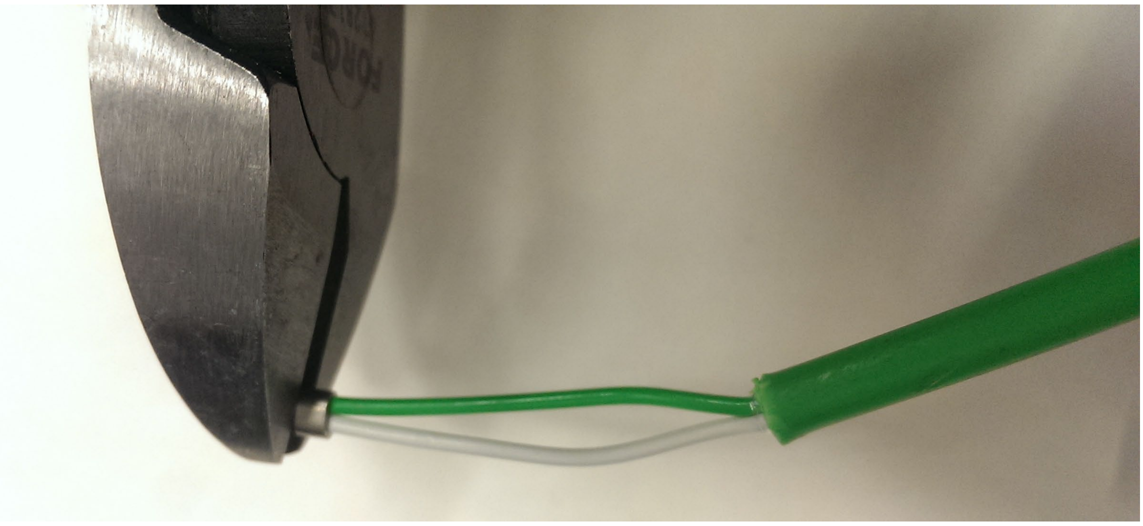

Figure 11: *Cutting the remaining thermocouple wires on the other side of the pressure connector.*

The thermocouple sensing/measurement junction is formed and ready to be used (see *Figure 12* and *Figure 13*).

Figure 12: *A formed sensing/measurement junction on a type-K thick thermocouple.*

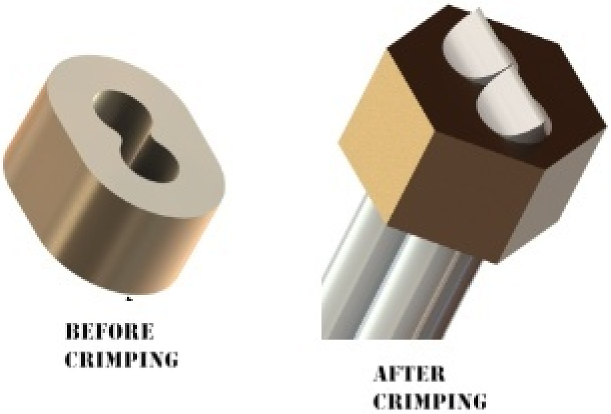

Figure 13: *A formed sensing/measurement junction on a type-K thick thermocouple.*

Remarks: for accurate air temperature measurements, it is recommended to use **silver-coated** pressure connectors (especially for air measurement in environments subjected to direct solar radiations or with a high-temperature gradient between surrounding surfaces and air).

2.5 Alternative robust assembly options for type K thermocouples

For some applications, the thermocouple might be subjected to electrical interference, aggressive physical wear or mechanical damage: metal-metal contact, shocks, friction, vibration, corrosion, fluid with debris, etc. It might therefore be interesting to protect the sensing junction of the thermocouple with one of the following robust assembly options.

2.5.1 Exposed welded/bead junction

A cheap alternative to twisting wires of thin thermocouples whilst insuring low sensor time constant and higher mechanical resistance and durability is to weld the junction of the thermocouple (see *Figure 14*). The welding can be done manually by forming the bead junction with an additional metal alloy (brazing). However, with the latter, the temperature limitation for usage of the thermocouple is dictated by the low temperature of fusion of the brazing metals (for example, tin with fusion temperature of 231.9 °C) which is much lower than the utilization temperature range of type-K thermocouples (-270 °C to 1370 °C). It is therefore recommended to use dedicated equipment to perform butt welded thermocouple measurement junction by resistance welding or by arc welding method [3].

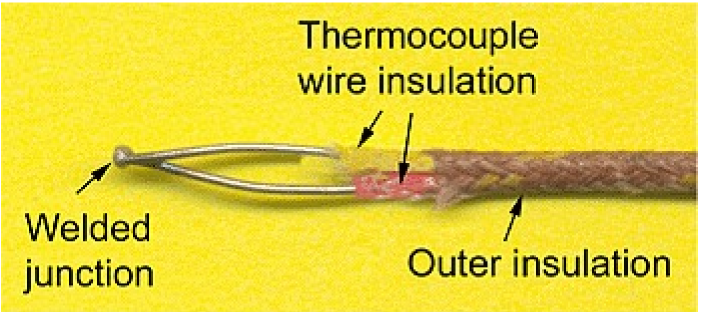

Figure 14: *Example of welded/bead junction for a thermocouple [4].*

2.5.2 Ungrounded sheath-protected junction

Sheath covered probes are used where the thermocouple wire must be protected. Here, the wires are embedded in ceramic insulation, with a stainless steel or nickel alloy sheath enclosing the assembly. The sensing/measurement junction of the thermocouple is placed at the tip of the protective sheath. The tip of the sheath is filled with highly-conductive thermal paste to ensure good thermal contact between the thermocouple junction and the surface of the sheath (and thus minimize the sensor's time constant). In that configuration, there is no direct contact in between the thermocouple junction and the metallic tip of the protective sheath. This configuration is denominated "ungrounded sheath-protected junction" (see *Figure 15*).

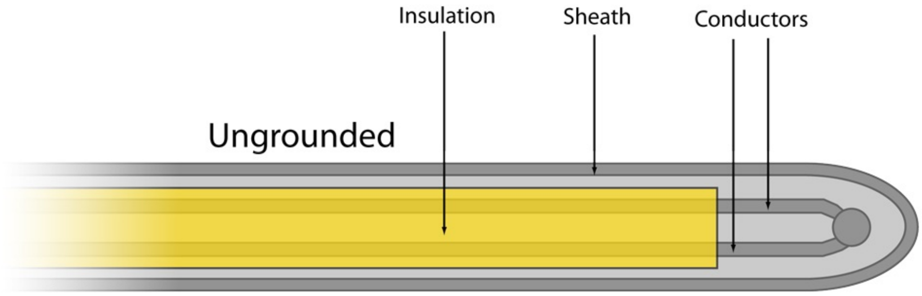

Figure 15: *Ungrounded sheath-protected junction.*

Ungrounded sheath-protected junction makes the thermocouple junction to be electrically isolated from the surrounding environment. The selection of sheath material depends on the thermocouple operating temperature and atmospheric environment. In addition, the ceramic insulator must survive the upper temperature limit. The protection sheath increases significantly the time constant of the sensor compared to exposed thermocouple junction. However, it is much more durable and resistant.

Make sure that the junction between the protective sheath and the sensor's cable is tightly sealed with adequate sealing tape or thermo-shrinking rings (see *Figure 16*).

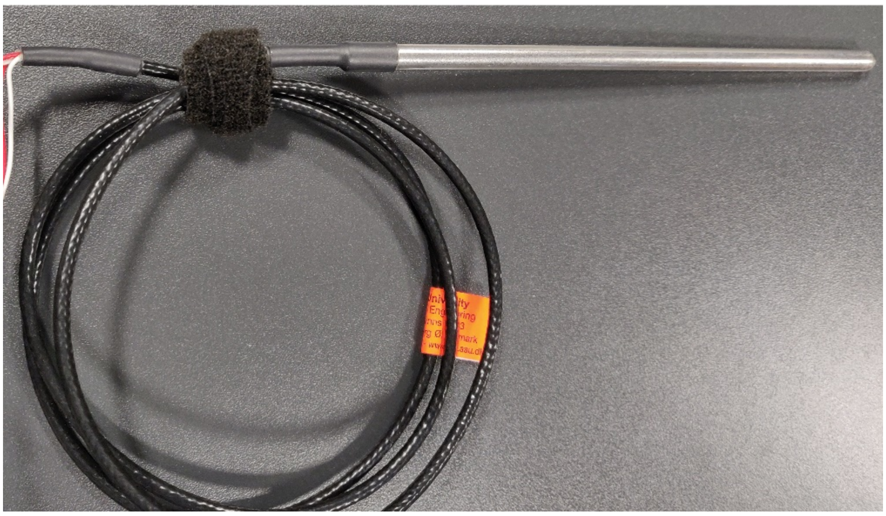

Figure 16: *Well-sealed temperature sensor inserted in a protective sheath.*

2.5.3 Grounded sheath-protected junction

To obtain a faster sensor response time (smaller time constant) and benefit from the protection of a protective sheath, the thermocouple can be welded to the inner surface of the metallic protective sheath (see *Figure 17*). The thermocouple junction is thus exactly at the tip of the metallic sheath, in between the two welded junction of the thermocouple inside the sheath.

