Co-UDlabs

Data Storage Report

Identifying sediment deposits from temperature signals

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V 1.0	Manuel Regueiro, Jose Anta (UDC)	01/09/2022	First version of the dataset
V 1.1	Jose Anta (UDC)	29/03/2023	Dataset ID updated

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Background: about the Co-UDlabs Project

Co-UDlabs is an EU-funded project aiming to integrate research and innovation activities in the field of Urban Drainage Systems (UDS) to address pressing public health, flood risks and environmental challenges.

Bringing together 17 unique research facilities, Co-UDlabs offers training and free access to a wide range of high-level scientific instruments, smart monitoring technologies and digital water analysis tools for advancing knowledge and innovation in Urban drainage systems.

Co-UDlabs aims to create a urban drainage large-scale facilities network to provide opportunities for monitoring water quality, UDS performance and smart and open data approaches.

The main objective of the project is to provide a transnational multidisciplinary collaborative research infrastructure that will allow stakeholders, academic researchers, and innovators in the urban drainage water sector to come together, share ideas, co-produce project concepts and then benefit from access to top-class research infrastructures to develop, improve and demonstrate those concepts, thereby building a collaborative European Urban Drainage innovation community.

The initiative will facilitate the uptake of innovation in traditional buried pipe systems and newer green-blue infrastructure, with a focus on increasing the understanding of asset deterioration and improving system resilience.

List of acronyms

Acronym / Abbreviation	Meaning / Full text
JRA	Joint Research Activity

Executive summary

This document is a data storage report of the Co-UDlabs project, funded under the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008626.

The aim of this document is to describe the experimental campaign and how data were collected on the research activity "Identifying sediment deposits from temperature signals" performed under Joint Research Activity "JRA 3- Improving Resilience and Sustainability in Urban Drainage solutions". This JRA aims:

- To develop consensus on methodologies needed to provide high resolution data to assess the performance of urban drainage technologies.
- To demonstrate how the urban flood resilience and pollution transport/retention properties of urban drainage technologies can be evaluated.
- To demonstrate and propose a methodology for the evaluation of the sustainability of new and emerging urban drainage technologies.

The data are described so that others can use them.

1. INTRODUCTION

1.1. SCIENTIFIC BACKGROUND

Sediment accumulation in urban drainage systems (UDS) is a serious problem, which requires costly maintenance and cleaning strategies. These tasks are often linked to previous experience, but there is no control or monitoring, nor a complete knowledge of the sediment transport processes in UDS. Sediment sources are diverse and depend on the system being treated. For example, sediment accumulation in urban drainage systems, such as gully-pots, occurs mainly because of solid particles settled from surface runoff and wash-off (Rietveld et al., 2020). Another well-known example is the accumulation in sewer pipes, whose main sediment deposition sources are particles carried by domestic and industrial wastewater which settle due to insufficient flow velocities during dry weather periods or after scouring from the upper side of the sewer pipe network during rainfall events (Ashley et al., 2004).

Attempts so far to monitor these processes have been based on techniques that require exhaustive work in their installation or in taking punctual field measurements. For instance, a sophisticated example was developed by Bertrand-Krajewski and Gibello (2008) to obtain sediment bed deposits along collectors and sewer pipes based on acoustic profilers. This device was composed of a sonar sensor to collect the information from the pipe invert and a laser to track and correct the position of the device (see also, Lepot et al., 2017). Furthermore, computer vision techniques were also developed to obtain a detailed information regarding the physical properties of the bed deposits and bedload transport dynamics (Oms et al. 2003; Shahsavari et al., 2017). Therefore, sediment monitoring in UDS remains challenging. Interestingly, recent work in rivers investigated streambed sediment transport with temperature measurements, based on considerations on heat transfer and ground-water flows (Tonina et al., 2014; Sebok et al., 2017; Sebok and Müller, 2019). The idea lies on analysing the difference on the temperature time series features (amplitude and phase) to estimate the deposition and erosion of streambed sediment or the groundwater fluxes, depending on the disposition of the temperature sensors.

