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Final Report

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Denis Smorgon, INRIM (Italy)

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EURAMET e.V., Bundesallee 100, 38116 Braunschweig, Germany
Phone: +49 531 592 1960 Fax: +49 531 592 1969 E-mail: secretariat@euramet.org
www.euramet.org

D. Smorgon, R. Salerno, S. Čohodarević

Hybrid Comparison between INRIM and IMBIH of air temperature sensors calibrations in the range -20 °C to 60 °C.

In the framework of the project EURAMET P1586

T.R. 09/2024 March 2024

I.N.RI.M. TECHNICAL REPORT

Sommario

Abstract in Italiano

L'INRIM e IMBIH hanno organizzato un confronto ibrido bilaterale sulle tarature di strumenti misuratori della temperatura dell'aria tra -20 °C e 60 °C. L'INRIM possiede le CMC in questo settore tra -20 °C e 80 °C, l'IMBIH utilizzerebbe gli eventuali risultati positivi per dimostrare le proprie capacità metrologiche come evidenza per la richiesta delle CMC nel settore in oggetto. Entrambi i laboratori hanno tarato un set di tre termometri e solo il migliore sotto il profilo della stabilità nel tempo è stato scelto come campione di trasferimento.

Inizialmente il TC-T Chair Dott. S. Rudtsch ha partecipato all'esercizio come terza parte indipendente, poi è stato sostituito dal suo successore Dott. M. Sadli.

L'attività era stata inizialmente pianificata come attività collaterale al progetto EURAMET P1456 ATM (Air Temperature Metrology) ma poi è stata ri-pianificata come attività indipendente nel progetto EURAMET P1586.

Abstract in Inglese

To demonstrate the technical competence of IMBIH with respect to the calibration of air temperature sensors/transducers/meters between -20 °C and 60 °C, in order to get support evidences to claim CMCs in this sector, a hybrid measurement comparison was performed with INRiM which already has published CMCs for this kind of instruments in the range between -20 °C to 80 °C. The comparison involved three UUTs as transfer instrument but only the best one was chosen as the comparison transfer standard.

Firstly, the EURAMET TC-T Chair Doc. S. Rudtsch was informed in advance about the comparison and agreed to act as the third independent party then he was substituted by his successor Doc. M. Sadli.

The activity was initially planned as part of the EURAMET project P1456 ATM (Air Temperature Metrology) but successively it was planned as an independent exercise in the EURAMET project P1586

Participants

Applicant NMI

Institut za mjeriteljstvo Bosne i Hercegovine - IMBIH
Semir Čohodarević
Branilaca Sarajeva 25
71 000 Sarajevo
Bosna i Hercegovina

Issuing NMI

ISTITUTO NAZIONALE DI RICERCA METROLOGICA - INRiM
Denis Smorgon
Strada delle Cacce, 91
10135 Torino
ITALY

Independent Third Party

EURAMET TC-T Chair ad interim
SADLI Mohamed
Laboratoire commun de métrologie (LNE-Cnam)
rue du Landy 61
93210 La Plaine Saint Denis
France

Transfer Standard

Three similar PRTs named respectively:

- 50_IGRO s/n 29 as UUT_1
- 50_IGRO s/n 30 as UUT_2
- 50_IGRO s/n 31 as UUT_3

were chosen as possible transfer standards.

The dimensions of the previous PRTs are:

- Diameter: 5 mm
- Length: 50 mm

The UUT with the best time-drift parameter between the initial and final calibration is used as the official transfer standards of the HILC.

The usage of three instruments was decided to have a couple of backup instruments during the exercise for not extending the HILC time in case of instruments failure or damage.

Comparison schedule/Communication

INRIM initial measurements: from 10/06/2023 to 28/06/2023

IMBIH measurements: from 29.08.2023 to 19.09.2023

INRIM final measurements: from 12/12/2023 to 04/01/2024

During the whole HILC period above, the communications between IMBIH and INRiM were forwarded as a copy to the independent third party.

