MIKES

EURAMET P1061

COMPARISON OF AIR TEMPERATURE CALIBRATIONS

Final Report
version 5

M. Heinonen, M. Anagnostou, J. Bartolo, S. Bell, R. Benyon, R. A. Bergerud, J. Bojkovski, N. Böse, V. Fernicola, K. Flakiewicz, M. J. Martin, S. Nedialkov, M. B. Nielsen, S. Oğuz Aytekin, J. Otych, M. Pedersen, M. Rujan, D. Smorgon, N. Testa, E. Turzó-András, A. Uytun, M. Vilbaste, M. White

Espoo, 19 January 2015

Contents

Version updates:

Version 5: A. Uytun was added to the author list

1 Background

It was agreed in the EURAMET TC-T Meeting in Delft in April 2008 that MIKES will co-ordinate a comparison of air temperature calibrations. The main objective of the project is to investigate the reliability and equivalence of calibration methods used by NMIs in calibrating air thermometers, i.e. thermometers that are used for measuring air temperature and are also calibrated in air (not immersed in a liquid bath). The focus of this project is in the errors due to self-heating and thermal radiation. The results can also be benefitted in developing RH CMC review protocol

2 Organisation

2.1 Method

In this project the effects specific to air temperature measurements and calibrations were studied by comparing calibrations performed by the participants with facilities of different types.

The comparison was carried out using an ASL F250 thermometer bridge with two Pt 100 probes and an HMT335 thermohygrometer as the transfer standards. The comparison covered the range -40 °C to +150 °C. Each laboratory carried out measurements at five measurement points covering the whole air temperature calibration range of the laboratory.

As the pilot laboratory, MIKES performed several calibrations for the transfer standards

2.2 Participants

Laboratories participated in this project are listed in Table 1. As shown in Table 2, many laboratories used subchambers of different kinds located in larger temperature controlled chambers to improve temperature control, enable and/or improve humidity control and minimise the effect of radiation heat transfer with chamber walls at slightly different temperatures. These subchambers are made of stainless steel, aluminium, copper or wood and their volume ranges from few decilitres to one litre. The subchambers of GUM and MIRS/UL-FE/LMK are equipped with a fan maintaining air circulation between the subchamber and its temperature controlled environment. Because of the outwards flow direction, the heat dissipated by the fan does not cause a temperature gradient in the subchamber. It is worth noticing that the air speed in most of the subchambers is significantly smaller than in the larger temperature controlled chambers without subchambers.

The volumes of the climatic chambers and other larger temperature controlled chamber ranges from 30 to 300 litres. The air speed is typically at the level of few meters per second. However, the air speed in the chamber of Thunder 2500 humidity generator is significantly smaller.

Traceability of temperature measurements is obtained by calibrating the reference thermometers by comparison in liquid bath and including the effects of thermal radiation and self-heating in the uncertainty analysis

Table 1 List of lab oratories participated in this comparison project

Lab. no.[1]	Laboratory id	Full name of the laboratory, town, country
1	MIKES	Centre for Metrology and Accreditation (MIKES), Espoo, Finland
2	MKEH	Hungarian Trade Licensing Office (MKEH), Budapest, Hungary
3	CEM	Centro Español de Metrología (CEM), Madrid, Spain
4	INTA	Instituto Nacional de Técnica Aeroespacial (INTA), Madrid, Spain
5	GUM	Central Office of Measures (GUM), Warsaw, Poland
6	CMI1033	Czech Metrology Institute (CMI), Prague, Czech Republic
7	CMI6036	Czech Metrology Institute (CMI), Brno, Czech Republic
8	INRIM	Istituto Nazionale di Ricerca Metrologica (INRIM), Turin, Italy
9	TCUT	Testing Centre,University of Tartu (TCUT), Tartu, Estonia
10	MCCAA	MCCA-Standards and Metrology Institute (MCCA-SMI), Kordin, Malta
11	EIM	Hellenic Institute of Metrology (EIM), Thessaloniki, Greece
12	BIM	Bulgarian Institute of Metrology (BIM), Sofia, Bulgaria
13	BRML-INM	National Institute of Metrology (BRML-INM), Bucharest, Romania
14	NML NSAI	National Metrology Laboratory (NSAI NML), Dublin, Ireland
15	NPL	National Physical Laboratory (NPL), Teddington, UK
16	DTI	Danish Technological Institute (DTI), Aarhus, Denmark
17	MIRS/UL/FE-LMK	University of Ljubljana, Faculty of Electrical Engineering (MIRS/UL/FE-LMK), Ljubljana, Slovenia
18	JV	Norwegian Metrology Service (JV), Oslo, Norway
19	TUBITAK-UME	TÜBİTAK Ulusal Metroloji Enstitüsü (UME), Kocaeli, Turkey
20	PTB	Physikalisch-Technische Bundesanstalt (PTB),Braunschweig, Germany

[1] The laboratory number was given in the order of registration.