1.2. OBJECTIVES

This experimental campaign is framed in the Joint Research Activity 3 (JRA3) within Co-UDlabs Project: "*Improving resilience and sustainability in urban drainage solutions*". In this sense, these experiments introduce a new approach which uses high-resolution temperature data to identify sediment bed deposits by analysing time series. Water (wastewater or drainage water in UDS) and sediments show different thermal properties and heat transfer dynamics. Thus, the aim of this project is to estimate or at least evidenced the presence of sediments by analyzing the differences between the temperature timeseries measured in the water phase and at the bottom of bed deposits. Results from this experimental campaign will help to understand heat transfer processes between water and saturated sediment mixtures and, therefore, develop new methodologies to estimate accumulation in UDS.

2. EXPERIMENTAL SETUP

2.1. PHYSICAL MODEL DESCRIPTION

The experimental setup consisted in four adiabatic boxes of 15×15×15 cm^3 (inner dimensions) made of Expanded Polystyrene (EPS) to avoid significant heat transfer at the contours. Sediment thicknesses of 2, 4, 6 and 8 cm have been respectively poured at the bottom of each box together with 2 cm layer of water covering them. Two temperature sensors were installed in each box for measuring the water and sediment-bed temperatures. In addition, coil systems, which were made of 5 mm (diameter) plastic tubes, were deployed within each box to introduce temperature gradients in the water layer by pumping water from a temperature-controlled system. This system consisted in a water bath with heating and cooling devices attached, and four pond pumps (200 L/h) to supply temperature oscillation to each box. Finally, two additional temperature sensors were set for measuring the room and water bath temperatures, respectively. Figure 1 summarizes the experimental setup performed in the Hydraulics Laboratory of Civil Engineering School at Universidade da Coruña.

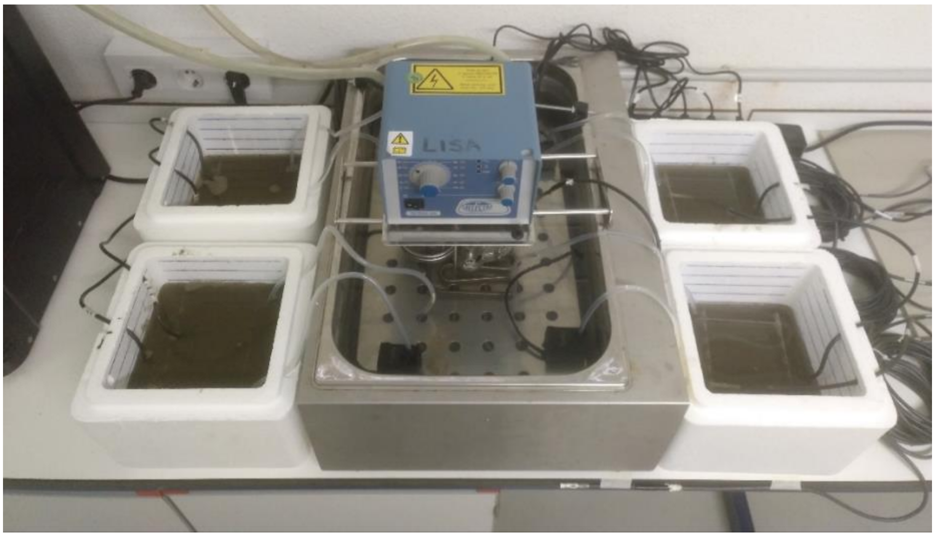

Figure 1. Photo of the experimental setup.

2.2. EXPERIMENTAL PROCEDURE

Two experimental procedures were carried out in this project.

- Pulse experiments (Figure 2a): these tests consist in short period increases of the water layer temperature within the boxes. The water was warmed up to 2ºC in 20 minutes, simulating heat dynamics due to sharp temperature gradients, such as stormwater inflows.
- Cycle experiments (Figure 2b): conversely previous procedure, these tests forced a prolonged heat-cooling cycle in the water layer. Cycles consisted of a 2-hour heating and a subsequent cooling. Water temperature oscillations were set in the range of 2°C, simulating daily temperature oscillations in wastewater or drainage water (Montserrat et al., 2013).

