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# A CALIBRATION FACILITY FOR AUTOMATIC WEATHER STATIONS

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## Abstract

The environment monitoring by automatic weather stations (AWSs) is growing as a result of the increasing number and reliability of surface observations. In order to ensure data traceability and to obtain more comprehensive data on the performance of AWSs, a new transportable calibration facility was manufactured at the Italian Institute of Metrology (INRiM) in the framework of the project MeteoMet. The facility is equipped with temperature and pressure reference sensors directly traceable to International System of Units (SI) to obtain meteorological data with well documented calibration uncertainty.

In this calibration system, temperature and pressure can be controlled simultaneously and independently so that all combinations over the ranges are possible. The nominal ranges are: absolute pressure 50 kPa to 110 kPa, temperature -25 °C to 50 °C. The availability of a large range of atmospheric variability and the possibility to study the mutual influence effects on sensors response are important characteristics of the facility.

This apparatus is designed also to permit a control in humidity, in order to complete the characterization of the whole AWS pressure-temperature-humidity modulus. As a matter of fact, the final version of the facility will be equipped with a humidity generator for hygrometers calibrations.

Finally, the calibration system was designed to be transportable, therefore allowing the calibration of AWSs located at sites that are difficult to access as Ny-Ålesund (Svalbard) stations, where the facility was employed.

The design and the technical characteristics are reported in this work.

**Key words:** automatic weather stations calibration, calibration chamber, pressure, simultaneous calibration of pressure and temperature, temperature, thermometers calibration in air, traceability for meteorological observations, uncertainty.

## 1. Introduction

The growing number of data recorded by AWSs as replacement for conventional observation instruments requires assurance of reliability and quality for this kind of measurements. The metrological traceability to SI through national standards is a milestone to address this objective. In order to provide data with good accuracy it is important to define a standard calibration procedure to be carried out in chambers that keep measured quantities both stable during the calibration period at each measuring point and uniform in the calibration volume around the sensors (Lopardo *et al.*, 2012). Currently, AWS sensors of pressure, temperature and humidity are usually calibrated separately (Saxholm *et al.*, 2010). This kind of

calibration procedure implies that mutual influences, e.g. the possible temperature related behavior of the pressure sensor, cannot be detected.

A new transportable calibration system, named EDIE1 (Earth Dynamics Investigation Experiment), capable of simultaneous and independent control of pressure and temperature, was developed at INRiM. The system is composed by a test chamber, an external thermostat (PolyScience PD07R-40-A12E), pressure (Druck DPI 740) and temperature sensors (100  $\Omega$  Platinum Resistance Thermometers (Pt100)), a vacuum pump and a pressure regulator pump. The system diagram is illustrated in Figure 1.