INRiM sent the measurement results to the third party on 29/02/2024. IMBIH sent its results directly to INRIM on 20/10/2023.

On 31st of January 2024 INRiM and IMBIH received the confirmation from the third party to share the results and further analysis of the data.

IMBIH Reference system and calibration procedure

The IMBIH setup consists of a temperature-controlled chamber VOTSCH VT.4021 in which a sub-chamber (13cm x 16cm x 34cm) is placed. Humidity in sub-chamber could be controlled by relative humidity generator Michell HG-10 system, and all measurement have been done in dry air (DP around -60°C), without condensation.

All 3 UUT sensors have been positioned in the sub-chamber and resistance measurements were performed simultaneously for all 3 UUT sensors and for reference temperature as well. Resistance of UUT PRT probes were measured by resistance bridge Fluke Superthermometer 1594A (s/n B5B287), and reference temperature was measured by digital thermometer Almemo Data Logger 710/V7r with PRT probe (H15080099; Al-02). Additionally, Mitchell S400 DP meter with external PRT probe (s/n 135019-1210) was used for reference temperature additional control measurement.

INRIM Reference system and calibration procedure

The INRIM reference system for the calibration of air temperature sensors/transducers consists of a thermostatic chamber VOETSCH VT7011 (s/n 58566167060010) in which a copper sub-chamber (diameter 150 mm and lenght 300 mm) is placed. In the middle of the sub-chamber are placed an ITS-90-traceable reference PRT and in the rest of the volume multiple (minimum 4) PRTs to investigate the temperature uniformity and the radiative effects. UUTs are placed very near to the sensing element of the reference PRT. Each PRTs and UUTs is connected to a temperature acquisition system for logging.

Results

Method for resistance to temperature conversion.
The three UUTs were calibrated in liquid bath in May 2022. The tables from 1 to 6 report the calibration data and the 4th order polynomial fitting curve coefficients and the associated fitting uncertainty (k=1).

TABLE 1. LIQUID CALIBRATION RESULTS FOR UUT_1

PRT:	UUT_1	
Certificate:	N° 22-0353-01 date: 2022/05/09	
Tref	***R***	***U***
°C	***Ω***	***°C***
0.000	99.9826	0.011
-70.047	71.7809	0.020
-40.042	83.9376	0.020
50.129	119.7872	0.011
99.977	139.1830	0.011
149.969	158.3370	0.020
180.013	169.7066	0.020
50.012	119.7443	0.011
0.000	99.9831	0.011

TABLE 2. FITTING CALIBRATION COEFFICIENTS FOR UUT_1

a	**b**	**c**	**d**	**OFF**
°C/Ω⁴	**°C/Ω³**	**°C/Ω²**	**°C/Ω**	**°C**
2.3677E-09	-7.3558E-07	1.0621E-03	2.3116E+00	-241.239
*u*_fit(*k*=1)	0.003			

TABLE 3. LIQUID CALIBRATION RESULTS FOR UUT_2

PRT:	UUT_2	
Certificate:	N° 22-0353-01 date: 2022/05/09	
Tref	***R***	***U***
°C	***Ω***	***°C***
0.000	100.0286	0.010
-70.046	71.8135	0.020
-40.043	83.9760	0.020
50.124	119.8422	0.010
99.975	139.2487	0.010
149.971	158.4129	0.020
180.012	169.7868	0.020
50.034	119.8079	0.010
0.000	100.0290	0.010

TABLE 4. FITTING CALIBRATION COEFFICIENTS FOR UUT_2

a	b	c	d	OFF
°C/Ω4	**°C/Ω3**	**°C/Ω2**	**°C/Ω**	**°C**
2.9942E-09	-1.0164E-06	1.1065E-03	2.3073E+00	-241.153
u_fit(k=1)	0.001			

TABLE 5. LIQUID CALIBRATION RESULTS FOR UUT_3

PRT:	UUT_3	
Certificate:	N° 22-0353-01 date: 2022/05/09	
Tref	***R***	***U***
°C	***Ω***	***°C***
0.000	100.0580	0.010
-70.046	71.8331	0.020
-40.043	84.0006	0.020
50.113	119.8731	0.010
99.977	139.2906	0.010
149.968	158.4594	0.020
180.014	169.8380	0.020
50.014	119.8351	0.010
0.000	100.0582	0.010