Table 2 Summary of air temperature calibration set-ups and temperature references used in this comparison

Lab. No.[1]	Laboratory [2]	Calibration set-up	Temperature reference
1	MIKES	a: Temperature controlled chamber Vötsch VT7004 b: Stainless steel subchamber in a climatic chamber Heraeus-Vötsch HC4020	a1: Two Pt100 (diam. 5 mm) connected to ASL F700B resistance bridge a2: Two Pt100 (diam. 1.6 mm) connected to a ASL F700B resistance bridge b: ASL F250 MkII digital thermometer with 2 Pt100 (diam. 1.6 mm)
2	MKEH	Self-designed air duct loop with heat flux free temperature field.	Anton Paar MKT 100 with a pair of PRTs
3	CEM	Peltier controlled air chamber, SELECTA	2 Pt100 connected to ASL F700 thermometric bridge
4	INTA	Stainless steel subchamber in a temperature controlled chamber Vötsch VT 7034	ASL F250 digital thermometer with four PRTs
5	GUM	Glass-Steel subchamber with a fan in a Heraeus-Vötsch HC7047	Digital quartz thermometer type 511E and ASL F600 thermometric bridge with 10 channel scanner and PRT sensors
6	CMI1033	Climatic chamber WEISS WK3-180/40	ASL F250 digital thermometer with two Pt100
7	CMI6036	Climatic Chamber	ASL F250 MkII digital thermometer with two Pt100 a Pt100 connected to ASL F17B resistance bridge
8	INRIM	Nickel-coated copper subchamber in a climatic chamber Weiss 300	Digital thermometer bridge, a Pt100 aspirated thermometer with radiation shield , two thermistors for axial uniformity
9	TCUT	Climatic Chamber Weiss WK 111-340	Michell S4000 dew-point/temperature meter with a Pt100
10	MCCAA	Thunder 2500 humidity generator	Secondary SPRT connected to Hart 1590 thermometer bridge
11	EIM	Climatic chamber Heraeus-Vötsch 4033	MBW DP30 dew-point/temperature meter with a Pt100
12	BIM	Climatic chamber CTS, type T -40/50	Digital Thermometer DTP 09A with Pt 100
13	BRML-INM	Climatic chamber, Angelantoni CH 340	Two digital thermometers Fluke 1502A with Pt100
14	NML NSAI	Climatic chamber Vötsch VC 7018	Hart Blackstack with three Pt100 (diam. 3 mm)
15	NPL	Stainless steel subchamber in a Montford Instruments climatic chamber	Three Pt100 connected to ASL F17 resistance bridge
16	DTI	Metal black box in a Thunder 2500 generator	Digital thermometer Hart Blackstack with four Pt100
17	MIRS/UL/FE-LMK	a: Wooden black box with fan in a Vötsch 7100 b: Copper insert in a Thunder 2500 generator	Ten Pt-100 thermometers connected to to digital multimeter HP34420A with Keithley 7001 scanner Five thermistors connected to digital multimeter HP34420A with Keithley 7001 scanner
18	JV	Climatic chamber Weiss SB22/160/40	ASL F250 digital thermometer with two Pt100
19	TUBITAK-UME	a: small stainless steel cylindrical capsule in a Thunder 2500 b: small stainless steel cylindrical capsule in a Weiss WK1-1000/70/5-LN2	SPRT connected to Fluke 1529-R thermometer bridge
20	PTB	test chamber of the PTB 2P-humidity generator	Pt25 connected to Anton Paar MKT25 thermometer bridge

[1] The laboratory number was given in the order of registration.
[2] The full names of the laboratories are given in Table 1.

2.3 Scheme

Transfer standards of this comparison consisted of a thermohygrometer and two platinum resistance thermometer (PRT) probes connected to a thermometer bridge. Each laboratory calibrated these instruments at five nominal temperatures in ascending order covering the air temperature calibration range of the laboratory. The number of measurement points was limited to five to reduce the total duration of the project. On the other hand, the optimal match of the comparison points with the calibration range of each laboratory was achieved by allowing to choose the points as any subset of -40 °C, -30 °C, -20 °C, -10 °C, -5 °C, +10 °C, +20 °C, +30 °C, +40 °C, +50 °C, +60 °C, +70 °C, +80 °C, +90 °C, +100 °C, +120 °C, +150 °C and +180 °C. Last three points, however, were not allowed after replacing one of the transfer standard PRTs. The last point (180 °C) was only measured by the coordinator; therefore this point was dropped off from the analysis of results. As shown in table 2, there are significant differences in calibration ranges between the participants. MIKES carried out calibrations in air and in liquid bath at all measurements points to enable reliable comparison of results obtained in different subranges.

The comparison was started as a subloop between the laboratories no 1 to 5 listed in Table 1. After checking by MIKES that the results are useful, the comparison was decided to continue with the same approach. Table 3 shows the dates of measurement at different laboratories. A significant delay between INRIM and TCUT was caused by the break of one of the PRTs

Table 3 Calibration dates and measurement points of the participants

Lab. No.[1]	Laboratory	Date of Calibration	Calibration points [2]
1	MIKES	1: January to March 2009 2: July to August 2009 (October 2010) [1] 3: February 2012 to June 2013	a1: all points -40 °C to +90 °C a2: all points -40 °C to +180 °C b : all points -36 °C to +90 °C
2	MKEH	March 2009	-5 °C, +10 °C, +20 °C, +30 °C, +40 °C
3	CEM	June 2009	+10 °C, +20 °C, +30 °C, +40 °C, +50 °C
4	INTA	May 2009	-40 °C, +10 °C, +50 °C, + 90 °C, +150 °C
5	GUM	July 2009	-40 °C, -5 °C, +20 °C, +50 °C, +90 °C
6	CMI1033	January 2010	-30 °C, +10 °C, +40 °C, +80 °C, +150 °C
7	CMI6036	January 2010	-30 °C, +10 °C, +40 °C, +80 °C, +150 °C
8	INRIM	February 2010	-20 °C, +10 °C, +30 °C, +50 °C, +80 °C
9	TCUT	November 2010	-10 °C, +10 °C, +20 °C, +50 °C, +80 °C
10	MCCAA	March 2011	+10 °C, +20 °C, +30 °C, +40 °C, +50 °C
11	EIM	February 2011	-40 °C, -10 °C, +20 °C, +50 °C, +80 °C
12	BIM	February 2011	-20 °C, +5 °C, +20 °C, +40 °C, +60 °C
13	BRML-INM	April 2011	-20 °C, +10 °C, +30 °C, +50 °C, +100 °C
14	NML NSAI	September 2011	-40 °C, -10 °C, +30 °C, +60 °C, +100 °C
15	NPL	May 2011	-40 °C, +10 °C, +30 °C, +80 °C, +100 °C,
16	DTI	June 2011	-10 °C, +10 °C, +30 °C, +50 °C, +70 °C
17	MIRS/UL/FE-LMK	July 2011	a:-40 °C, -20 °C, +40 °C, +70 °C, +100 °C b: -7 °C, +20 °C, +40 °C, +60 °C, +70 °C
18	JV	September 2011	-40 °C, 0 °C, +20 °C, +40 °C, +80 °C
19	TUBITAK-UME	October 2011	a:-10 °C, +10 °C, +30 °C, +50 °C, +70 °C b:-40 °C, -10 °C, +30 °C, +70 °C, +100 °C
20	PTB	January 2012	+10 °C, +20 °C, +30 °C, +40 °C, +50 °C