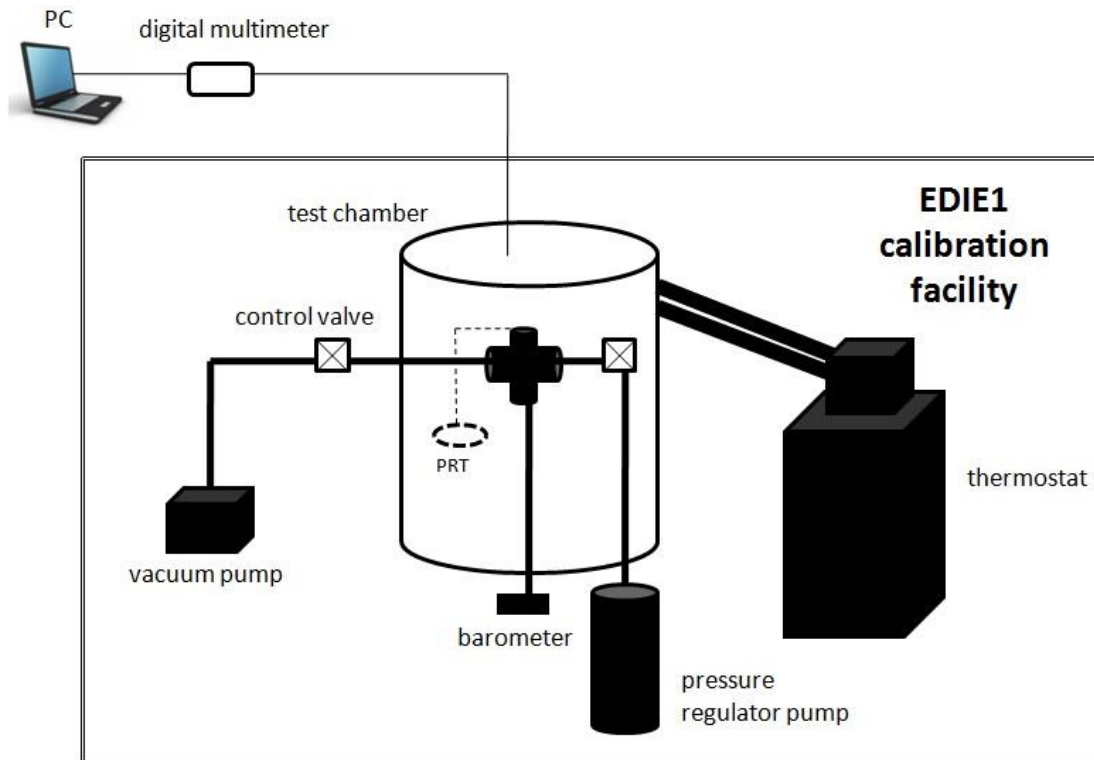


Figure 1: The system diagram of the EDIE1 calibration chamber and acquisition system (digital multimeter and PC).

This apparatus is designed to allow also the control in humidity, therefore completing the characterization of the whole AWS pressure-temperature-humidity (PTU) modulus. In fact, the final version of the system will be equipped with a humidity generator for hygrometers calibrations in variable temperature conditions, also allowing the calibration of thermometers and barometers under different humidity values as quantity of influence. At the moment, the development of humidity generator is in progress and this article reports only about pressure and temperature performances of the facility.

This chamber has similar dimensions and similar auxiliary external fluid-based thermal control as other devices previously manufactured at INRiM for thermal metrology (Merlone *et al.*, 2007). The most important feature, with respect to other systems, is that EDIE1 allows temperature calibrations in air, instead of in a bath, in order to simulate the real operational conditions and characterize the sensor response more accurately.

A characteristic of this facility is its ability to cover a wide range of atmospheric variability with one media. The temperature is controlled between  $-25\text{ }^{\circ}\text{C}$  and  $+50\text{ }^{\circ}\text{C}$  and the pressure between 50 kPa and 110 kPa. This temperature range together with adjustable pressure conditions in the chamber gives extensive simulation scenarios for instruments and other components which are exposed to weather changes during operation. One of the big advantages of this apparatus is its reduced dimensions. The good compromise between measuring inner chamber (inner diameter 220 mm and volume of about 15 l) and external total dimensions (350 mm x 650 mm) makes it transportable for in-situ calibration campaigns (Bertiglia *et al.*, 2013), allowing at the same time the housing of the whole sensor and datalogger. In this manner, the whole measurement chain can be tested in working conditions to reduce further calibration uncertainty contributions due to the datalogger, ADC conversion, and software elaboration. Today the most used approach is a field verification, consisting of a travelling high quality “reference” sensor which is installed for some days in the proximity of operational sensors; then an inter-comparison trial is carried out. This test is not considered as a “calibration” process but only a check, allowing the identification of possible sensor malfunctions or larger deviations at one point (Lopardo *et al.*, 2012). A robust metrological traceability is therefore missing when such a procedure is adopted. The use of this new facility can avoid these problems allowing metrological traceability also for these AWSs installed in remote areas, where access difficulties can delay or prevent periodic calibrations (Merlone *et al.*, 2014). During June and July 2014 the EDIE1 calibration facility was shipped to the Ny-Ålesund research site, in the Norwegian polar area (Musacchio *et al.*, 2014). The site hosts a GRUAN (Global Climate Observing System (GCOS) Reference Upper Air Network) station, so the facility was used for the calibration of those pressure and temperature measuring instruments used as ground check for the radiosondes sensors just before launch.

In this paper, the constructed apparatus and its performance characterization are described. Tests covering the temperature control in the whole range of interest are reported.