TABLE 6. FITTING CALIBRATION COEFFICIENTS FOR UUT_3

a	b	c	d	OFF
°C/Ω4	**°C/Ω3**	**°C/Ω2**	**°C/Ω**	**°C**
4.3207E-09	-1.6698E-06	1.2236E-03	2.2974E+00	-240.888
*u*_fit(*k*=1)	**0.001**			

The coefficients reported in Table 2, 4 and 6 are used to convert the measured UUTs resistance during the calibration in air both for INRIM and IMBIH. The associated fitting uncertainty (*u*_fit) is considered as negligible for the scopes of the HILC.

INRIM initial air temperature calibration

The Table 7, 8 and 9 report the INRIM initial in air calibration results associated to the three instruments.

TABLE 7. INRIM INITIAL AIR CALIBRATION OF UUT_1

*T*_nom	*T*_ref	*R*_UUT_1	*T*_UUT_1	*T*_UUT_1 - *T*_ref	*U*(*T*_UUT_1 - *T*_ref)
°C	°C	Ω	°C	°C	°C
-20	-20.233	91.8984	-20.238	-0.005	0.04
0	-0.142	99.9231	-0.150	-0.007	0.04
20	19.981	107.9087	19.968	-0.013	0.04
40	40.000	115.8110	39.999	-0.001	0.04
60	60.063	123.6791	60.067	0.004	0.06

TABLE 8. INRIM INITIAL AIR CALIBRATION OF UUT_2

*T*_nom	*T*_ref	*R*_UUT_2	*T*_UUT_2	*T*_UUT_2 - *T*_ref	*U*(*T*_UUT_2 - *T*_ref)
°C	°C	Ω	°C	°C	°C
-20	-20.233	91.9416	-20.236	-0.003	0.04
0	-0.142	99.9727	-0.141	0.001	0.04
20	19.981	107.9600	19.971	-0.010	0.04
40	40.000	115.8156	40.010	0.010	0.04
60	60.063	123.7412	60.077	0.014	0.06

TABLE 9. INRIM INITIAL AIR CALIBRATION OF UUT_2

*T*_nom	*T*_ref	*R*_UUT_3	*T*_UUT_3	*T*_UUT_3 - *T*_ref	*U*(*T*_UUT_3 - *T*_ref)
°C	°C	Ω	°C	°C	°C
-20	-20.233	91.9742	-20.222	0.011	0.04
0	-0.142	100.0061	-0.130	0.012	0.04
20	19.981	107.9986	19.988	0.007	0.04
40	40.000	115.8191	40.019	0.019	0.04
60	60.063	123.7817	60.088	0.025	0.06

INRIM final air temperature calibration

The Table 10, 11 and 12 report the INRIM final in air calibration results associated to the three instruments.

TABLE 10. INRIM FINAL AIR CALIBRATION OF UUT_1

*T*_nom	*T*_ref	*R*_UUT_1	*T*_UUT_1	*T*_UUT_1 - *T*_ref	*U*(*T*_UUT_1 - *T*_ref)
°C	°C	Ω	°C	°C	°C
-20	-20.385	91.8394	-20.386	-0.001	0.04
0	-0.251	99.8803	-0.257	-0.006	0.04
20	19.943	107.8976	19.939	-0.004	0.04
40	40.028	115.8231	40.030	0.001	0.04
60	59.916	123.6206	59.917	0.001	0.06

TABLE 11. INRIM FINAL AIR CALIBRATION OF UUT_2

*T*_nom	*T*_ref	*R*_UUT_2	*T*_UUT_2	*T*_UUT_2 - *T*_ref	*U*(*T*_UUT_2 - *T*_ref)
°C	°C	Ω	°C	°C	°C
-20	-20.385	91.8810	-20.386	-0.001	0.04
0	-0.251	99.9274	-0.257	-0.006	0.04
20	19.943	107.9492	19.939	-0.004	0.04
40	40.028	115.8796	40.030	0.001	0.04
60	59.916	123.6812	59.917	0.001	0.06