[1] Calibration was only performed in liquid.
[2] Reference to different calibration set-ups are described in Table 1.

3 Transfer standards

3.1 Platinum resistance thermometers

A pair of 100 ohm PRTs with different dimensions and surface properties was primarily used as the transfer standard in this comparison. One of the PRTs (named as ChA) was a rod type stainless steel probe manufactured by Pentronic. It was covered by a black painted stainless steel tube when performing measurements in air (see Fig. 3.1). When performing stability checking in liquid baths, the cover was removed. The diameter and length of the ChA probe are 2.2 mm and 250 mm, respectively. The diameter of the cover is 3 mm.

Until break between INRIM and TCUT, the other PRT (named as ChB1) was a rod type stainless steel probe manufactured by Hart Scientific with length of 230 mm and diameter of 5 mm. It was replaced by a stainless steel capsuled PRT (named as ChB2) with length of 25 mm and diameter of 3 mm.

To avoid inconsistencies in measurement current etc. the transfer standard package included a thermometer bridge ASL F250 (s/n 1365030997) that was used to measure the resistance of the PRTs. The measurement current of the bridge is 1 mA, and the full resolution of 1 m▪ was used in all measurements. The probes were named according to the input channels of the bridge as used in this project.

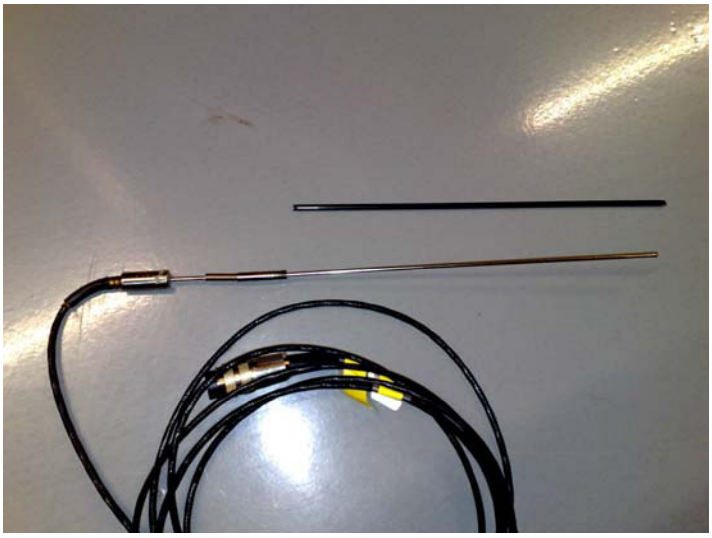


Figure 3.1 The probe A with its cover and when pulled apart from its handle part.

3.2 Thermohygrometer

As air temperature measurements are highly relevant to humidity measurements, a Vaisala HMT335 thermohygrometer (s/n Z4610004) was included in the transfer standard package for collecting information relevant to calibrations of this type of instruments. The length and diameter of the metal covered probe are 240 mm and 13.5 mm, respectively. The probe of the thermohygrometer HMT335 was not exposed to direct contact with water or other liquids. Although both relative humidity and temperature readings were recorded, only the temperature readings were used for the comparison.

3.3 Stability of the transfer standards

Calibrations in liquid baths were performed for detecting possible drift of the transfer standard PRTs during the comparison. All laboratories performed these calibrations at +10 °C and +80 °C before and after their calibrations in air. MIKES calibrations included several points covering the whole comparison range at beginning and end of the project and the range below +100 °C in intermediate checks. The probe ChB2 was never calibrated above +100 °C. All the measurements were performed with the ASL F250 thermometer bridge in terms of resistance. In these calibrations, ChA was measured without the black painted stainless steel tube cover and ChB2 was measured in a protective glass tube.

Fig. 3.2 shows the drift of ChA as determined from the results of MIKES calibrations in liquid baths. All results are presented as the temperature difference to the first calibration at MIKES in January 2009. Similarly, results of MIKES results for ChB1 and ChB2 are shown in Fig. 3.3. However, it should be noticed that the uncertainty for ChB2 is significantly larger than for the other thermometer probes because the calibrations were performed in the glass tube.

The results of the calibrations performed by all participants in liquid baths at +10 °C and +80 °C are summarised in figures 3.4 to 3.6. The reported expanded uncertainties of the reference temperature values range from 0.005 °C to 0.033 °C while the deviations of the resistance readings were significantly smaller. These uncertainty values do not include the effect of the protective glass tube.