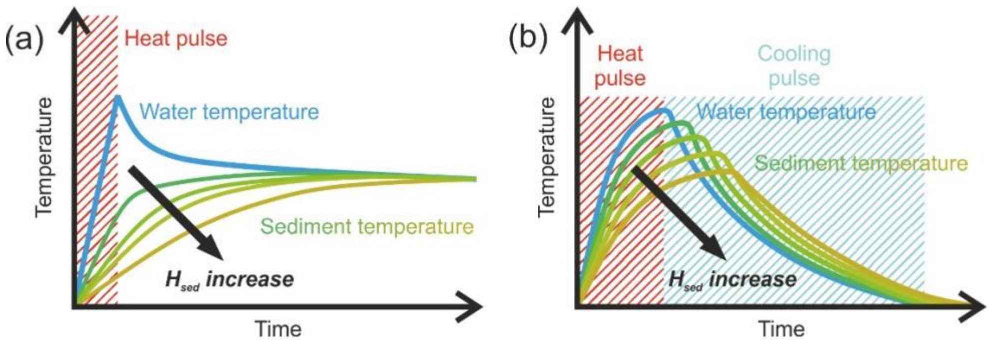

Figure 2. Scheme of experimental procedures: pulse (a) and cycle (b).

Each experimental procedure was applied to each box. Therefore, 8 tests were performed. Table 1 shows the experiments carried out and their configuration:

Table 1. Temperature test configurations.

Experiment ID	Experimental procedure	Sediment thickness (cm)
PulseB1_2cm	Pulse test	2
CycleB1_2cm	Cycle test	2
PulseB2_4cm	Pulse test	4
CycleB2_4cm	Cycle test	4
PulseB3_6cm	Pulse test	6
CycleB3_6cm	Cycle test	6
PulseB4_8cm	Pulse test	8
CycleB4_8cm	Cycle test	8

2.3. SPATIAL AND TEMPORAL REFERENCE SYSTEMS

Regarding the spatial system, sediment thickness reference was measured from the temperature sensor placed at the bottom of the box up to the water-sediment interface. On the other hand, relative time systems were used for collecting the data from temperature sensors. Time resolution was set in 5 seconds. In addition, each pair of sensors were connected to a different data acquisition system, which were controlled by Arduino Nano boards with a RTC. Measurements were synchronized by turning on the power of the electronic boards and initializing the heat pulse pumping at the same time.

2.4. FIXED PARAMETERS

The following parameters have been assumed to be fixed:

- Mechanical and thermal properties of the sewer sediments were assumed to be constant, regardless of height, time or box.
- The same calibration parameters of the temperature sensors were applied during the entire campaign.

3. TEMPERATURE MEASUREMENTS

3.1. INSTRUMENTS

Temperature measurements were recorded with 4-wire PT100 sensors (TF44, WIKA Instruments) using an Adafruit PT100 RTD Temperature Sensor Amplifier - MAX31865 connected to Arduino Nano boards. The Arduino boards were mounted in a shield with integrated SD card and RTC DS3231 boards. In total, 5 Arduino nano boards were used:

- PT0 board was installed with two PT100 to measure air room (PT0a) and water bath (PT0b) temperatures.

- PT1 to PT4 boards were installed with two PT100 each to measure Box 1 to Box 4 water (PTXw) and sediment (PTXs) temperatures.

The following Table 2 summarizes the information about the temperature sensors, also included in file *Measuring_info.csv*.

Table 2. Temperature sensor information

ID	Measure	Location	Plan view position	Zcoord. (m)	Sensor	Manufacturer	Time res. (s)	Acquisition units (*)	Result units
PT0a	Temp.	Room	-	-	PT100-TF44	WIKA Instruments	5	ohms	deg.C
PT0b	Temp.	Water bath	-	-	PT100-TF44	WIKA Instruments	5	ohms	deg.C
PT1w	Temp.	Box 1	center	0.03	PT100-TF44	WIKA Instruments	5	ohms	deg.C
PT1s	Temp.	Box 1	center	0.00	PT100-TF44	WIKA Instruments	5	ohms	deg.C
PT2w	Temp.	Box 2	center	0.05	PT100-TF44	WIKA Instruments	5	ohms	deg.C
PT2s	Temp.	Box 2	center	0.00	PT100-TF44	WIKA Instruments	5	ohms	deg.C
PT3w	Temp.	Box 3	center	0.07	PT100-TF44	WIKA Instruments	5	ohms	deg.C
PT3s	Temp.	Box 3	center	0.00	PT100-TF44	WIKA Instruments	5	ohms	deg.C
PT4w	Temp.	Box 4	center	0.09	PT100-TF44	WIKA Instruments	5	ohms	deg.C
PT4s	Temp.	Box 4	center	0.00	PT100-TF44	WIKA Instruments	5	ohms	deg.C

(*) PT100 sensors report ohms in hexadecimal format

3.2. MEASURED PARAMETERS

PT100 sensors measure the temperature through the resistance of a Platinum strip. As a reference, they present a resistance of 100 ohms at a temperature of 0ºC. In this project, we first analyzed the resistance measurements by each sensor (ohms in hexadecimal format), to later obtain the temperature values by applying the Callendar-van Dusen (CvD) formula (see section 3.4).