TABLE 12. INRIM FINAL AIR CALIBRATION OF UUT_3

T_nom	*T*_ref	*R*_UUT_3	*T*_UUT_3	*T*_UUT_3 - *T*_ref	*U*(*T*_UUT_3 - *T*_ref)
°C	°C	Ω	°C	°C	°C
-20	-20.385	91.9070	-20.386	-0.001	0.04
0	-0.251	99.9552	-0.257	-0.006	0.04
20	19.943	107.9791	19.939	-0.004	0.04
40	40.028	115.9125	40.030	0.001	0.04
60	59.916	123.7164	59.917	0.001	0.06

UUTs drift investigation and HILC transfer standard choice

The table 13 reports the difference in °C from the final and initial INRIM calibration of the three UUTs.

TABLE 13. UUTS DRIFT BETWEEN INITIAL AND FINAL CALIBRATION IN AIR

*T*_nom	UUT_1	UUT_2	UUT_3
°C	°C	°C	°C
-20	0.004	0.002	-0.012
0	0.001	-0.008	-0.018
20	0.010	0.007	-0.011
40	0.003	-0.009	-0.018
60	-0.003	-0.013	-0.024

From the analysis of the value in the previous table is evident that the best UUT with the lowest drift is UUT_1. **So, the UUT_1 is considered the transfer standard of the HILC.**

The drift reported in the second column of the Table 13 will be considered as an additional uncertainty source in the calculation of the DoE.

Ice-bath check

In the following table is reported the value of the R_0 measured in ice bath during the HILC exercise.

TABLE 14. R_0 VALUES OF UUT_1 ALONG THE HILC

	UUT_1
	Ohm
R_0 After INRIM liquid calibration 2022	99.9831
R_0 After INRIM INITIAL air calibration	99.9819
R_0 After IMBIH air calibration	99.9877
R_0 Receving at INRIM after IMBIH shipment	99.9812
R_0 After INRIM FINAL ari calibration	99.9811

IMBIH air temperature calibration

The Table 15, 16 and 17 report the IMBIH initial in air calibration results associated to the three instruments.

TABLE 15. IMBIH AIR CALIBRATION OF UUT_1

*T*_nom	*T*_ref	*R*_UUT_1	*T*_UUT_1	*T*_UUT_1 - *T*_ref	*U*(*T*_UUT_1 - *T*_ref)
°C	°C	Ω	°C	°C	°C
-20	-20.070	91.9674	-20.066	0.004	0.125
0	0.004	99.9927	0.025	0.022	0.125
20	20.011	107.9357	20.036	0.025	0.125
40	40.112	115.8608	40.125	0.014	0.126
60	60.070	123.6898	60.094	0.024	0.125

TABLE 16. IMBIH AIR CALIBRATION OF UUT_2

*T*_nom	*T*_ref	*R*_UUT_2	*T*_UUT_2	*T*_UUT_2 - *T*_ref	*U*(*T*_UUT_2 - *T*_ref)
°C	°C	Ω	°C	°C	°C
-20	-20.070	92.0129	-20.058	0.012	0.125
0	0.004	100.0409	0.030	0.027	0.125
20	20.011	107.9870	20.039	0.028	0.125
40	40.112	115.9176	40.132	0.021	0.126
60	60.070	123.7514	60.104	0.034	0.125

TABLE 17. IMBIH AIR CALIBRATION OF UUT_3

*T*_nom	*T*_ref	*R*_UUT_3	*T*_UUT_3	*T*_UUT_3 - *T*_ref	*U*(*T*_UUT_3 - *T*_ref)
°C	°C	Ω	°C	°C	°C
-20	-20.070	92.0400	-20.058	0.012	0.125
0	0.004	100.0695	0.029	0.025	0.125
20	20.011	108.0179	20.037	0.027	0.125
40	40.112	115.9518	40.133	0.022	0.126
60	60.070	123.7875	60.103	0.033	0.125