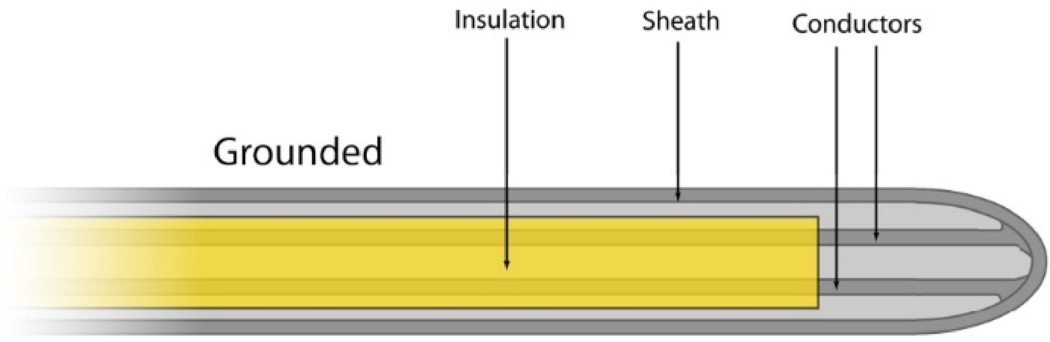

Figure 17: *Grounded sheath-protected junction.*

2.6 Connecting type-K thermocouples to measurement module

The connection of a thermocouple to a dedicated measurement module is fairly simple and straightforward. Simply connect the negative wire of the thermocouple to the negative pin of the measurement module, and the positive wire of the thermocouple to the positive pin of the measurement module. To determine which thermocouple wire is positive and which is negative, look at the colour code in *Figure 18*.

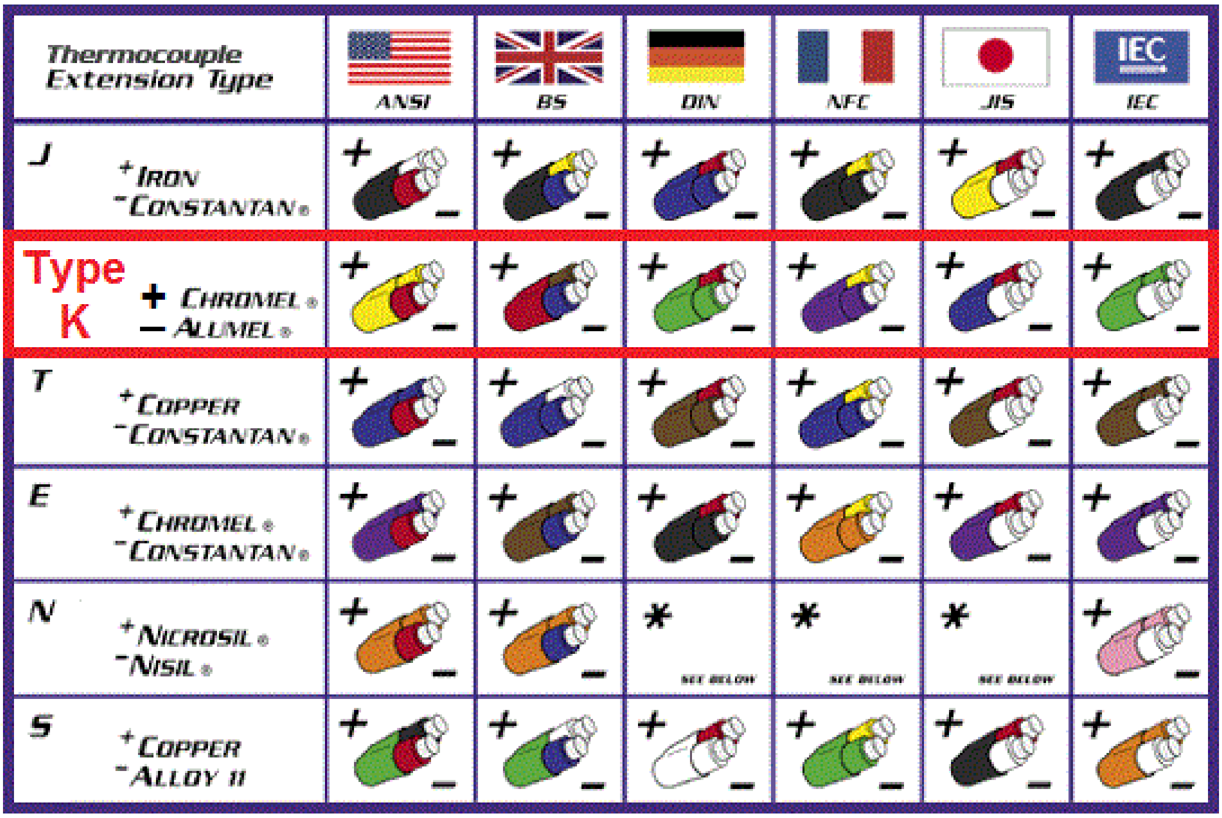

Figure 18: *Thermocouple colour code to find + positive (high) and – negative (low) wires.*

One can see in *Figure 19* the example of a screw terminal on which negative and positive thermocouple wires can be directly connected. One should note on that example that the connected wires are not well attached, which can cause short-circuits. One should be very careful and tidy up the wire connections inside the screw terminal. If the thermocouple has a shielding sheath around its cable, it should be connected to the ground screw terminal.

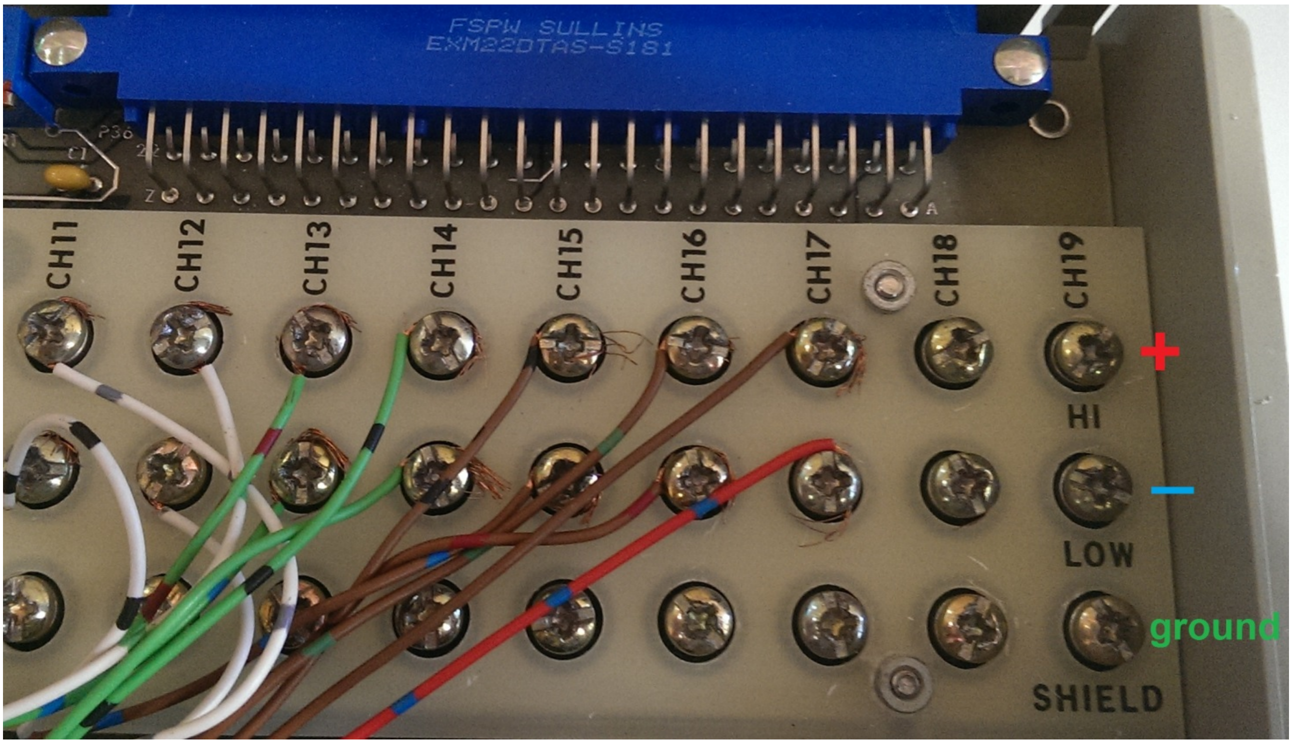

Figure 19: *Screw terminal of a Fluke Helios multi-channel voltmeter.*

Some measurement module have specific pin connector sockets for the connection of the thermocouples. The adequate connector pin should be chosen: type-K Chromel / Alumel connector (see *Figure 20*).