3.3. DATA COLLECTION

Raw temperature measurements were saved as text files by the Arduino microcontrollers in microSD cards. Subsequently, raw measurements were corrected by introducing calibration coefficients, which were previously obtained from controlled-uniform temperature measurements, and transformed in degrees Celsius (deg.C or ºC).

Data were saved in both raw and calibration-corrected formats. Next section summarizes how to introduce the calibrating coefficients and obtain the resulting units in degrees Celsius.

3.4. POST-PROCESSING

PT100 sensors were calibrated before the experimental campaign by setting constant temperatures in the water bath, within the temperature range expected to be used in the experiments (20-35ºC). For this purpose, temperature measurements were measured once each water temperature was stabilized in the water bath (*Sensors_calibration*). Resistance Temperature Detector (RTD) measurements were compared and adjusted with the data collected from one of the PT100 sensors (PT4s), which was taken as a reference. Therefore, a linear regression was applied to perform the transformation from raw to corrected RTD measurements (further details in Appendices).

After correcting RTD measurements, the Callendar-van Dusen (CvD) formula was applied to transform the RTD values (in ohms) to temperature units (in degrees Celsius):

$$RTD = R_0 \cdot (1 + A \cdot T + B \cdot T^2), \text{ if } T > 0$$

where T is the temperature (ºC), R_0 is the resistance at 0ºC and its value is equal to 100 ohms, and $A = 3.9083 \times 10^{-3}$ and $A = -5.775 \times 10^{-7}$ are the coefficients of the CvD formula. This formula accurately approximates the relationship between resistance and temperature, with a maximum error of 0.0022ºC within a temperature range of 0 to 200 ºC (King and Fukushima, 2004). To transform the RTD from a hexadecimal to a ohms-based decimal format it is necessary to apply the following equation:

$$RTD = \frac{RTD_{cc}}{32768} \cdot R_{\text{ref}}$$

where RTD_{cc} is the calibration-corrected RTD measurements, 32768 refers to 8000 in hexadecimal (base 16) format, and $R_{\text{ref}} = 430$ is the value of the reference resistance of the resistor (ohms) PT100 RTD Temperature Sensor Amplifier - MAX31865 given by the manufacturer.

3.5. ADDITIONAL REMARKS

NA

4. SEDIMENT PROPERTIES ANALYSIS

4.1. INSTRUMENTS

To carry out the analysis of sewer sediment properties, several sub-samples were taken and analyzed according to standardized methods. For this purpose, laboratory equipment such as test tubes, capsules, pycnometers, high-precision weighing scales, drying ovens, etc. were used. Additionally, specific devices were also used for performing grain size distribution analysis. On the one hand, wet sieving method was applied by using sieves ranged from 0.063 to 2 mm. On the other hand, laser diffraction analysis was also performed with a Beckman Coulter LS 13 320 (Aqueous Liquid Module).

4.2. MEASURED PARAMETERS

This study was focused on characterizing mechanical properties of sediments. The properties analyzed are listed below (see also *Sediment_prop.csv*):

- Moisture content (%).
- Organic matter (%).
- Density (kg/m[3]): wet, bulk, dry-bulk and solid density.
- Porosity (-).
- Mean grain size (mm).

4.3. DATA COLLECTION

Subsamples from sewer sediment were analyzed by following several standard methods, which are listed in the following Table 3.

Table 3. Standard methods for sample analysis.

Parameter (sediment property)	Standard method reference
Moisture content	2540G, APHA (1998)
Organic Matter	2540G, APHA (1998)
Wet density / Specific gravity	2710F, APHA (1998)
Solid density	UNE EN 1097-7:2009
Grain size distribution	ISO 13320:2009 and ISO 2591-1:1988

4.4. POST-PROCESSING

The following parameters were obtained from the combination of parameters obtained by applying standard methods (Table 2).