The results of partners agree well with the MIKES stability monitoring data. A clear drift cannot be identified in the results of figures 3.2 to 3.6 but corresponding standard uncertainties were assigned for all thermometer probes: 0.006 °C for ChA, 0.003 °C for ChB1 and 0.006 °C for ChB2.

The repeatability of results was estimated by comparing the results obtained by the participants in liquid baths before and after calibrations in air. The repeatability was within ± 0.010 °C. A few results show larger values but these were assumed to be due to the uncertainty related to the use of the glass tube with ChB2.

For determining possible drift in the temperature measurement of the thermohygrometer, MIKES results obtained in air before and after all other laboratories were compared to each other. These results shown graphically in Fig. 3.7 indicate that the instrument has been stable and the corresponding standard uncertainty is 0.010 °C. A larger deviation of the results can be seen in the range below 0 °C but this is due to a larger heat conduction error in January 2009 (the calibration was performed in smaller chamber than in April 2013).

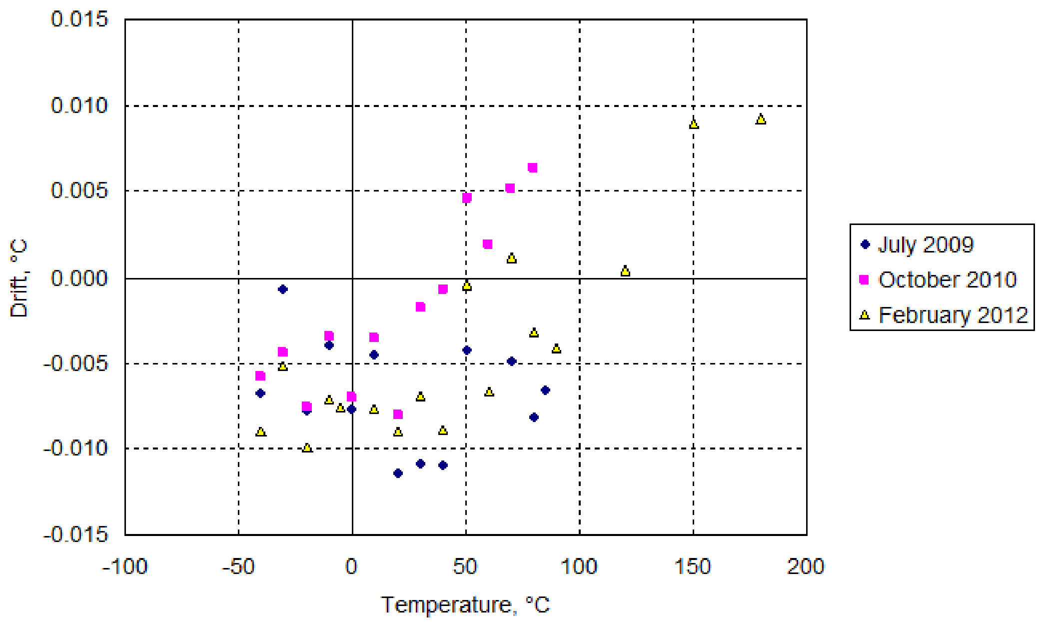


Figure 3.2 The drift of the probe ChA connected to the ASL F250 resistance bridge as determined from the results of the MIKES calibrations in liquid. The results are presented as the difference to the calibration in January 2009. The expanded uncertainty of the calibrations ($k = 2$) was 0.008 °C and 0.017 °C in the ranges below and above +100 °C, respectively.

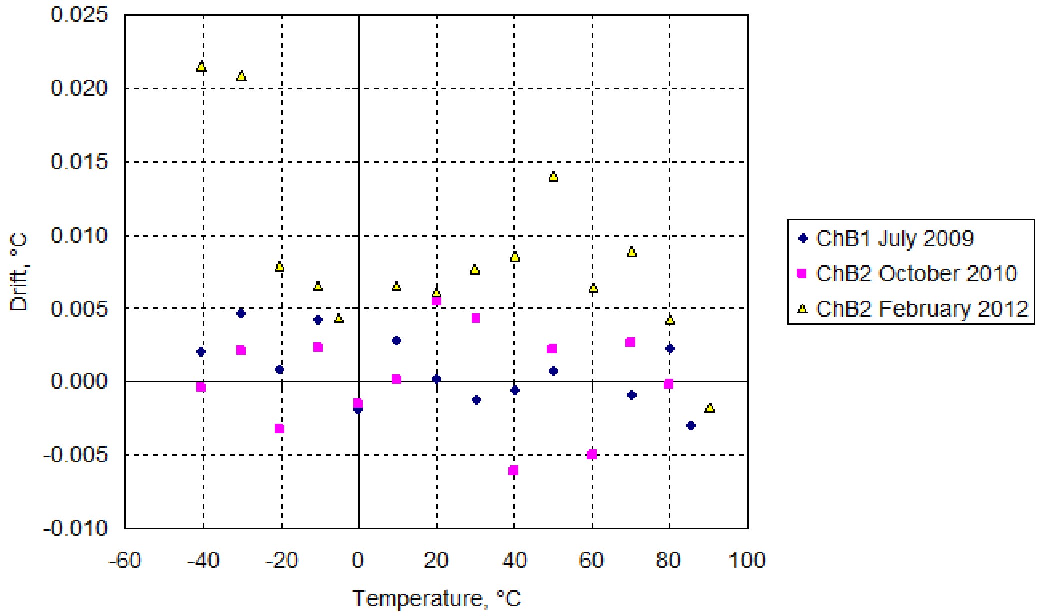


Figure 3.3 The drift of the probes ChB1 and ChB2 connected to the ASL F250 resistance bridge as determined from the results of the MIKES calibrations in liquid. The results for ChB1 and ChB2 are presented as the difference to the calibration in January 2009 and October 2010, respectively. The expanded uncertainty of the calibrations ($k = 2$) was 0.008 °C for ChB1 and 0.030 °C for ChB2.