## 2. Test chamber

The test chamber (Figure 2.a) is formed by two concentric steel cylinders; between them there is an interspace in which vacuum is created as thermal insulator. The inner cylinder is the test zone; it contains a copper cylinder on which a cooling coil, directly connected to the external thermostat, is soldered (Figure 2.b). Copper bottom and cover of this internal volume are to guarantee the best thermal uniformity with the walls. The thermostatic fluid flow is used for thermal control. A steel pipe, connecting the inner chamber with the outside, allows pressure control and is also used for permanent electrical wiring. The humidity control, not yet realized, will be obtained by a dedicated small saturator placed on the external part of the chamber; traceability will be guaranteed by a standard hygrometer directly traceable to Italian national primary standard. The humid gas generator will be based on a single-pass isothermal saturator, targeted to generate dew/frost point temperatures between  $-25\text{ }^{\circ}\text{C}$  and  $50\text{ }^{\circ}\text{C}$ . The reference relative humidity will be calculated by means of the dew/frost point temperature measured by a reference chilled-mirror hygrometer and the air temperature measured with a reference platinum resistance thermometer inside the EDIE1 chamber. The duct, through humid air fluxes, will be thermal-conditioned by long proximity with thermostatic coils in order to allow simultaneous control of temperature and humidity. Air will leave the chamber through a short pipe near the top directly opened towards the laboratory, without any kind of pressure valve; in this case simultaneous control in pressure and humidity will not be possible.

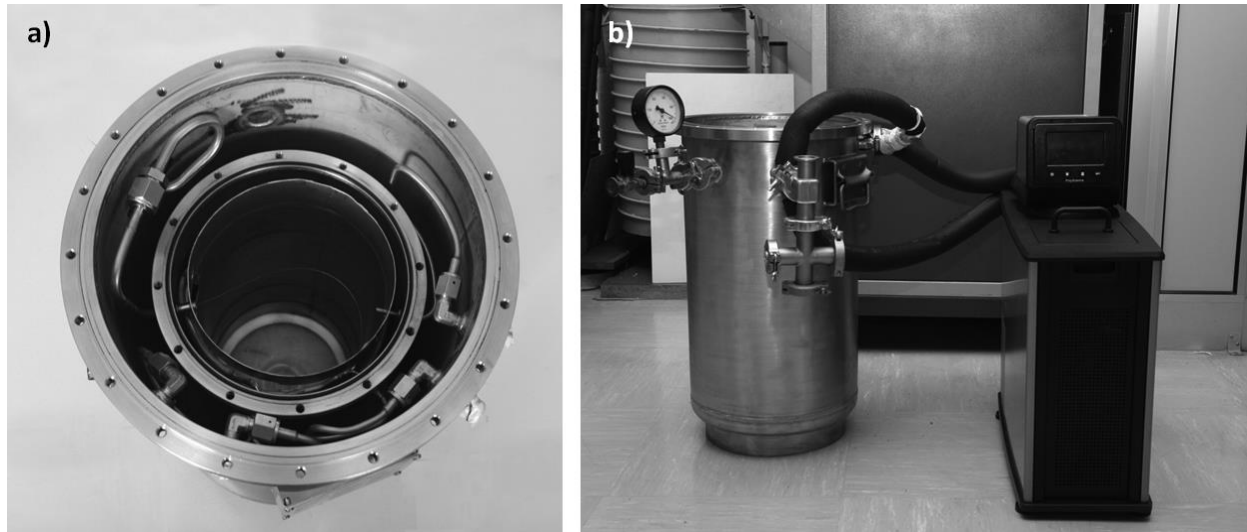


Figure 2: a) Test chamber without covers. The vacuum interspace hosting the steel pipes connections and the inner cylinder with thermalized copper cylinder are visible. b) the test chamber and external thermostat. The pressure controller and the vacuum pump are not shown in the picture.

### 3. Performance characterization

The pressure characterization of the test chamber was carried out through a Druck DPI 740 barometer calibrated against INRiM secondary standard. The expanded uncertainty for pressure readings inside the chamber is 10 Pa ( $k=2$ ) in the range from 50 kPa to 110 kPa. No pressure leaks were detected during long lasting tests in this range.

The temperature characterization aims to determine uniformity and stability of temperature in the test chamber, at different set points, in still air. The uniformity was tested in two different experiments: one test regarded axial uniformity, a second one dealt with vertical temperature changes along the measuring volume.