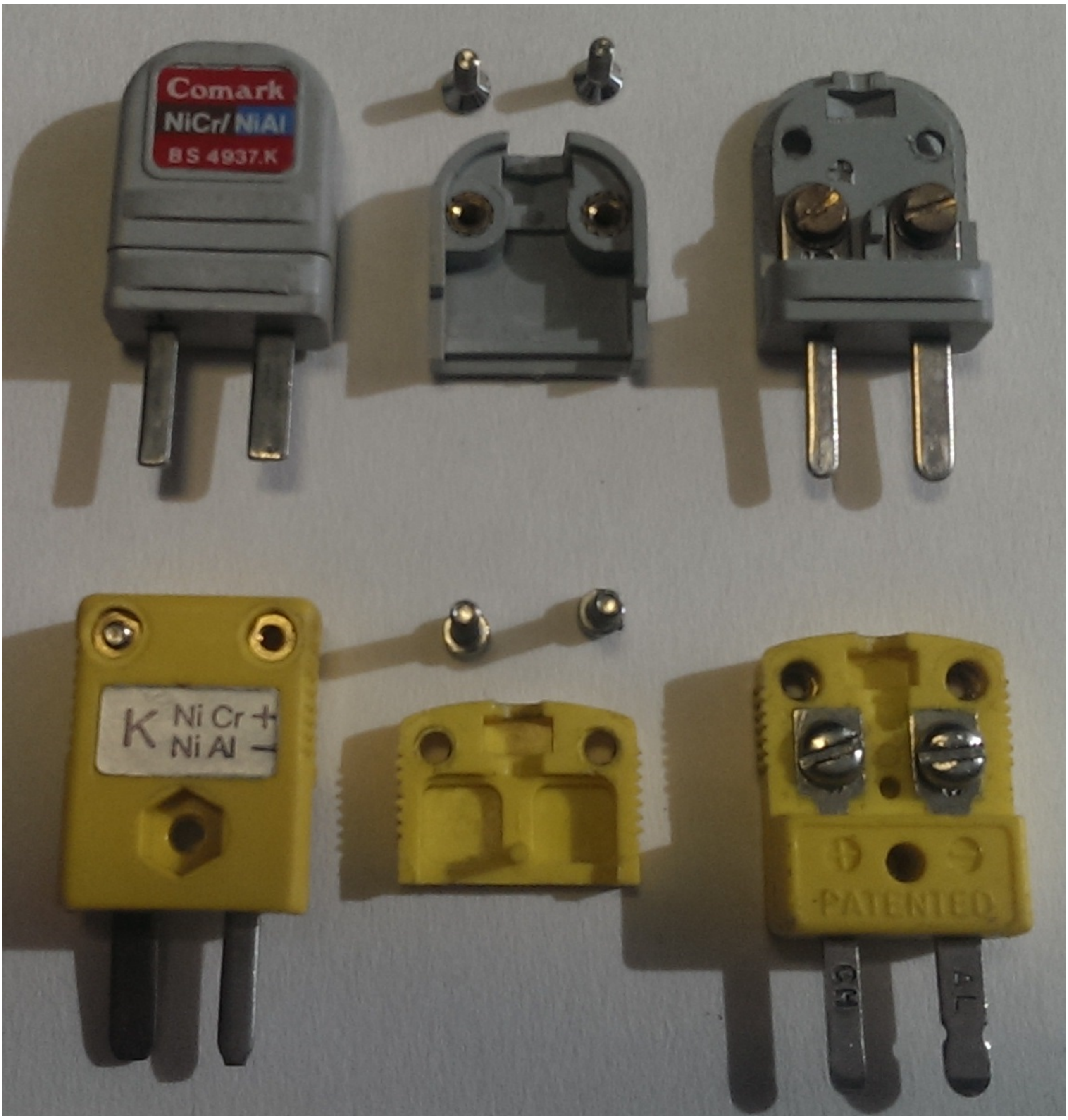

Figure 20: *Flat pin connectors for type K thermocouples.*

3. Resistance temperature detectors RTDs: 4-wire Pt100

3.1 Introduction

Resistance temperature detectors (RTDs) are temperature sensors that are commonly used to measure temperature in many applications, including building systems. RTDs have an electrical resistance that varies as a function of their temperature. Therefore, the measurement of their electrical resistance enables us to know the temperature they are exposed to. One of the most common RTD in use is the Pt 100. “Pt 100” means that the RTD sensor is made of platinum and its electrical resistance is 100 Ohms at 0 °C. Platinum is used because it is a noble and stable metal and has the most stable resistance–temperature relationship over the largest temperature range. Pt 100 RTDs are therefore very stable over time, with a very linear (and monotonic) correlation between their electrical resistance and the measured temperature. Since Pt 100 are very accurate, precise and stable temperature sensors (better than most thermocouples in these regards), they are widely used in applications below 600 °C.

Pt 100 RTDs can be mounted with 3 different configurations: 2-wire, 3-wire and 4-wire configuration. The 4-wire configuration is the most accurate and precise one. Therefore, this guideline only concerns 4-wire configurations (see *Figure 21*). For more details on the different RTD configurations, read [5].

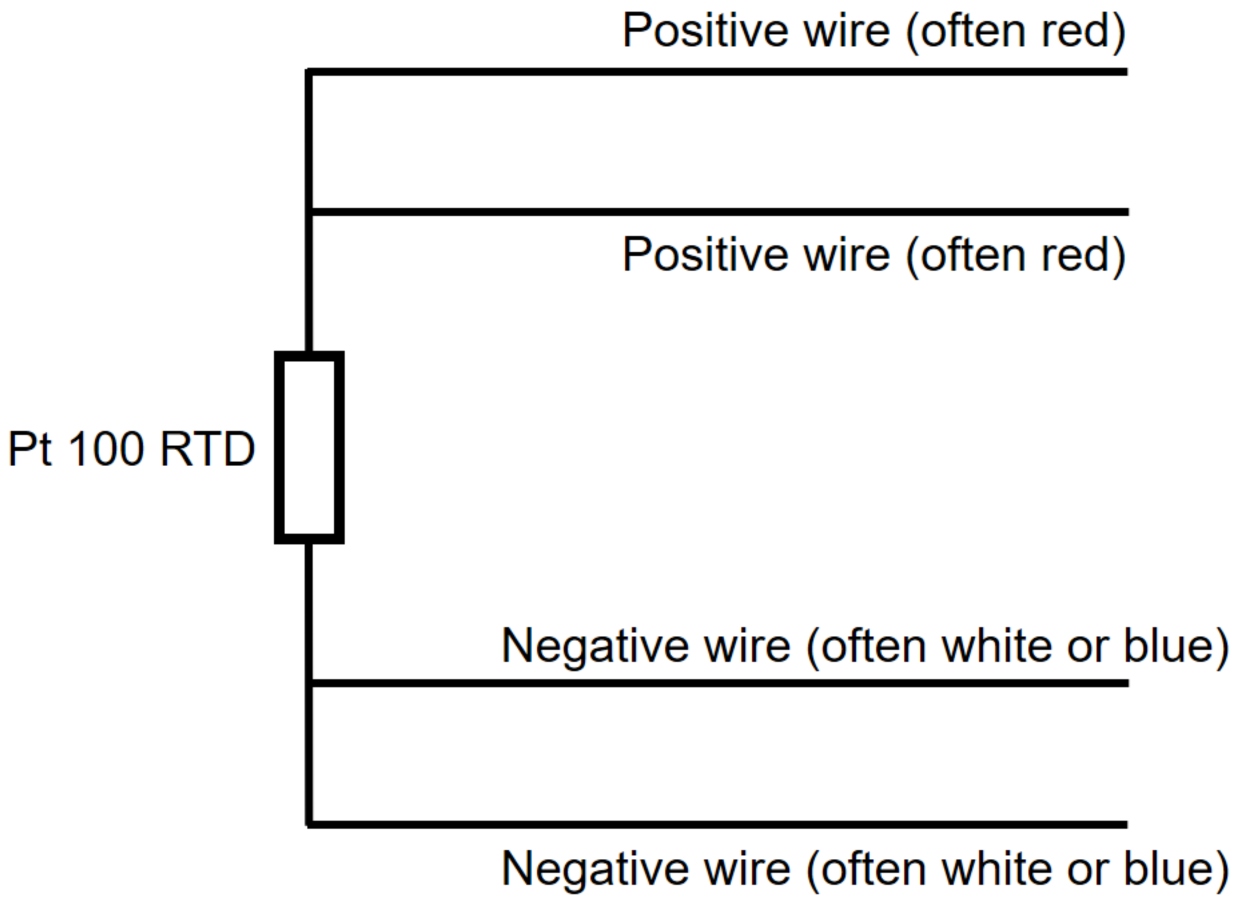

Figure 21: *4-wire Pt 100 RTD configuration.*

3.2 Mounting Pt 100 RTD

Pt 100 RTD can be bought already mounted inside a protective sheath and with cables (see *Figure 22*). Those Pt 100 RDTs are ready to be used. The wires can be shortened or extended if needed.