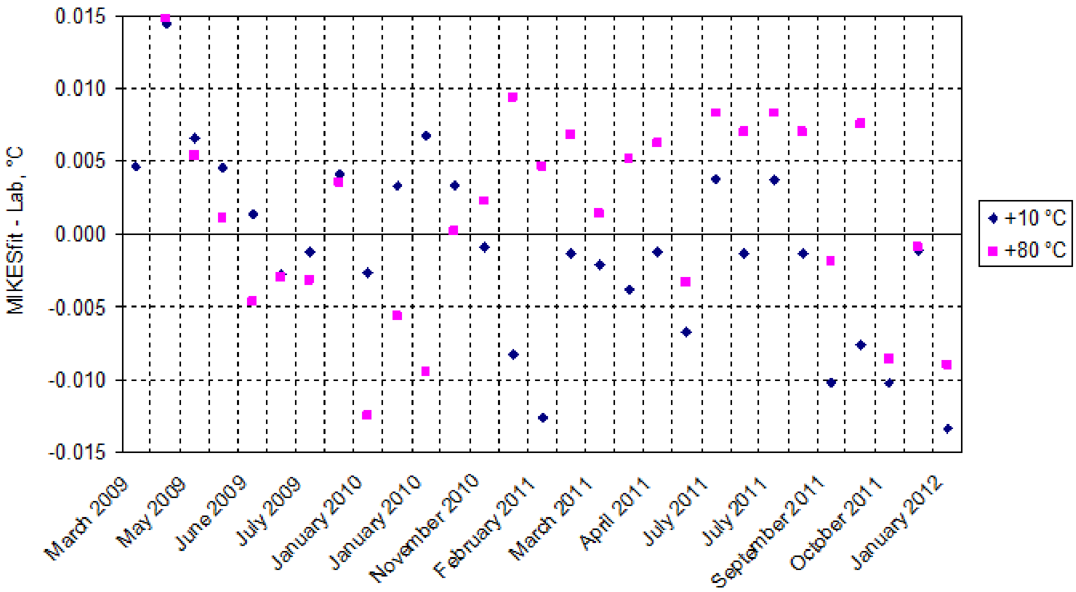


Figure 3.4 The drift of the probe ChA connected to the ASL F250 resistance bridge as determined from the results of the calibrations in liquid reported by the participants. The results are presented as the difference to the MIKES calibration in liquid in January 2009. The reported expanded uncertainties of the reference temperature values are between 0.005 °C and 0.033 °C ($k = 2$). Note: the time scale on x-axis is not even.

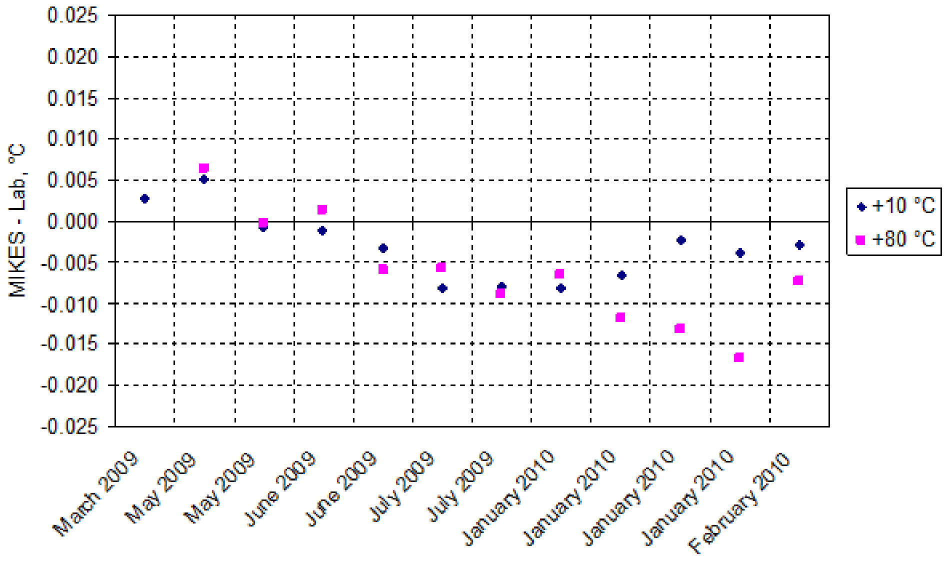


Figure 3.5 The drift of the probe ChB1 connected to the ASL F250 resistance bridge as determined from the results of the calibrations in liquid reported by the participants. The results are presented as the difference to the MIKES calibration in liquid in January 2009. The reported expanded uncertainties of the reference temperature values are between 0.005 °C and 0.033 °C (k = 2). Note: the time scale on x-axis is not even.