The selected set points were:  $-25\text{ }^{\circ}\text{C}$ ,  $-10\text{ }^{\circ}\text{C}$ ,  $0\text{ }^{\circ}\text{C}$ ,  $10\text{ }^{\circ}\text{C}$ ,  $25\text{ }^{\circ}\text{C}$ ,  $40\text{ }^{\circ}\text{C}$ ,  $50\text{ }^{\circ}\text{C}$  in order to cover the whole calibration range for atmospheric sensors. Measurements were performed with three Pt100. All Pt100 were calibrated in bath against INRiM secondary standards in the temperature range from  $-40\text{ }^{\circ}\text{C}$  to  $50\text{ }^{\circ}\text{C}$ ; the maximum value of their calibration standard uncertainty was  $0.011\text{ }^{\circ}\text{C}$  as reported in table I (table I, line 1).

The temperature data were recorded by a digital multimeter, having a resolution of 8-1/2 digits (Model Keithley 2002), equipped with a scanner. The sampling time was 10 s. The contribution to standard uncertainty due to the nanovoltmeter readings was  $0.004\text{ }^{\circ}\text{C}$ , as reported in table I (table I, line 2). The repeatability is assumed to be the standard deviation of the readings along 10 minutes.

In order to study the temperature vertical profile, three Pt100 were placed inside the test chamber. The measuring volume, where major thermal uniformity is expected, is limited by the upper and lower thermometers and the middle thermometer is located in the center of this area. The distance between each thermometer is 10 cm, the bottom one being placed at 17 cm from the bottom, the second at 27 cm and the top one at 37 cm.

After a period, necessary to reach and stabilize the temperature, the readings of the 3 thermometers were compared averaging on 10 minutes of measurements. Thermal vertical gradients as a function of temperature in the two regions (between middle and upper

thermometers, and lower and middle one) and in the whole measuring volume (between lower and upper thermometers) are reported in Figure 3. The upper volume (between middle and upper thermometers) turns out to be more uniform, while the lower thermometer is more subject to external temperature perturbations. This figure shows also a different type of air temperature stratification for temperatures lower and higher than ambient one.

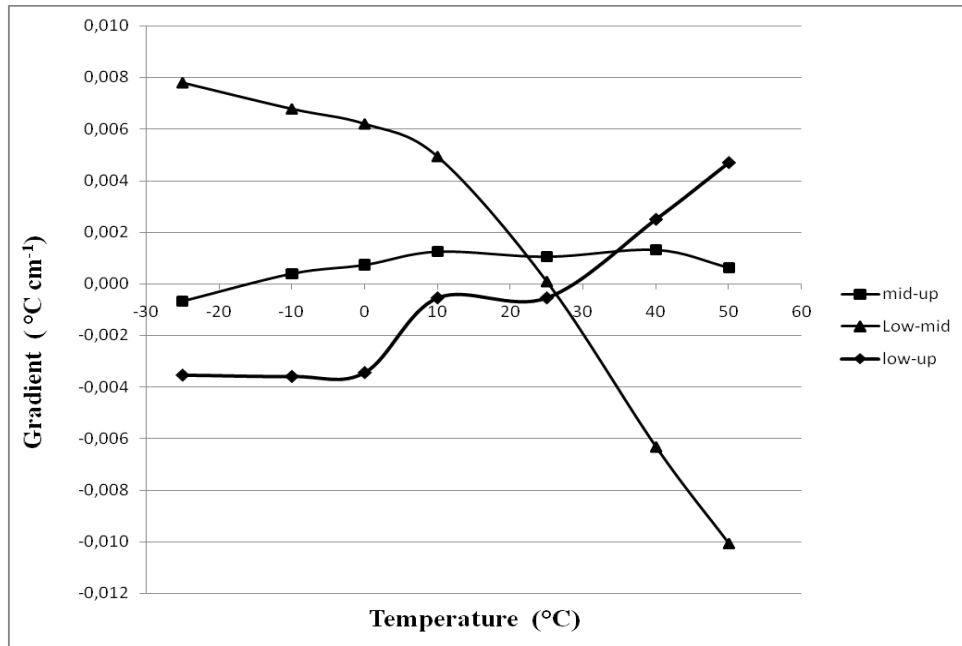


Figure 3: Thermal vertical gradients as a function of temperature. Gradients are calculated between middle and upper thermometers (mid-up), between lower and middle thermometers (low-mid) and between lower and upper thermometers (low-up). Gradient is here defined as the ratio of the difference in temperature and the distance between thermometers.