Figure 22: *Ready-to-use Pt 100 RTD.*

However, ready-to-use Pt 100 RTDs in protective sheath are expensive and might be too large and with a too long time constant for a given application. The Pt 100 element itself can be bought separately (see *Figure 23*) and be assembled manually. The instruction to assemble such Pt 100 elements can be found hereafter.

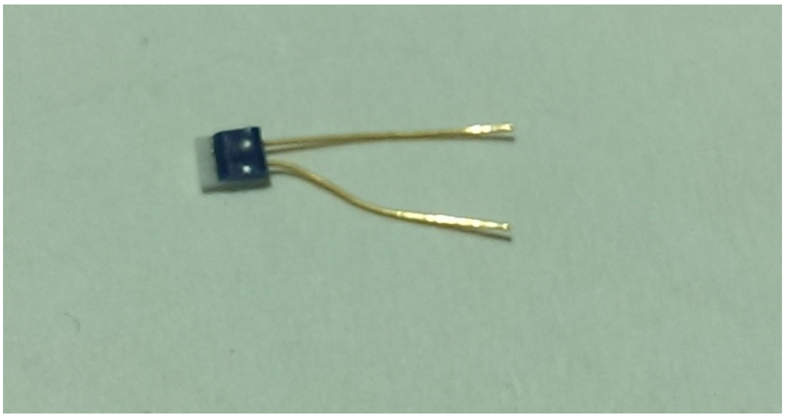

Figure 23: *A thin film Pt 100 RTD.*

Select a 4-wire electrical cable with internal wires that are rather thin. Cut it to the desired length. Remove the insulation plastic layer of the cable and the wires on about 8 cm on one side (long side) (see *Figure 24*) and on about 6 cm on the other side (short side) (see *Figure 25*).

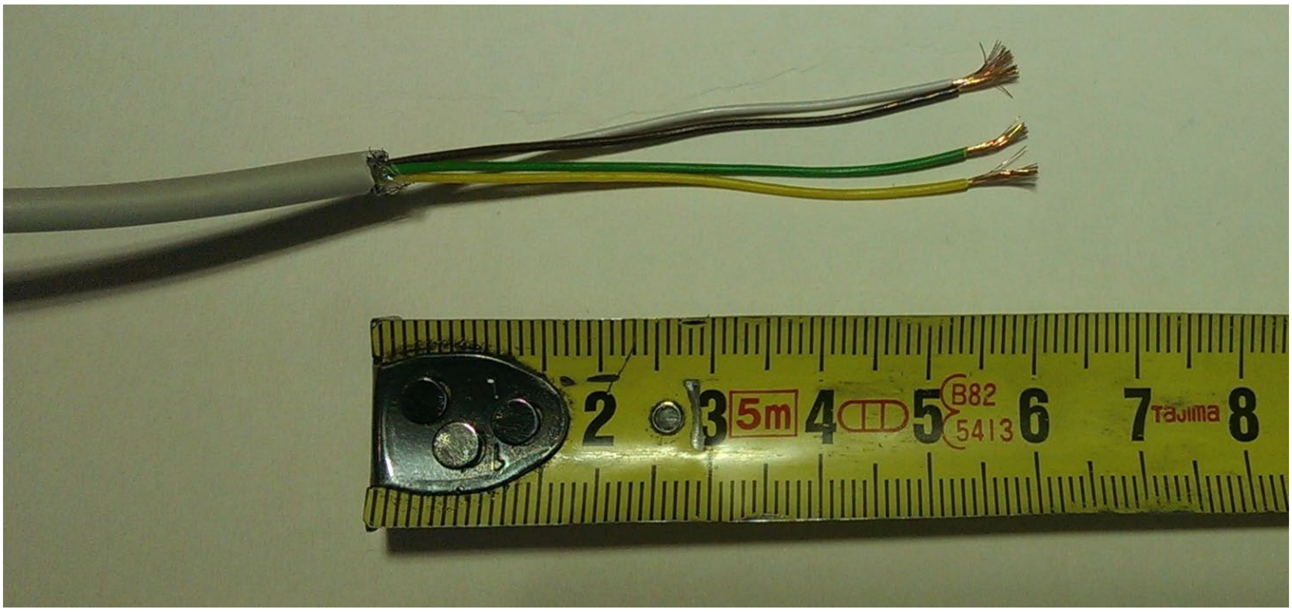

Figure 24: *Remove insulation plastic layer of the cable and wires inside it.*

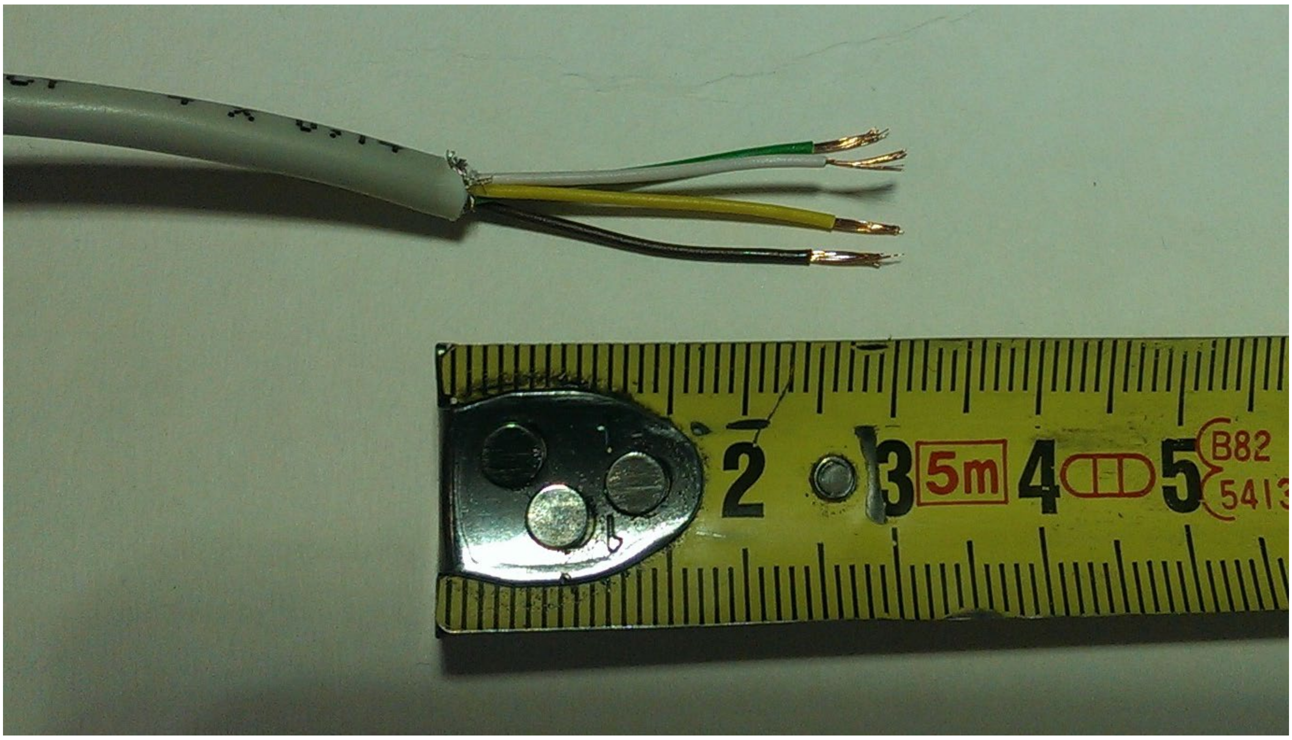

Figure 25: *Remove insulation plastic layer of the cable and wires inside it.*

The short side is used to attach the Pt 100 sensor. The short side is used to be connected to the measurement module. Choose 2 wires (colours) to be the positive wires of the sensor. Connect them together (twist the copper wires) and place a red thermo-shrinking ring (see *Figure 26*) on the insulation layer (see *Figure 27*). Take the 2 other wires to be the negative wires of the sensor. Connect them together (twist the copper wires) and place a blue thermo-shrinking ring on the insulation layer (see *Figure 27*).