Degree of equivalence

The comparison results can now be easily expressed in terms of degree of equivalence:

- $T_{IMBIH} - T_{INRIM}$
- $U(T_{IMBIH} - T_{INRIM}) = 2 \cdot \sqrt{u^2{}_{IMBIH} + u^2{}_{INRIM} + \left(Drift_{Transfer}/\sqrt{3}\right)^2}$

TABLE 18. INRIM-IMBIH DEGREE OF EQUIVALENCE

T_{NOM}	$T_{IMBIH-INRIM}$	$U_{IMBIH-INRiM}$ (k=2)	E_N
°C	°C	°C	°C/°C
-20	0.009	0.13	0.1
0	0.029	0.13	0.2
20	0.039	0.13	0.3
40	0.015	0.13	0.1
60	0.021	0.14	0.1

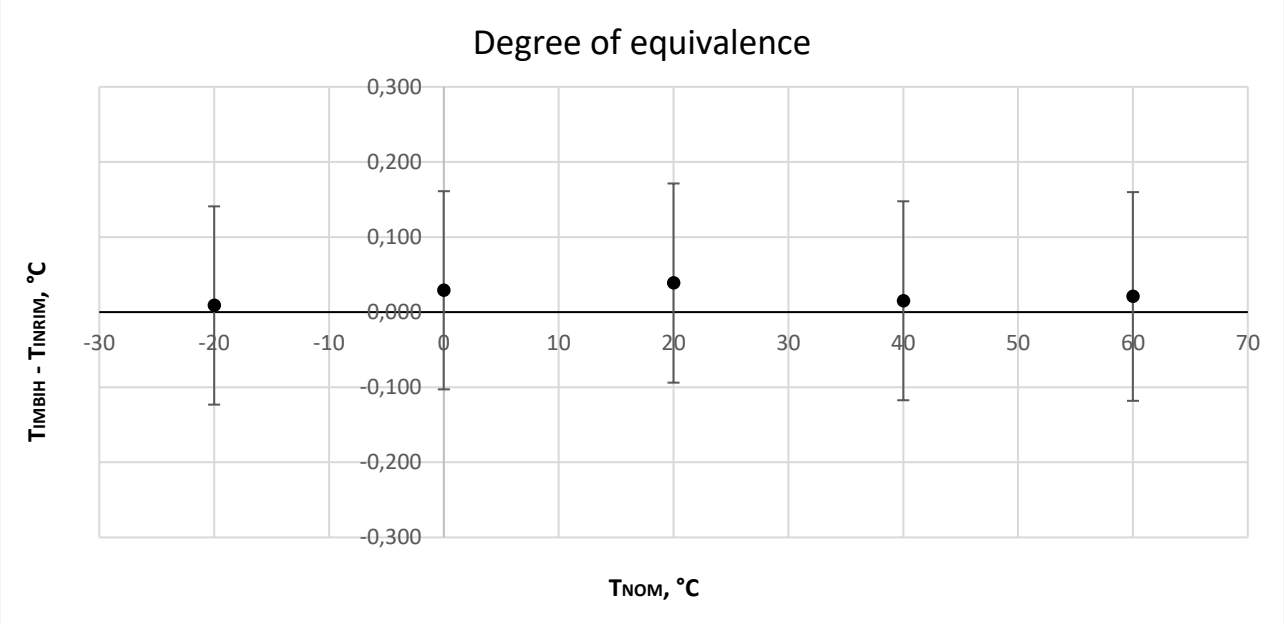

FIGURE 1. PLOT OF THE DOE BETWEEN INRIM AND IMBIH

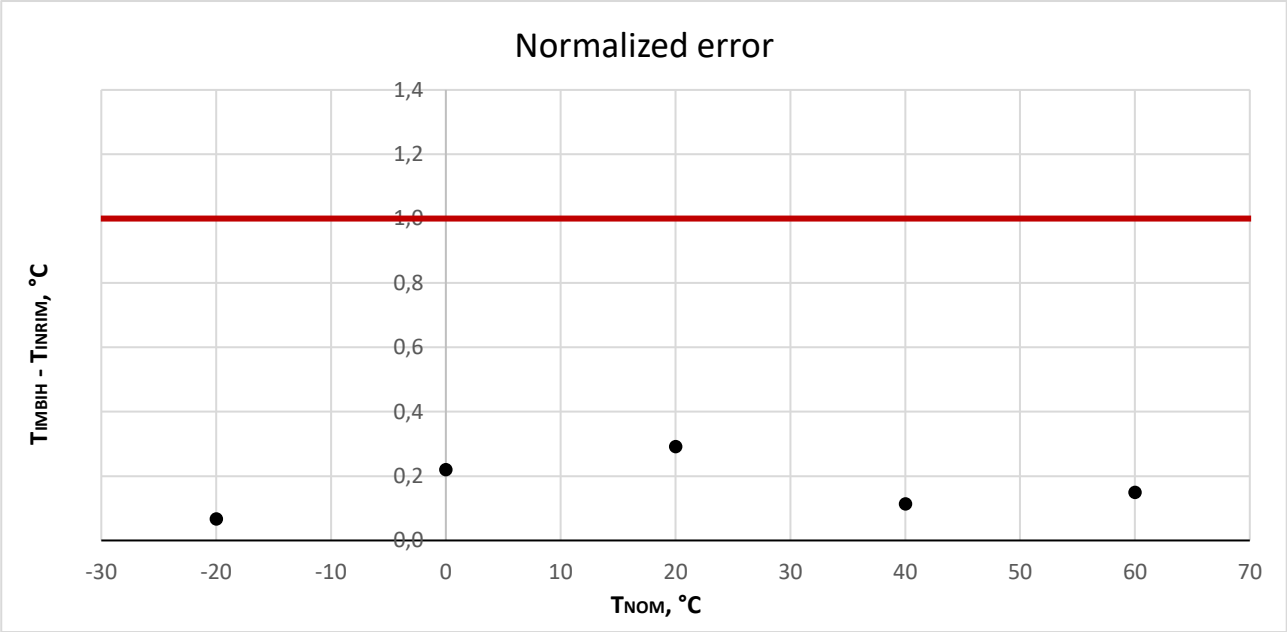

FIGURE 2. NORMALIZED ERROR AT THE CALIBRATION POINTS

Appendix: IMBIH Uncertainty Budget

Quantity		u-20 °C	u 0 °C	u 20 °C	u 40 °C	u 60 °C
Ref Temp Calibration		0,0150	0,0150	0,0150	0,0150	0,0150
Ref Temp Drift		0,0115	0,0115	0,0115	0,0115	0,0115
Ref Temp Observations		0,0000	0,0049	0,0060	0,0067	0,0000
Ref Temp Resolution		0,0029	0,0029	0,0029	0,0029	0,0029
Ref Temp Stability & Uniformity of the sub_chamber		0,0590	0,0590	0,0590	0,0590	0,0590
Radiative heating		0,0000	0,0000	0,0000	0,0000	0,0000
UUT - Calibration of resistance bridge		0,0002	0,0002	0,0002	0,0002	0,0002
UUT - Drift of resistance bridge		0,0000	0,0000	0,0000	0,0000	0,0000
UUT - Resolution of ref resistance bridge		0,0001	0,0001	0,0001	0,0001	0,0001
UUT - Hysteresis		0,0022	0,0022	0,0022	0,0022	0,0022
UUT - Selfheating		0,0065	0,0065	0,0065	0,0065	0,0065
UUT - Repeatability of resistance measurement		0,0023	0,0011	0,0003	0,0026	0,0011
Total	***u*** **°C**	**0,0625**	**0,0626**	**0,0627**	**0,0628**	**0,0624**
	k	2	2	2	2	2
	U **°C**	**0,1249**	**0,1252**	**0,1254**	**0,1257**	**0,1248**