Quantifying the effect of thermal heat radiation emitted by the walls of a climatic chamber on temperature measurements

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Abstract. The study consists in quantifying the effect of the thermal radiation of the climatic chamber walls on air temperature measurements for contact thermometry. Air temperature measurements are affected by surface interactions with the environment, such as those of the thermometer and walls (surface condition, emissivity and air velocity). The walls of the enclosure are generally made of stainless steel, a potentially radiating material. To characterize the effect of the walls, we have varied environmental conditions such as the emissivity of the walls of the chamber and the sensors, the surface of the sensors, temperature and illumination. These different configurations allow us to deduce their impacts on the temperature measurements. To quantify this effect we simulated different configurations to isolate the radiation effect. Two surface states are tested: low emissivity metal surface and painted surface with matte black paint of high emissivity. This study highlights the effect of the walls on the air temperature measurements in the center of the climatic chamber. The experimental results were also subject to a theoretical verification using the equation of the standard ISO 7726 [1]. The quantification of the effect of radiation from the walls of the climate chamber on temperature measurements becomes significant from 100 °C. Quantification of thermal radiation is 0.4 °C at 100 °C and 0.8 °C at 150 °C.

1 INTRODUCTION

1.1 General context

Temperature is an important measure for climate chamber testing that is widespread in the industry (example: FDX 15 140). This is a parameter identified as an influence parameter on the quality of climate testing. It is therefore essential to know its value. Temperature depends on three heat transfers: conduction, convection and radiation. This last transfer of heat causes many quantification difficulties. Numerous studies have been conducted to assess or reduce the effect of radiation on temperature measurements, but no quantification has been proposed.

1.2 General at CETIAT

1.2 Context at CETIAT

CETIAT's temperature Measurement Laboratory is an accredited laboratory, by the French Accreditation Committee (COFRAC). The CETIAT is able to perform temperature calibrations ranging from -90 °C to 1050 °C [2]. Calibration for this study was carried out at the Cetiat.

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Fig. 1. Calibration in thermometric laboratory

2 DESCRIPTION OF THE STUDY

As part of the quantification of the effect of the climatic chamber wall's thermal radiation on temperature measurements, we will address five main points: (1) Sensors choice, (2) Test volume, (3) Sensors calibration, (4) Different emissivity conditions of climatic chamber and sensors environment, (5) Sensors location.

Two steps are carried out at CETIAT, one where the probes are placed inside the tubes and another where the sensors' sheaths are painted or not with high emissivity paint.

2.1 Choice of sensors

RTDs (platinum resistance sensors 100 ohm) are used for measurements in the center of the volume. We use T-type thermocouples to measure the temperature of the walls, an infrared camera to control the homogeneity of surfaces (Fig. 9) and a hot wire anemometer to measure air velocity. The acquisition is being carried out on an HP34972 power plant.

2.2 Test volume: climatic chamber

The temperature measurements were performed in climatic chambers. A climatic chamber is used to generate controlled thermal conditions: temperature [-70; 160] °C; relative humidity [10; 95] % RH.

Fig. 2. Climatic chamber

To quantify the effect of the radiation of the walls, temperature measurements are made in the center of the enclosure. Other measurements will also be made at the walls for calculus. The choice of sensors requires special attention in order to adapt the uncertainty of the measurement. To measure the temperature in the center of the climatic chamber, platinum resistance thermometers, which have a low uncertainty and provide a reliable result, were chosen. To measure the walls temperature, thermocouples are used. These sensors are not bulky and allow direct measurement on the wall.

2.3 Calibration of the sensors

The temperature sensors were previously calibrated in an overflow thermostatic bath, compared to a Standard Platinum Resistance Thermometer (TRPE). Calibration is performed at the four desired temperature levels: 25 °C, 50 °C, 100 °C and 150 °C. The expanded uncertainty of the calibration of the measurement chain is 0.06 °C.

Fig. 3. Calibration of sensors in calibration bath

2.4 Variation of different physical quantities

Emissivity is the ability of a surface to absorb radiated energy. To quantify the effect of wall radiation on temperature measurements, we use removable walls. One side, in rock wool covered with matte black paint of strong emissivity (0.95), the other side, a reflective aluminium foil (0.04) [3]. Figure 4 shows an example of the surface condition of removable walls. By reversing these faces, we can assess their impact on temperature measurements with the same heat flow conditions.

Fig. 4. Removable walls of different emissivity (aluminium and rock wool painted in black)

The emissivity of the sensors used to measure the air temperature in the center of the chamber has also been modified. Some sensors sheaths are in stainless steel, others painted with matte black. Figures 5 and 6 show two different sizes of sensors. We have two different emissivity sheaths sensors but same geometry.

Fig. 5. Two platinum resistance thermometers of different emissivity with a diameter of 6 mm.

The radiation emitted or absorbed by the sensor also depends on its area of exchange. Different sensor diameters are used to assess the impact on temperature measurement: 2 mm and 6 mm are chosen.

Fig. 6. Two platinum resistance thermometers of different emissivity with a diameter of 2mm.