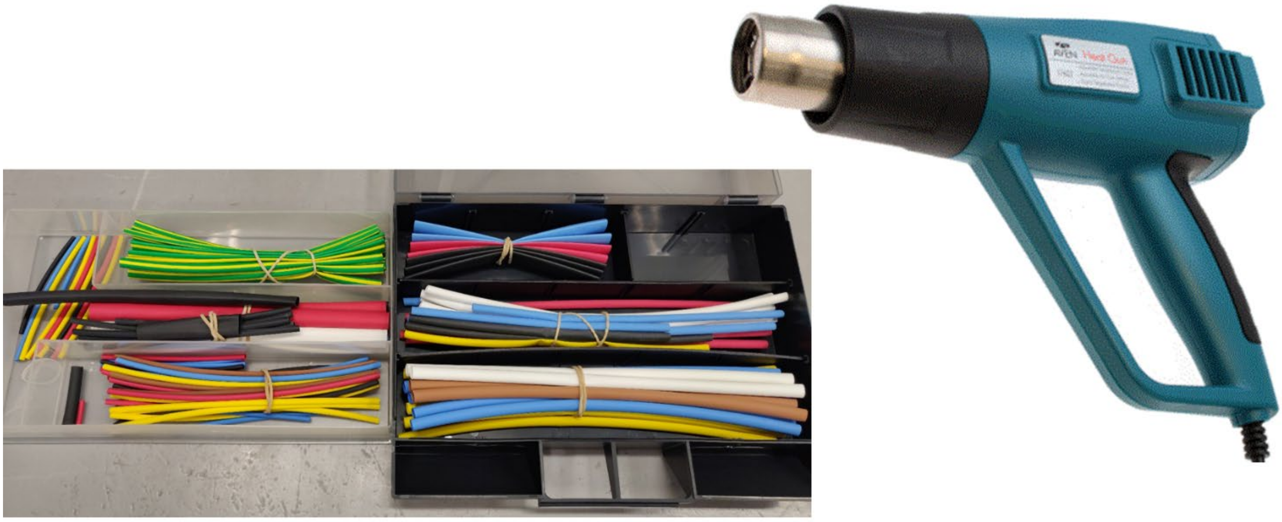

Figure 26: *Colored thermo-shrinking ring (left) and heat gun to shrink the rings (right).*

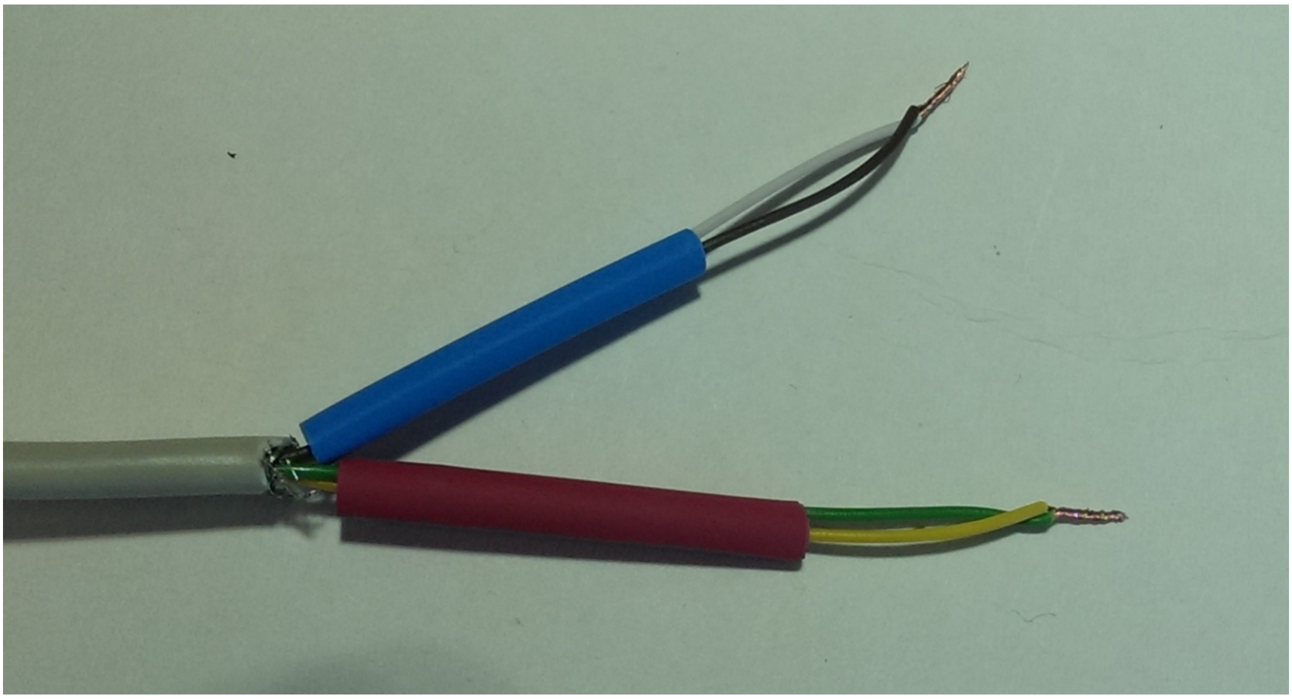

Figure 27: *Short side connected to the measurement module.*

Add a larger thermo-shrinking ring to make the junction between the cable insulation and the red and blue thermo-shrinking rings. Crimp the wire ends with appropriate crimping heads and tools (see *Figure 28*).

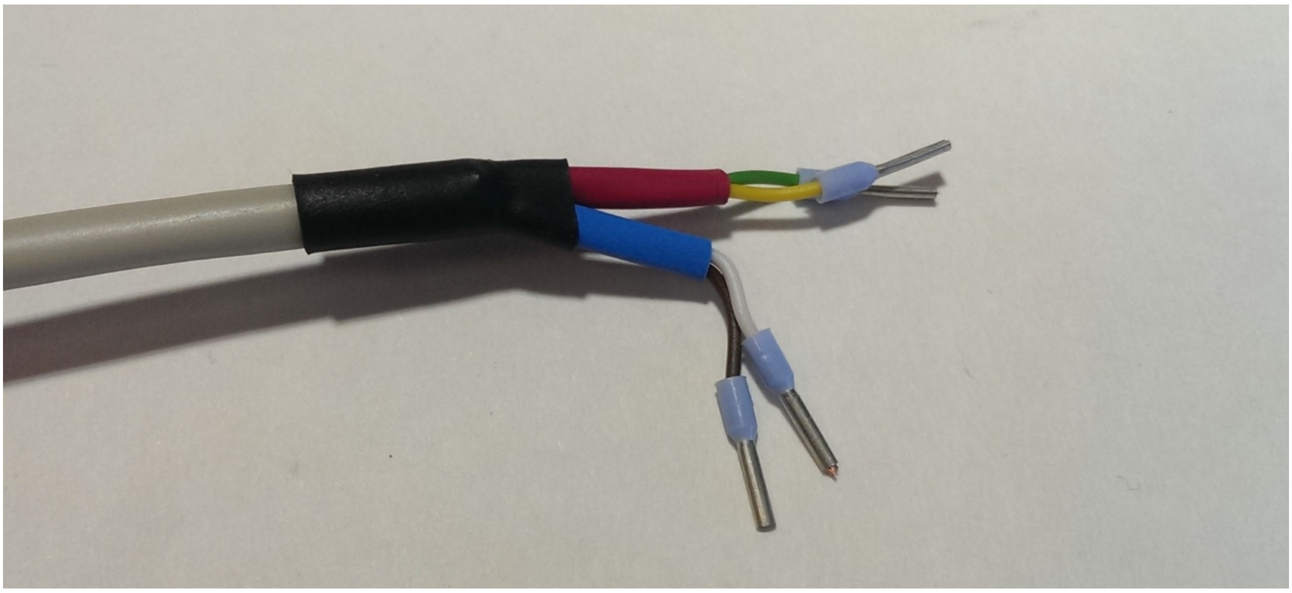

Figure 28: *Assembled short side to be connected to the measurement module.*

On the long side (where the Pt 100 sensor will be mounted), connect the 2 positive wires (make sure that the colours of the long side match the colours of positive and negative wires on the short side) and solder them with tin (see *Figure 29*). Be careful when soldering: use a proper soldering iron with protective goggles and ventilation exhaust. It is recommended to fix the wires on a vice (or third hand) for easier soldering. Once the connection is made, place a red thermo-shrinking ring around the 2 positive wires but **DO NOT** heat it up. The ring will be shrunk later (see *Figure 29*).