- Dry bulk density (kg/m^3): $\rho_{dry-bulk} = \rho_{bulk}/(1 + w/100)$, where ρ_{bulk} is the bulk density (kg/m^3) and w is the moisture content (%).
- Porosity (-): $\varphi = 1 - \frac{\rho_{bulk}}{\rho_{solid}}$, where ρ_{solid} is the solid density (kg/m^3).

In addition, the overall characterization of the sewer sediment was obtained by averaging the values obtained from the subsample analysis.

4.5. ADDITIONAL REMARKS

NA

5. DATA AND RESULT FILES ORGANIZATION

Main data collection was based on data from temperature sensors and sediment properties. Temperature data were stored in csv files, which are organized in folders according to test procedure and sediment thickness conditions (Table 4). Thus, folder names combine the type of test (Pulse or Cycle), the number of the box (B1, B2, B3 and B4), and the sediment thickness (in cm.) or the reference to room and water bath temperatures (B0). Data from each experiment considered in Table 1 are stored in separate folders, which include the following files:

- “*C1_Temperatures_RawSignal(RTD).csv*”: Raw temperature time series measured by the PT100 sensors located at the sediment-bed and in the water layer.
- “*C1_Temperatures_Processed(degC).csv*”: processed temperature time series after applying the calibration coefficients and CvD formula to transform temperature from resistance to degree Celsius values.

Please, note that C1 is the reference to the experiment.

Table 4. Folders and file organization.

	CycleB0_room&wbath_Temp	Folder
	Room_Temperature_Processed(degC).csv	.csv file
	Room_Temperature_RawSignal(RTD).csv	.csv file
	CylcleB1_2cm	Folder
	CylcleB2_4cm	Folder
	CylcleB3_6cm	Folder
	CylcleB4_8cm	Folder
	PulseB0_room&wbath_Temp	Folder
	PulseB1_2cm	Folder
	PulseB2_4cm	Folder
	PulseB3_6cm	Folder
	PulseB4_8cm	Folder
	Sediment_properties	Folder
	Standard_methods	Folder
	APHA_methods.csv	.csv file
	…	.csv files
	Sediment_prop.csv	.csv file
	Sensors_calibration	Folder
	Step1_Temperatures_RawSignal(RTD).csv	.csv file
	…	.csv files
	Measuring_info.csv	.csv file

Figure 3 plots water and sediment-bed processed temperatures for the eight experiments performed:

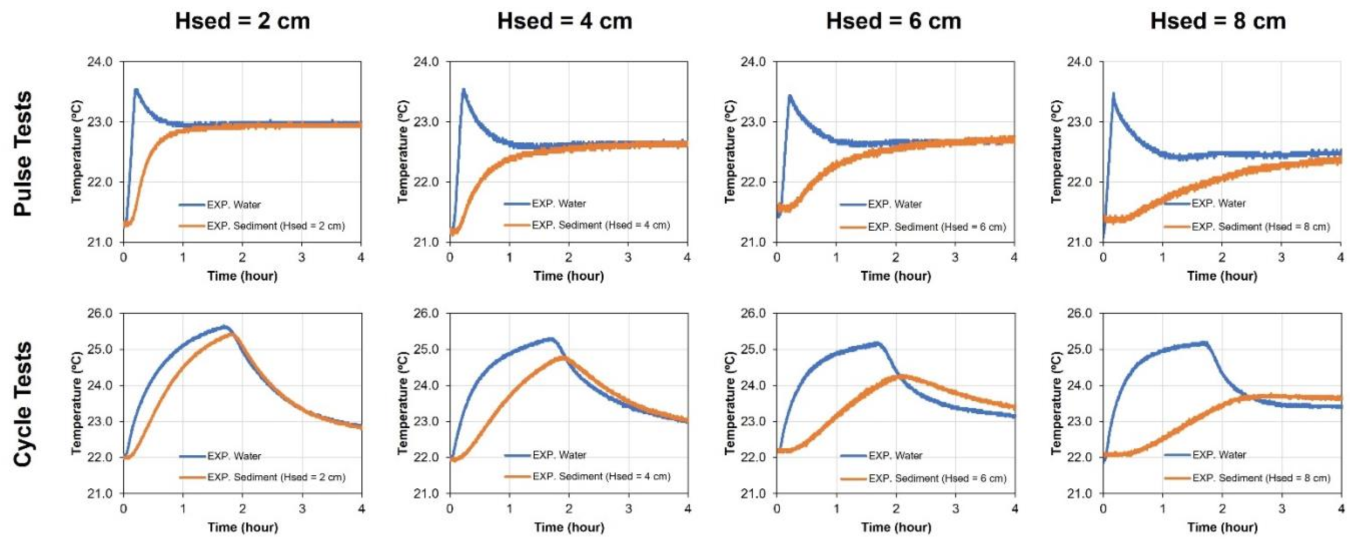

Figure 3. Temperature time series in water and sediment-bed for pulse and cycles tests, and sediment thicknesses ranged from 2 to 8 cm.