Initial tests are carried out with copper tubes 22 mm in diameter. These tubes are painted with strong emissivity's paint inside and /or outside. The sensors are positioned in the center of the tubes. These results are also presented, but the convective effect also occurs. Figure 7 shows the installation in the climatic chamber.

Fig. 7. Sensors positioned in tubes of different emissivity

2.5 Location of sensors

In the end, four platinum resistance thermometers of different emissivities and diameters are placed in the center of the chamber, equidistant from the walls. The thermocouples are placed at the center of the walls of the enclosure.

Fig. 8. Measurement device and configuration

Fig. 9. Test position sensors and infrared wall control picture

3 RESULTS AND DISCUSSION

After carrying out the measurements at four temperatures (25 °C, 50 °C, 100 °C and 150 °C) with the two different emissivity walls (matte black and aluminium), we proceed to the counting. Several results allow us to observe phenomena related to the radiation of the walls. These results will be compared to those obtained during the previous study with the tubes.

3.1 Effect of emissivity

The temperature measurements obtained with the different emissivity walls show variations. According to figure 11, we observe the temperature differences between the aluminium and matte black walls. Also, between the painted and unpainted probes.

At 25 °C and 50 °C, the effect of the walls is about 0.01 °C which is negligible compared to the quality of the sensors. At 100 °C and 150 °C, the effect of radiation begins to have an impact on the measurements. Table 1 provides the values obtained. Temperature differences between walls with stainless steel and probes are 0.4 °C and 0.75 °C per 100 °C and 150 °C respectively. These results confirm the effect of wall radiation on temperature measurements, obtain in first study.

Table 1. Difference between black and stainless steel sheaths (2019)

Wall	Temperature (°C)	Diameter 6mm $\theta_{\text{black}}/\theta_{\text{alu}}$ (°C)	Diameter 2mm $\theta_{\text{black}}/\theta_{\text{alu}}$ (°C)
Matte-al.	25	-0,01	-0,01
	50	0,00	0,05
	100	-0,51	-0,27
	150	-0,73	-0,79

The differences are similar according to the two studies carried out. Although the capsules surrounding the sensor have a larger exchange surface, they reduce the effect of convection on the temperature measurement. This phenomenon may explain the difference between the results.

Table 2. Difference between black and copper tubes (2018)

Wall	Temperature (°C)	tube black/copper (°C)
Matte-copper.	50	0,0
	100	-0,3
	160	-0,4

The results obtained in 2018 with the tubes show much larger discrepancies. See graph below. The implementation of the tubes around the sensors is not appropriate, since the measured temperature corresponds to both convection and radiation heat transfer. In this study, the sensors' sheaths have been directly painted to have different emissivities but identical surfaces.

Fig. 10. Comparison of the results obtained according to the studies.

3.2 Effect of sensor diameter

Temperature differences due to the different diameters of the sensors are weak. The difference is about 0.05 °C. The ratio of the exchange surface between the walls of the enclosure and the sensors is too low. In conclusion there is no significant effect of diameter on results compared to the uncertainty.

Fig. 11. Effect of probe diameters. [4]

We noticed that the temperatures measured by the emissivity sensors are lower. We could have expected an opposite phenomenon.

3.3 Calculations by form factor

The objective is to calculate the effect of radiation. We used the method of form calculation. This simplified calculation determines the average temperature of the radiation from the temperature of the surrounding surfaces and the shape factors. The form factor measures the fraction of the radiated flow from an isothermic surface received by another surface in a non-participatory environment.

To calculate the average radiation temperature, we used the following equation [1]:

$$\bar{T}_r = \sqrt[4]{\sum_j (F_{hj}^4 \cdot T_j^4)} \quad (1)$$

Where $\bar{T}_r$ is the average radiation temperature, in Kelvin;

T_j is the surface temperature of the surface, in Kelvin;

F_{hj} is the form factor between a sheath and the surface.

We perform two calculations: with the matte and aluminium wall temperatures. The following table summarizes the temperatures of the matte and aluminum walls of the enclosure, measured at 100 °C.

Table 3. Temperatures used for calculation

Walls	T bottom (K)	T right (K)	T top (K)	T left (K)
painted	371.81	371.88	371.71	369.79
aluminum	372.2	372.41	371.29	370.13

The form factors "F" are calculated from an abacus. This abacus corresponds to a rectangular plane and an axis cylinder located in the middle plane to the rectangle [5]. The coefficients are provided in the table below.

Table 4. Form factors

Wall	1	2	3	4
F	0.4	0.54	0.59	0.51

With the matte and aluminium wall temperatures, we obtain the two respective results 1.5 °C and 1.6 °C for 100 °C. The difference between the two values can be the effect of the radiation of the walls, quantified at 0.1 °C. The experiments give higher values. These results will need to be confirmed by further tests and more comprehensive calculations.

4 Conclusion

This study is carried out with platinum-resistant thermometers placed at the center of a climate chamber. Measurements with different configurations were made (painting, diameter).

The results confirm an effect of radiation on these temperature measurements. The effect of the radiation of the walls becomes significant around 100 °C. These results are almost confirmed by calculations. This effect is 0.4 and 0.75 respectively at 100 and 150 degrees Celsius. However these initial results have yet to be confirmed by others tests.

References

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