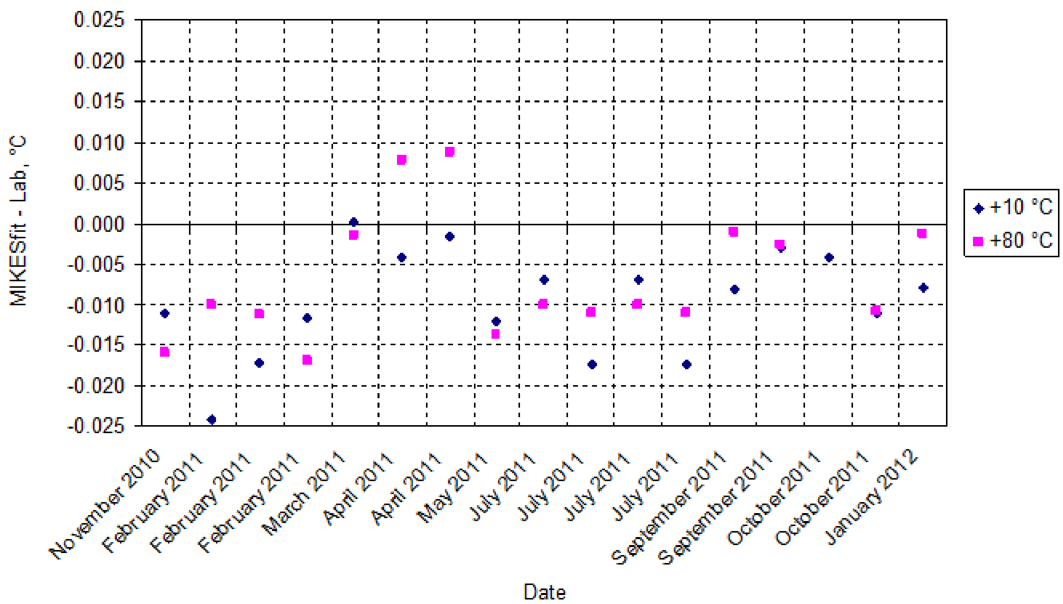


Figure 3.6 The drift of the probe ChB2 connected to the ASL F250 resistance bridge as determined from the results of the calibrations in liquid reported by the participants. The results are presented as the difference to the MIKES calibration in liquid in October 2010. The reported expanded uncertainties of the reference temperature values are between 0.005 °C and 0.033 °C (k = 2). Note: the time scale on x-axis is not even.

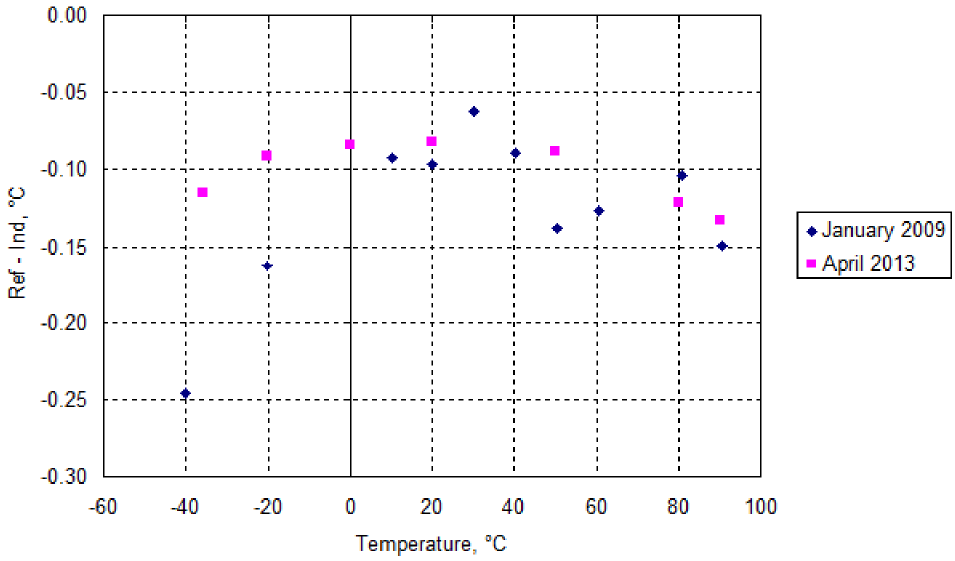


Figure 3.7 Comparison of calibration results obtained by MIKES in air for the thermo-hygrometer. The expanded uncertainties of the reference temperature values are between 0.04 °C and 0.10 °C ($k = 2$).

3.4 Self-heating and Effect of Cables

Self-heating studies were performed for ChA and a thermometer probe identical to ChB2. In the first study, the resistance of the ChA probe was measured at MIKES with an ASL F700B resistance bridge using measurement currents of 0.1 mA and 1 mA. These measurements were performed at -30 °C and +90 °C with and without a sub-chamber in the MIKES climatic chamber. In the former case, the air speed was at a level of 1 m/s whereas in the latter case measurements were done in still air and with air speed of about 5 mm/s. In the open climatic chamber, the effect of the change in heat dissipation was less than 10 mK at -30 °C and 37 mK at +90 °C. In the subchamber, the effect was about 20 mK at both temperatures. According to a test at DTI, the effect for a thermometer probe identical to ChB2 was 36 mK at +70 °C.

The effect of heat conduction along the cables was studied at MIKES with ChA and HMT335 at +90 °C by varying the length of the cable inside the climatic chamber between 40 cm and 100 cm. We could not identify any correlation between the reading and the cable immersion length.

4 Comparison of Calibration Results

4.1 Results Obtained with a Single PRT

To obtain an overall picture of comparability between calibrations performed with different methods, all calibration systems were compared to each other. Only the ChA provides results for direct comparison between all participants of this project because the ChB1 was replaced with the ChB2 during the project. For the comparison, a characteristic equation, Rc(t), based on the IEC60751 standard [6] was fitted in the results of the first MIKES calibration in liquid baths. All results of calibrations in air are compared to the characteristic curve:

$$\Delta t_i = \left[R_i - R_c(t_{Ri})\right]\left(\frac{\partial R_c(t_{Ri})}{\partial t_{Ri}}\right)^{-1} \qquad (1)$$