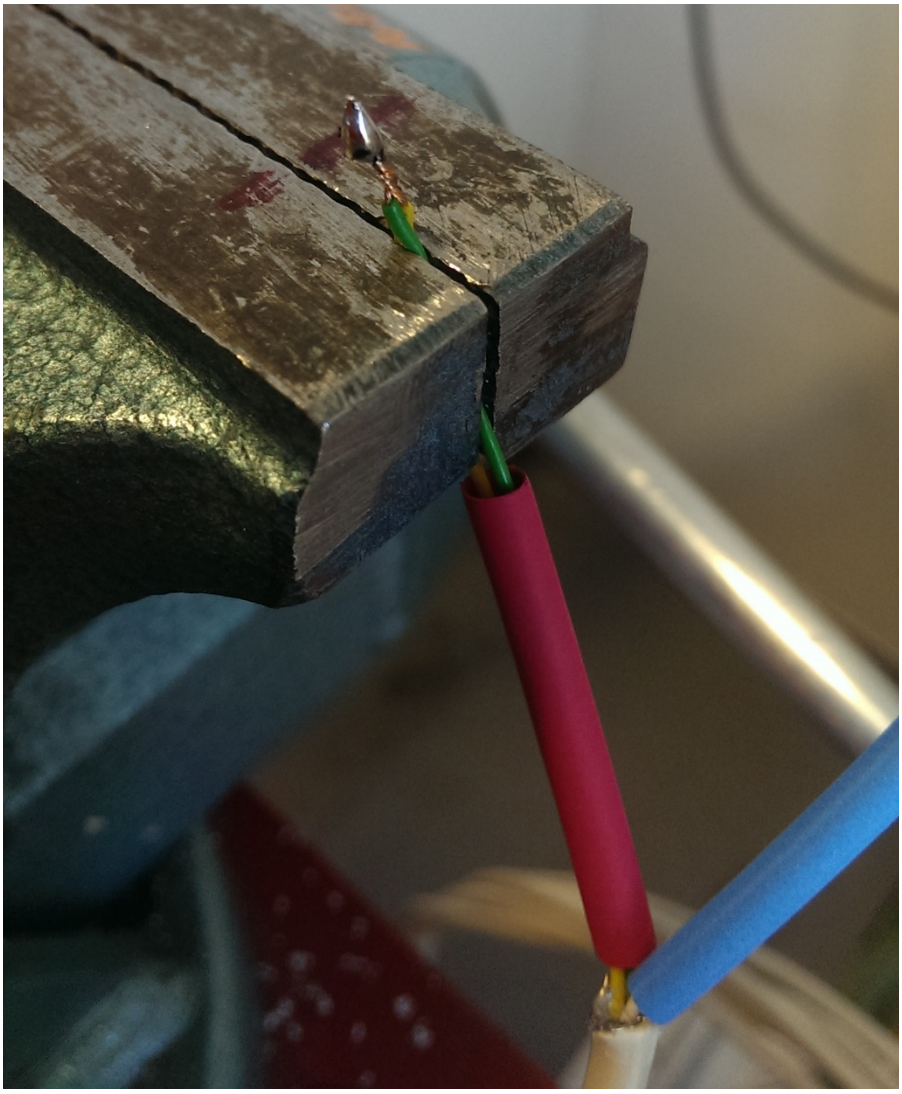

Figure 29: *Long side connection made on a vice (third hand).*

Perform the same procedure with the negative wires with a blue thermo-shrinking ring.

It is now time to solder the Pt 100 component on the wires. The Pt 100 element does not have polarity, meaning that any leg can be chosen as the positive of the negative pin. In order to protect the Pt 100 from the high temperature of the soldering iron, the soldering iron should not be in contact with the Pt 100. Melt the tin that is deposited on the wire first, and then insert the leg of the Pt 100. Hold the Pt 100 leg to be inserted with a thick plier (see *Figure 30*) so that the later act as a heat sink to protect the Pt 100.

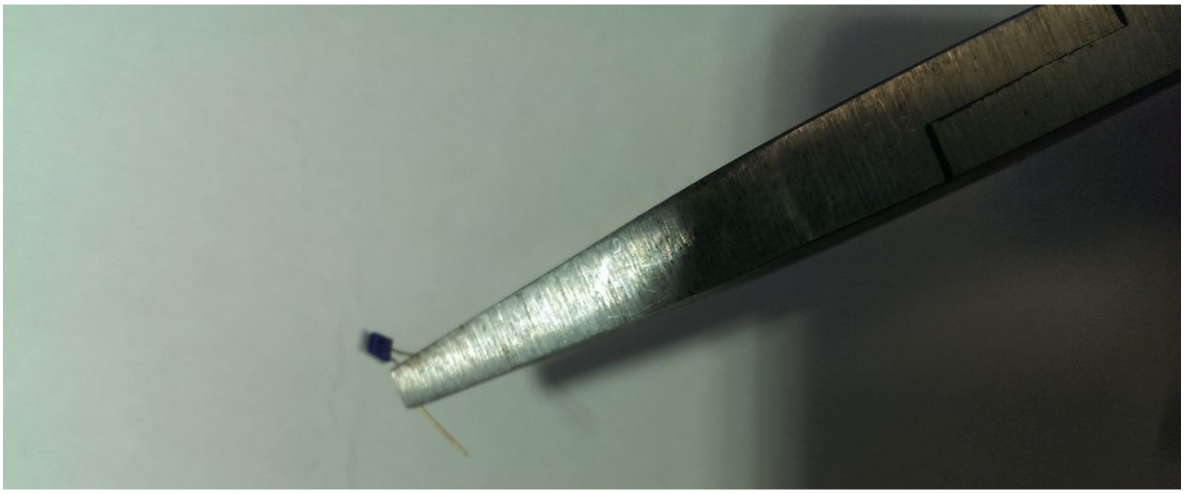

Figure 30: *Holding the leg of the Pt 100 that will be connected to the long side wire. The leg that is inserted (in contact with molten tin) is the one held by the plier and not the other one.*

Once the first Pt 100 leg has been inserted into the tin for connecting to the wire (see *Figure 31*), slide the thermo-shrinking ring on the leg of the Pt 100 sensor to cover the soldering connection and the leg of the sensor (see *Figure 32*) and heat it up to shrink the ring tight.

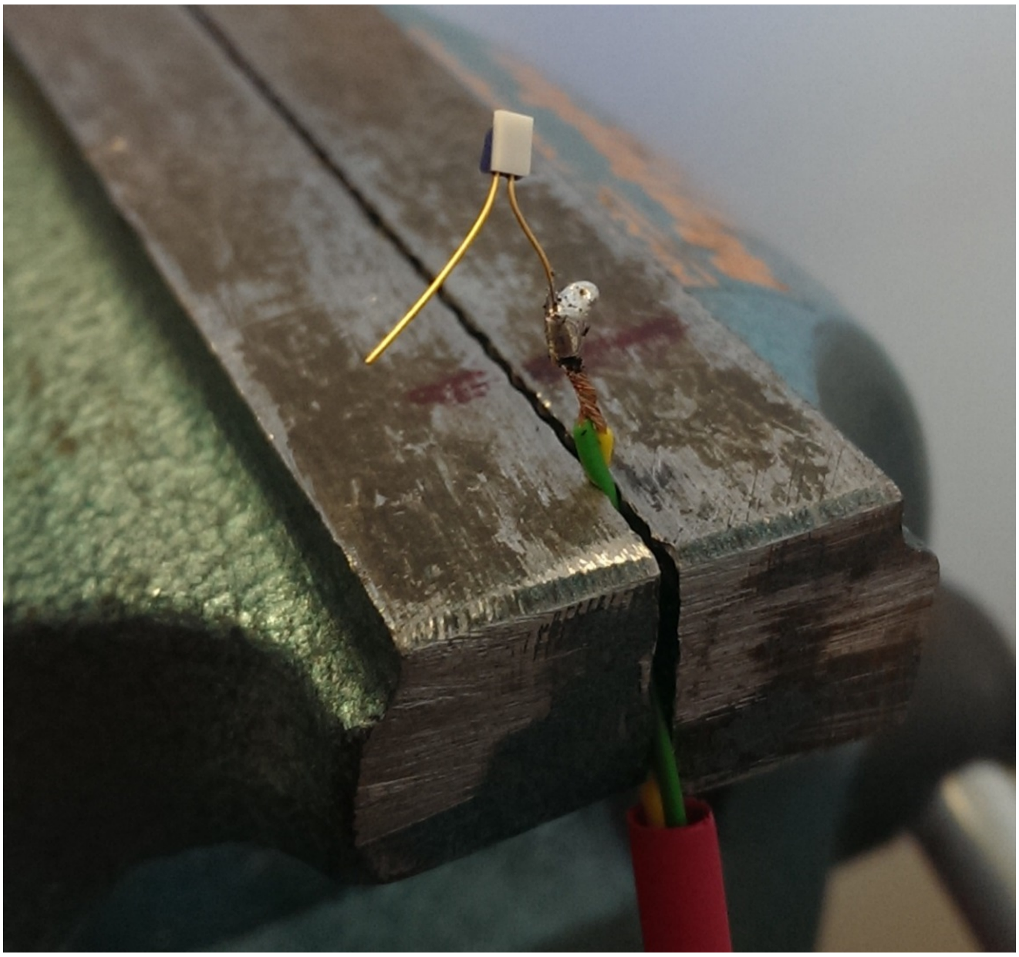

Figure 31: *Positive leg of the Pt 100 element connected (soldering) on the positive wires.*