Furthermore, sensor calibration and sediment properties were respectively stored in separate folders. Regarding sensor calibration, the folder contains raw temperature time series from 6 steps in the range of (20-35ºC). In addition, sediment properties are summarized in the file: *Sediment_prop.csv*. Raw analysis data are also provided in the folder: *\Standard_methods*.

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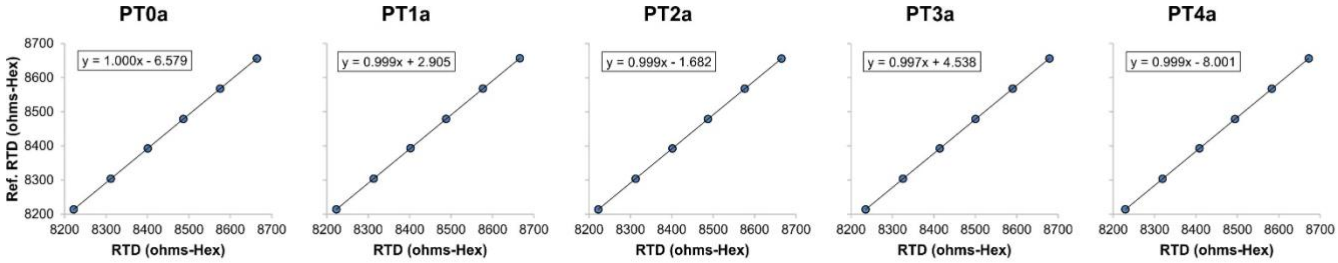
7. APPENDICES

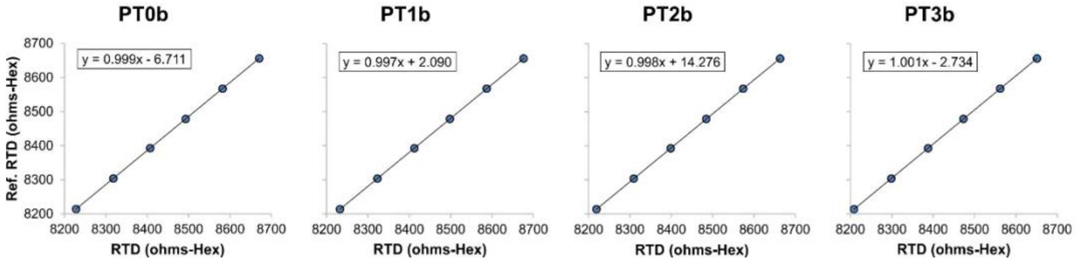
7.1. PT100 TEMPERATURE SENSOR CALIBRATION

PT100 sensors were calibrated by setting 6-step temperatures in the water bath in the rage of 20-35ºC. For this purpose, all sensors were introduced in the water control system and temperatures were measured for 4-5 minutes with a time resolution of 5 seconds. Temperatures measured by PT4b sensor were selected as reference values. Thus, linear regression equations could be obtained by setting the following equation:

$$RTD_{\mathrm{cc}} = m \cdot RTD_{\mathrm{raw}} + n$$

where RTD_{raw} represent raw RTD measurements (ohms, in hexadecimal format), and m and n are the linear regression coefficients of the PT100 calibration. m-coefficients showed values close to 1, as expected, while n-coefficients showed slight oscillations in the offset setting. Figure 4 represents the calibration lines of the PT100 sensors.





Step	RTD ref. (ohms-HeX)	Temp. ref. (deg.C)
Step 1	8214	19.98
Step 2	8304	23.02
Step 3	8393	26.03
Step 4	8479	28.94
Step 5	8568	31.95
Step 6	8656	34.95

Figure 4. Regression lines obtained from the calibration steps of the PT100 sensors. PT4b sensor measurements were chosen as reference values.