Regarding axial uniformity, two Pt100, located respectively 5 cm and 1.5 cm from the center of the measuring volume, were compared. Temperature differences between 0.004 °C and 0.075 °C were detected in the calibration range. The axial gradient as a function of temperature is reported in Figure 4. As expected, readings of the farthest thermometer from center are more influenced by the cooling coil: the temperature in the external area is higher than in the central one at 50 °C and lower at -25 °C.

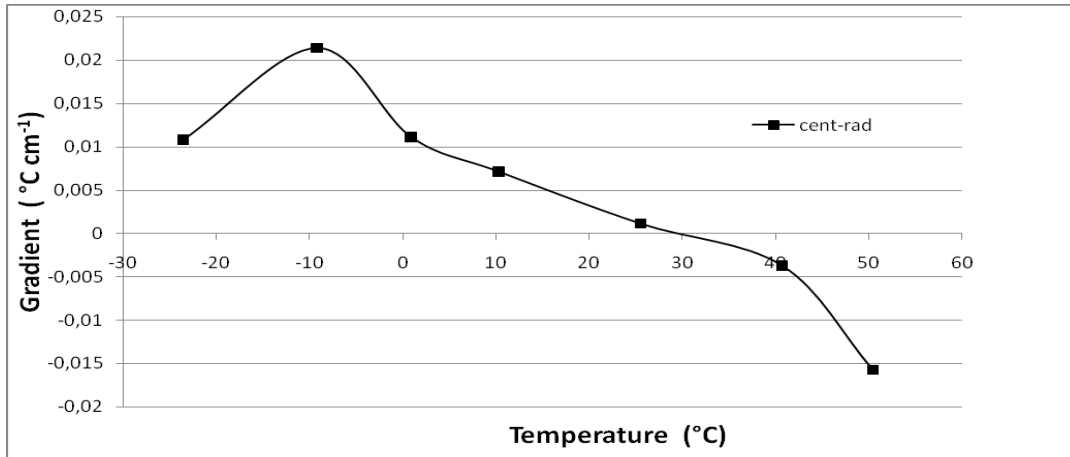


Figure 4: axial gradient as a function of temperature. Gradient is defined as the ratio of the difference in temperature and the distance between thermometers.

The temperature stability was determined at different temperatures, recording the outputs of a thermometer located in the center of the measuring volume. Figure 5 shows the record for a set point near  $-25\text{ }^{\circ}\text{C}$ . A temperature drift of  $0.08\text{ }^{\circ}\text{C}$  was observed during a 12 h period. At  $+25\text{ }^{\circ}\text{C}$  the maximum deviation during a 2 h period was  $0.03\text{ }^{\circ}\text{C}$ .