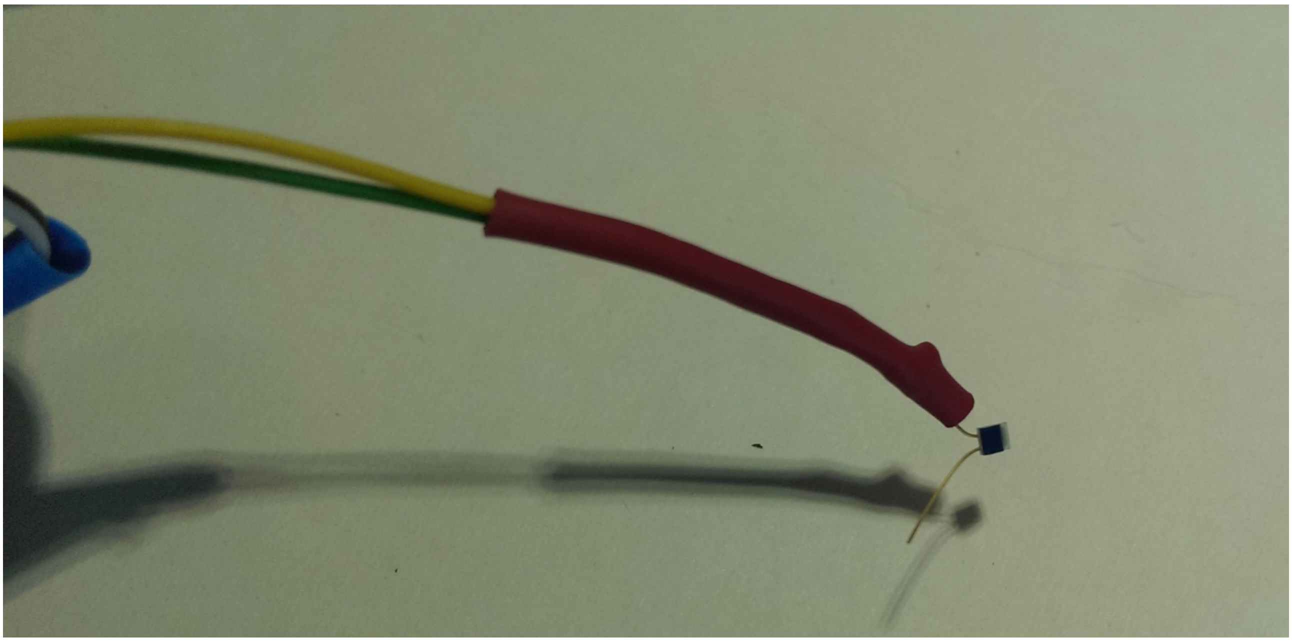

Figure 32: *Thermo-shrinking ring tightened onto the sensor's soldering connection.*

Repeat the same operation with the other leg on the other wire connection. Slide the second thermos-shrinking ring all the way to the top of the Pt 100 leg to ensure that no short-circuit can occur in between the 2 legs of the sensor. Add a larger thermos-shrinking ring to cover the connection between the red and blue rings and the plastic insulation of the cable (see *Figure 33*). The Pt 100 RTD is assembled and ready to be used for measurement.

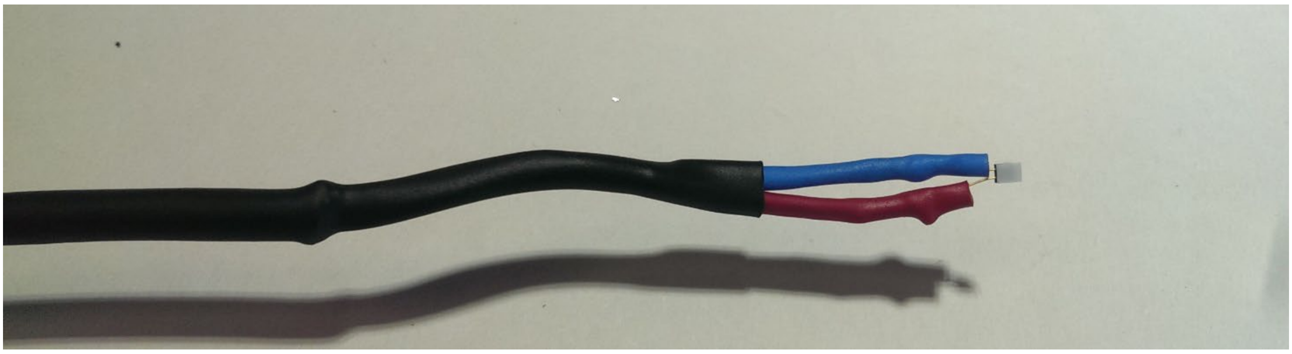

Figure 33: *Completed Pt 100 RTD connection on the long side.*

3.3 Protecting Pt 100 RTD (optional)

To protect further the Pt 100 assembly, glue can be applied on the sensor's legs and directly on the sensor. It should be noted that glue on the sensor will increase the time constant of the Pt 100 sensor (see *Figure 34*).

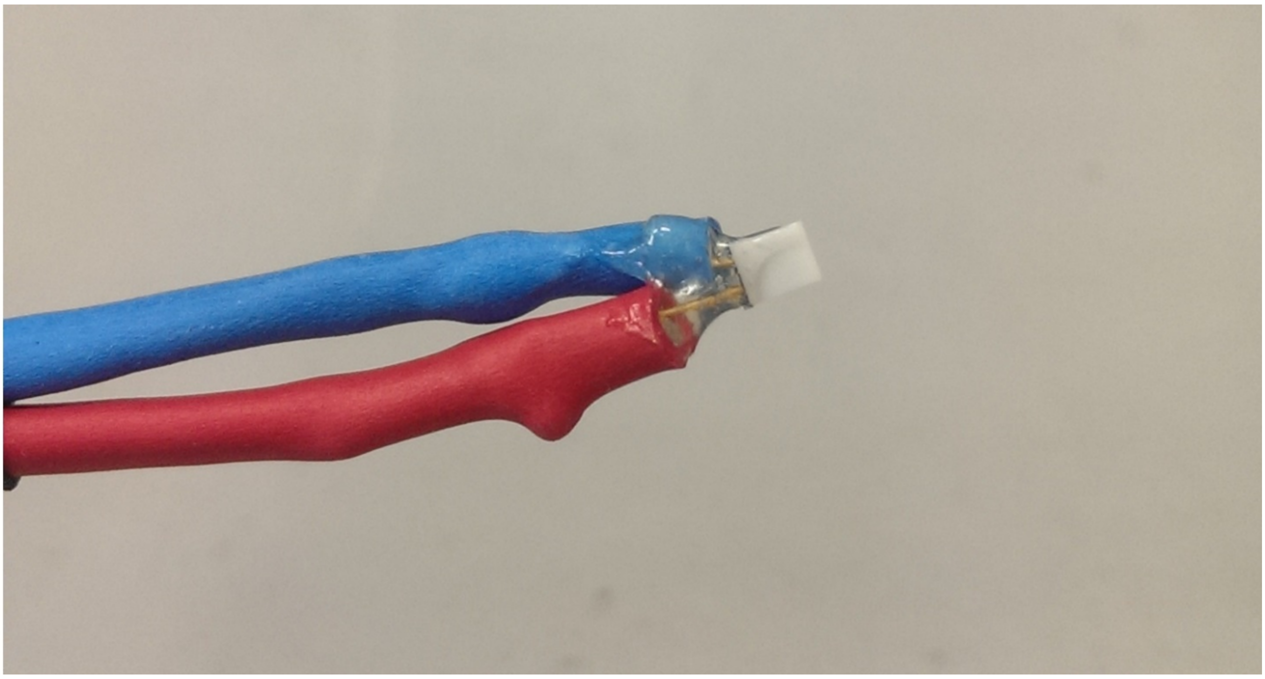

Figure 34: *Glue to protect a Pt 100 assembly.*

The Pt 100 assembly can also be protected with a protective sheath. Make sure that the sheath containing the Pt 100 element is filled with thermal paste to ensure good thermal conductivity and lower time constant. Also seal the sheath tightly (see *Figure 35*).