Here, Ri and tRi are the measured resistance of ChA and corresponding air temperature determined by the laboratory i in air calibrations, respectively. To take the uncertainties of measurement results into account in the analysis, a comparison reference function, Δt_{crf}, was determined by means of weighted nonlinear least square fitting in the Δt_i data. The uncertainties of the reference temperature values determined by the participating laboratories were used as the weights. The fitting was carried out using CurveExpert software that uses the Levenberg-Marquardt method [7]. The best fit was found to be:

$$\Delta t_{crf}(t) = \sum_{j=0}^{2} a_j t^j \qquad (2)$$

where a_0 = 0.0159174 °C, a_1 = -2.76058 × 10^{-4} and a_2 = -1.41652 × 10^{-6} °C^{-1}. The uncertainty of the function was calculated as the standard deviation of fitting residuals weighted by the uncertainties. The resulting standard uncertainty is 0.0005 °C. It should be noted, however, that this value does not include the uncertainties of individual measurements nor the uncertainty due to the drift of the transfer standard. All Δt_i values and the comparison reference function are shown graphically in Fig. 4.1. Results with standard uncertainties smaller and larger than 0.04 °C, respectively, are shown with different colours in the figure. When comparing to the distance from the comparison reference function, we can see that the distance and the uncertainty correlates well in most cases.

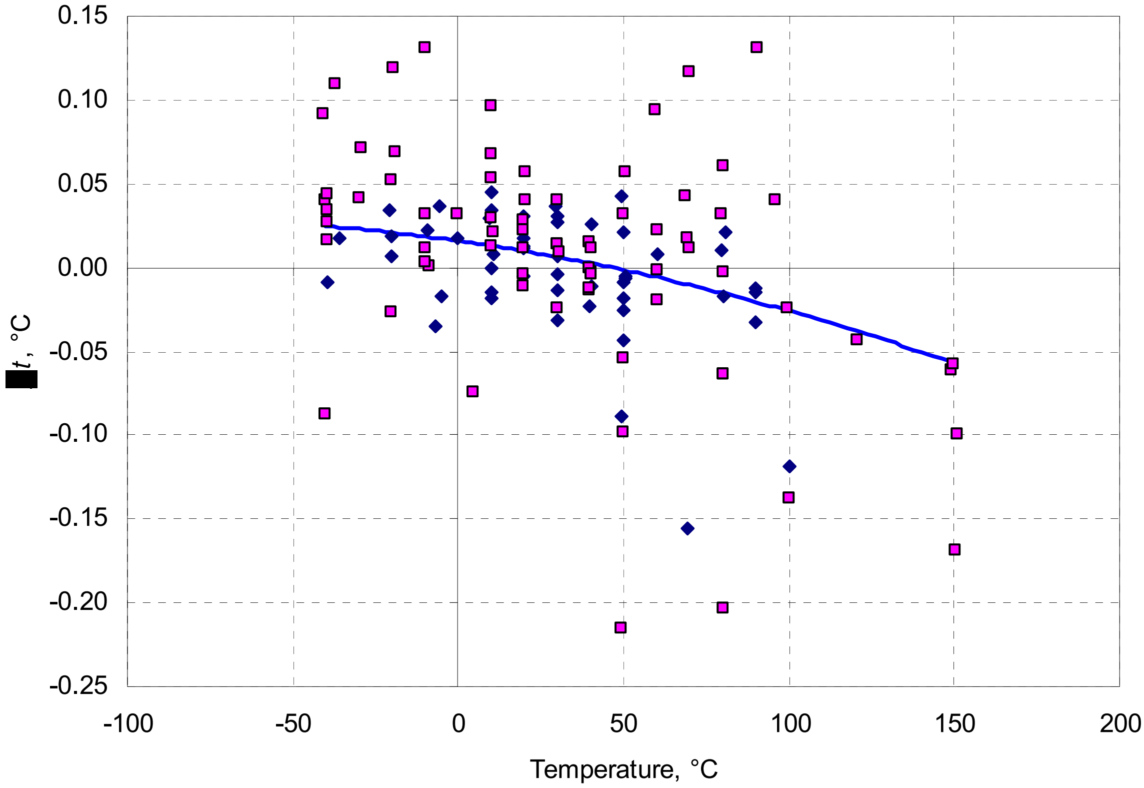


Figure 4.1 Differences between calibrations in air performed by all laboratories and the first MIKES calibration in liquid (Δt_i). Dark blue diamonds show results with estimated standard uncertainties in air smaller than 0.04 °C. The results with larger uncertainties are shown with pink squares. The solid line shows the comparison reference function (Δt_{crf}).

Determined Δt_i values represent differences between the calibrations in air and liquid in the system of laboratory i whereas the difference

$$d_i = \Delta t_{crf}(t_{Ri}) - \Delta t_i \qquad (3)$$

shows the equivalence of the result obtained at the temperature t_{Ri} with the calibration system of laboratory i to the results obtained with all calibration systems involved in this comparison. Because the standard uncertainties of the reference temperature values ranges from 0.01 °C to 0.19 °C, it is useful to normalise the difference d_i with its expanded uncertainty ($k = 2$):

$$D_{ni} = \frac{\Delta t_{crf}(t_{Ri}) - \Delta t_i}{2\,u(d_i)} = \frac{\Delta t_{crf}(t_{Ri}) - \Delta t_i}{2\sqrt{u^2(t_{Ri}) - u^2(\Delta t_{crv}) + u_d^{\ 2}}} \qquad (4)$$

Here u_d is the standard uncertainty due to the drift of the transfer standard. The negative sign in the denominator of Eq. (4) is due to the correlation between t_{Ri} and Δt_{crf} through Δt_i.

As Fig. 4.2 shows, most of the normalised differences (D_n) are within ±1 indicating that the uncertainty estimations performed by the laboratories are mostly realistic. However, some results show larger deviation than its uncertainty and also significant temperature dependent trends can be identified in some results.