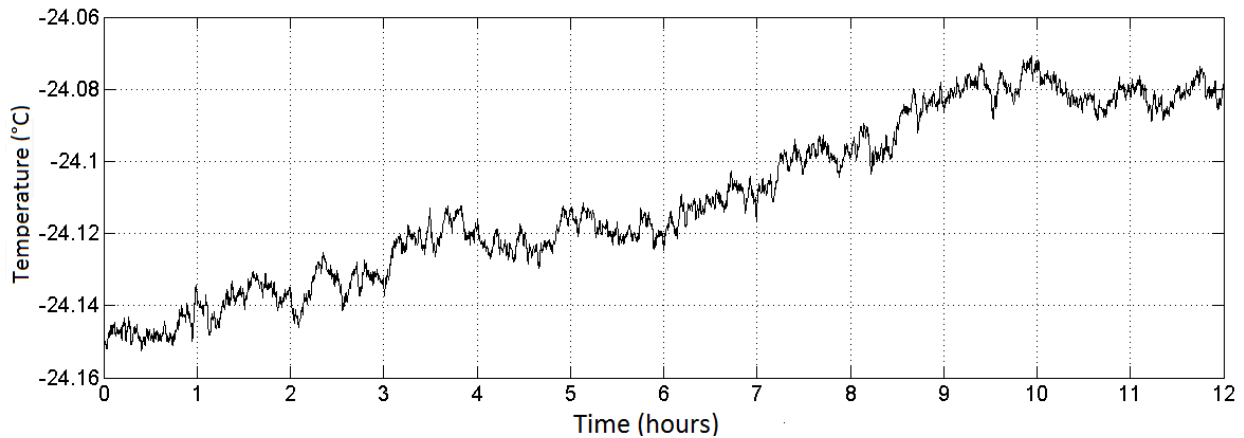


Figure 5: Long term stability test in a period of 12 hours. The set point temperature was about  $-25\text{ }^{\circ}\text{C}$

#### 4 Conclusions

The calibration facility designed and manufactured at INRiM provides a suitable instrument for accurate in-situ calibration of AWSs, and in general of meteorological sensors, located in remote regions allowing metrological traceability to key observables for climate change evaluation.

This calibration facility allows to perform calibrations in a wide range of atmospheric conditions (temperature:  $-25\text{ }^{\circ}\text{C} \div 50\text{ }^{\circ}\text{C}$ , pressure:  $50\text{ kPa} \div 110\text{ kPa}$ ); using a more powerful external thermostat may even extend the temperature range towards lower temperatures ( $-50\text{ }^{\circ}\text{C} \div 50\text{ }^{\circ}\text{C}$ ) to cover extreme atmospheric conditions as occurring in Himalaya or Polar regions .

Combined pressure and temperature conditions, which are not possible were the devices tested or calibrated separately, are achievable in this apparatus Besides, the final version of the facility, equipped with a humidity generator and controller, will allow extension of the calibration and mutual influences analysis to humidity sensors.

The test chamber characteristics allow to perform calibrations by comparison against reference standards with limited uncertainty contributions:

- axial chamber uniformity contribution to standard calibration uncertainty: 0.075 °C (maximum difference recorded in the calibration range)
- vertical chamber uniformity contribution to standard calibration uncertainty: 0.1 °C (maximum difference recorded in the calibration range)
- chamber stability contribution to standard calibration uncertainty: 0.01 °C (stability evaluated during a 1h observation period).

Table 1 reports the contributions to the total calibration standard uncertainty for temperature measurements: Pt100 calibration uncertainty, uncertainty due to the digital multimeter, uncertainty due to chamber manufacturing characteristics. The expanded uncertainty is equal to 0.076 °C in  $k=2$ , corresponding to a confidence level of approximately 95%. The expanded uncertainty ( $k=2$ ) for pressure is 10 Pa.

EDIE1 is the first example of transportable calibration facility for atmospheric sensors developed at INRiM in the framework of the European Project MeteoMet ([www.meteomet.org](http://www.meteomet.org)). It is now used for in field calibration activities in cooperation with weather and climate observation services and for scientific research. Its design and technical characteristics have allowed to extend the project to other specific needs of traceability. For example, a second chamber, EDIE2, dedicated to measurements in the Everest area, was developed. This chamber, working in a wider range of atmospheric variability and with smaller dimensions than EDIE1, was installed on the EV-K2-CNR Everest pyramid observatory (Merlone *et al.*, 2014).

Uncertainty contribution			Probability distribution	Contribution to standard uncertainty (°C)
PT100 thermometer	Calibration uncertainty	0.02 °C	Normal	0.011
	Fitting uncertainty	0.01 °C		
Digital multimeter	Resolution	0.005 mΩ	Rectangular	$7.5 \cdot 10^{-6}$
	Uncertainty	2.8 mΩ	Rectangular	0.004
	Repeatability	0.1 mΩ	Normal	0.001
Chamber	Axial uniformity	0.075 °C	Rectangular	0.021
	Vertical uniformity	0.1 °C	Rectangular	0.028
	Stability	0.01 °C	Normal	0.01
			Standard uncertainty	0.038
			Expanded uncertainty ( $k=2$ )	0.076



**Table 1:** Summary of the sources of uncertainty for temperature measurements. The standard uncertainty is the quadratic sum of all uncertainty contributions and expanded uncertainties is the standard uncertainty multiplied for the coverage factor ( $k=2$ ) corresponding to a level of confidence of approximately 95%.

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