Figure 35: *Sealed Pt 100 RTD with protective sheath.*

3.4 Connecting Pt 100 RTD to measurement module

Connection of a 4-wire Pt 100 RTD to a dedicated measurement module is fairly simple. Connect one of the positive wires (red) to the RTD+ pin of the measurement module. Connect the other positive wire (red) to the positive excitation pin of the module. Connect one of the negative wire (blue) to the RTD- pin of the measurement module. Connect the other negative wire (blue) to the negative (COM) excitation pin of the module (see *Figure 36* and *Figure 37*). If in doubt of the pinouts, read the documentation of the measurement module.

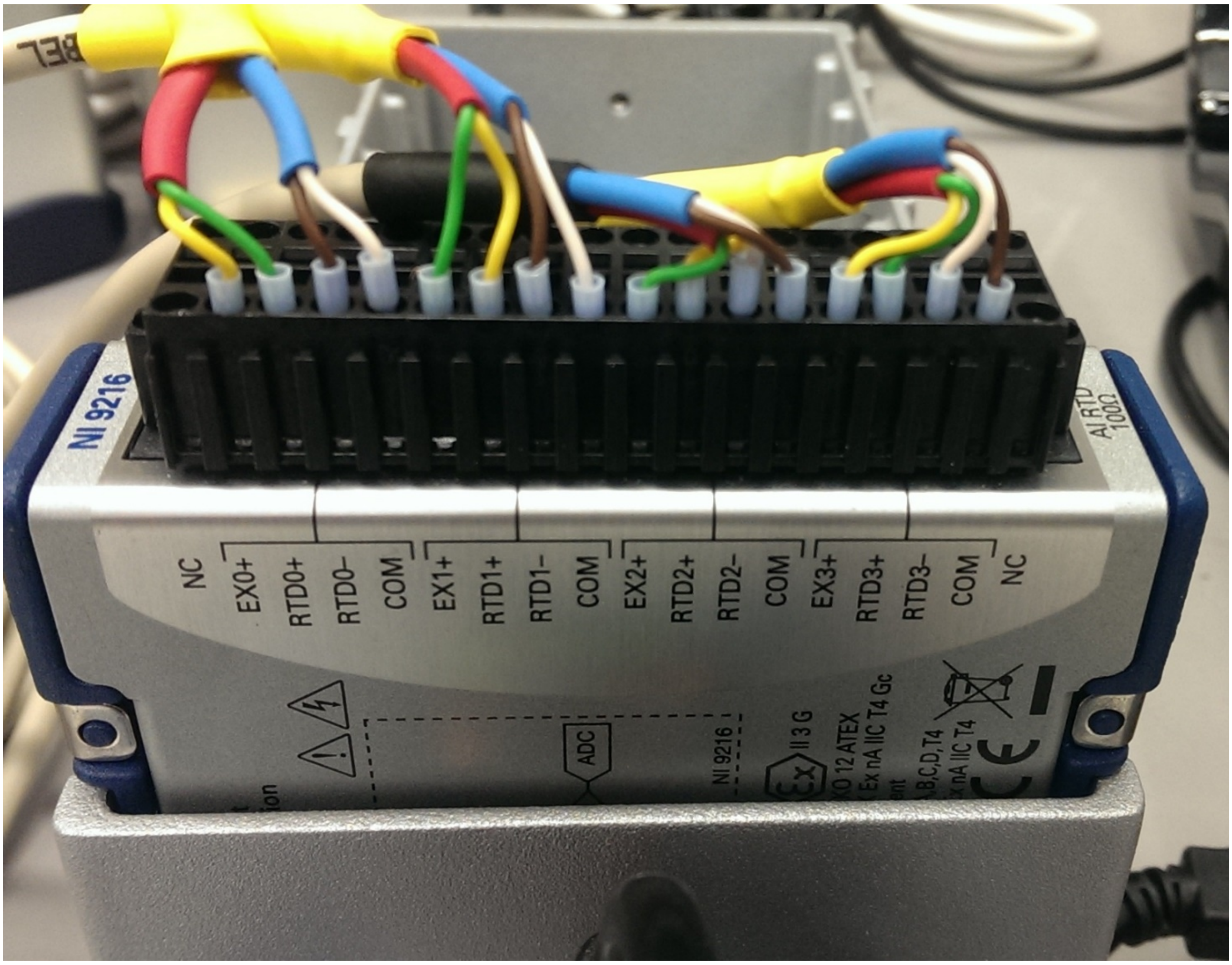

Figure 36: *Example of 4-wire Pt 100 RTDs connected to a measurement module (NI 9216 from National Instruments).*

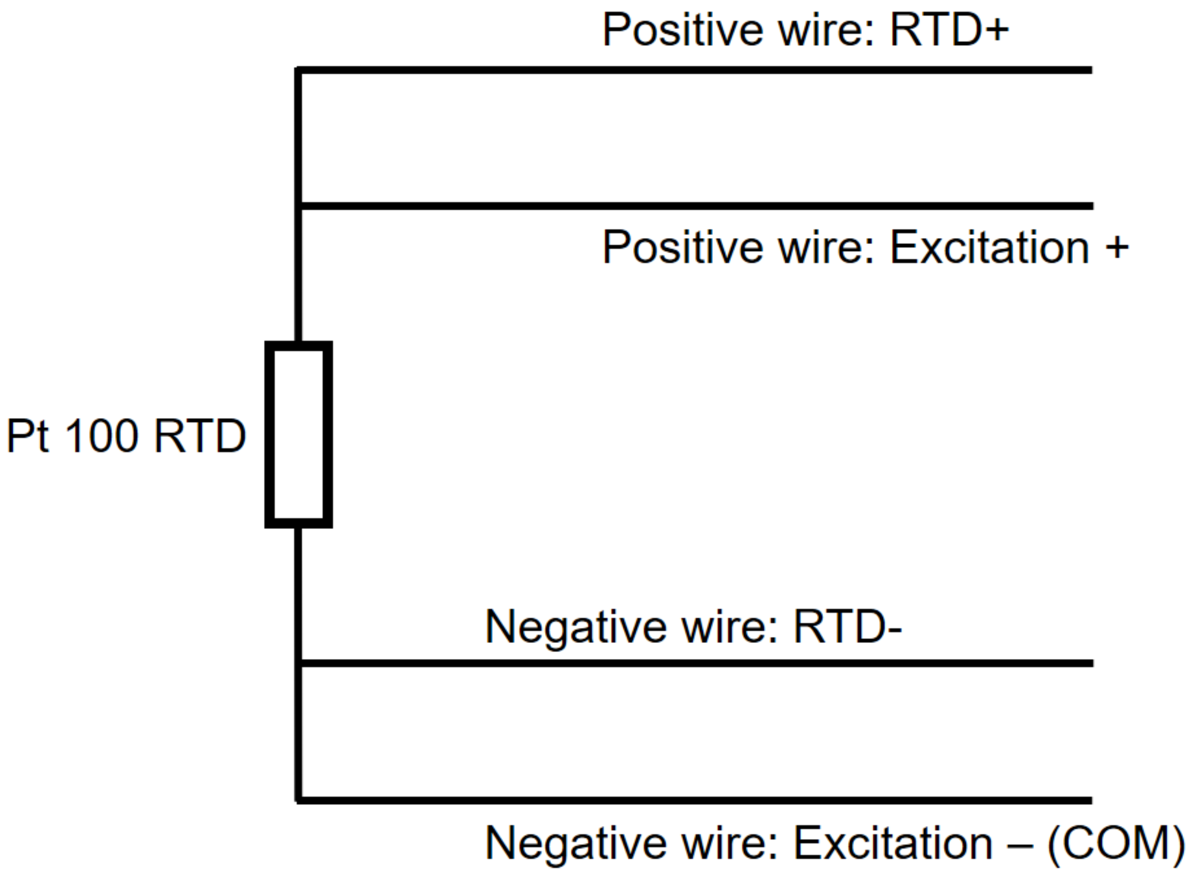

Figure 37: *Connection of a 4-wire Pt 100 RTD to a dedicated measurement module.*

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