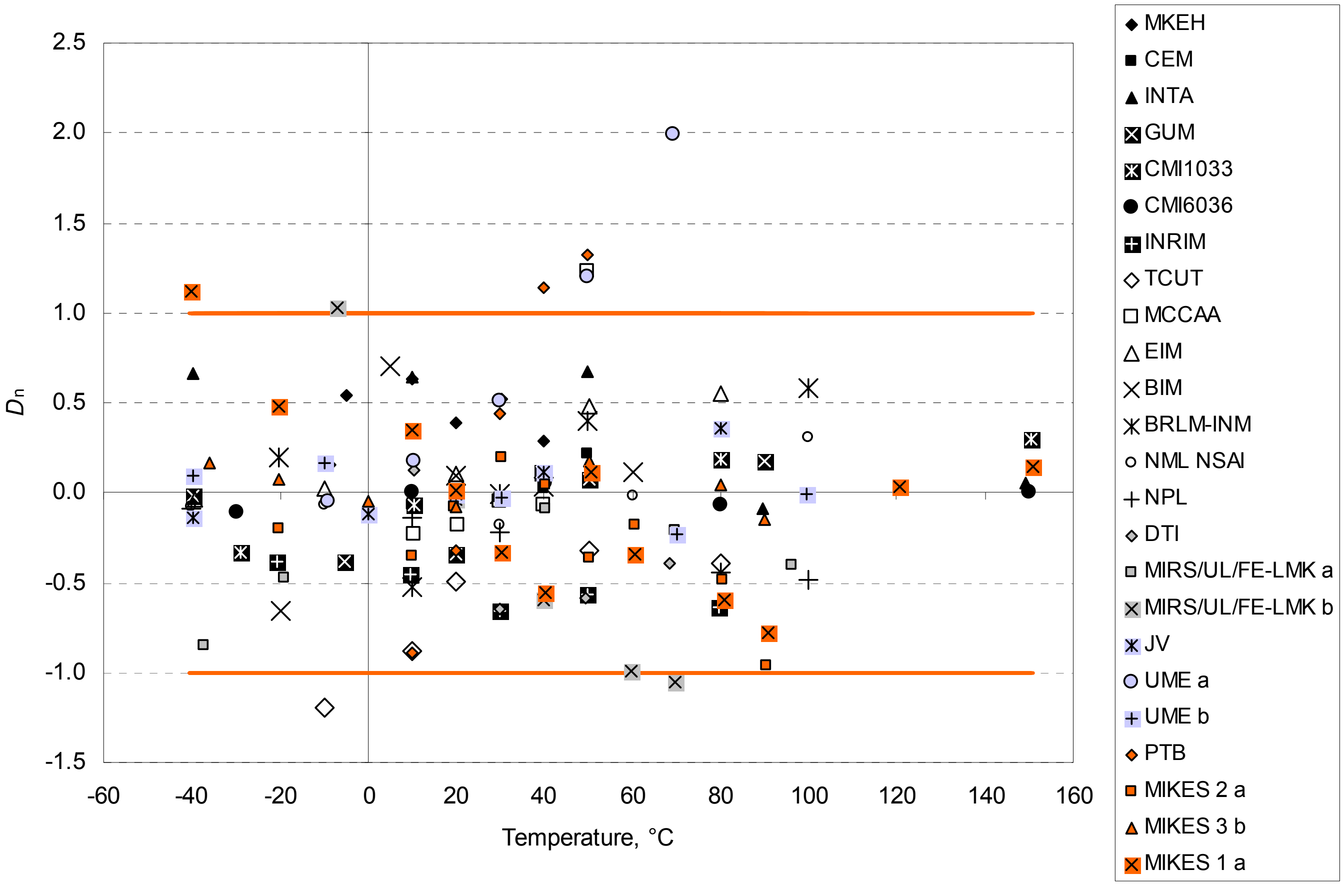


Fig. 4.2 Normalised differences (D_n) of all air calibration results for ChA determined by the participants. The mean values of the results between the solid lines are smaller than their expanded uncertainties (k = 2). The letters in MIRS/UL/FE-LMK, UME and MIKES labels refer the calibration setups listed in Table 2. The numbers in MIKES result labels refer to the measurement periods listed in Table 3.

4.2 Results Obtained with Pairs of PRTs

When investigating the results in two parts, i.e. before and after the replacement of ChB thermometer probe, we can combine results of two thermometer probes of different kinds. The results are analysed in the same way as in Section 4.1 except we replace Δt_i with Δt_{ABi} defined as:

$$\Delta t_{ABi} = (\Delta t_{Ai} + \Delta t_{Bi}) / 2 \qquad (5)$$

where Δt_{Ai} and Δt_{Bi} are the differences according to Eq. (1) for the probe ChA and ChB1 (first comparison part) or ChB2 (second comparison part), respectively. Also, the comparison reference function similar to Eq. (2) was fitted separately to part 1 and part

2 results. As the result, the fitting parameters for the part 1 function are a_0 = 7.1351 × 10^{-3} °C, a_1 = -1.3333 × 10^{-4} and a_2 = -8.1492 × 10^{-7} °C^{-1}. For the part 2 function, the parameters are: a_0 = -1.0455 × 10^{-3} °C, a_1 = 4.2173 × 10^{-4} and a_2 = -4.6605 × 10^{-6} °C^{-1}. Table 4 gives a summary of the deviations from the comparison reference functions and the uncertainties of the deviations.

Normalised differences were calculated with Eq. (4) for part 1 and 2 are shown in Fig. 4.3. The symbols of the part 1 results are the first seven in the label list. Also, the MIKES 1 results belong to part 1 results.

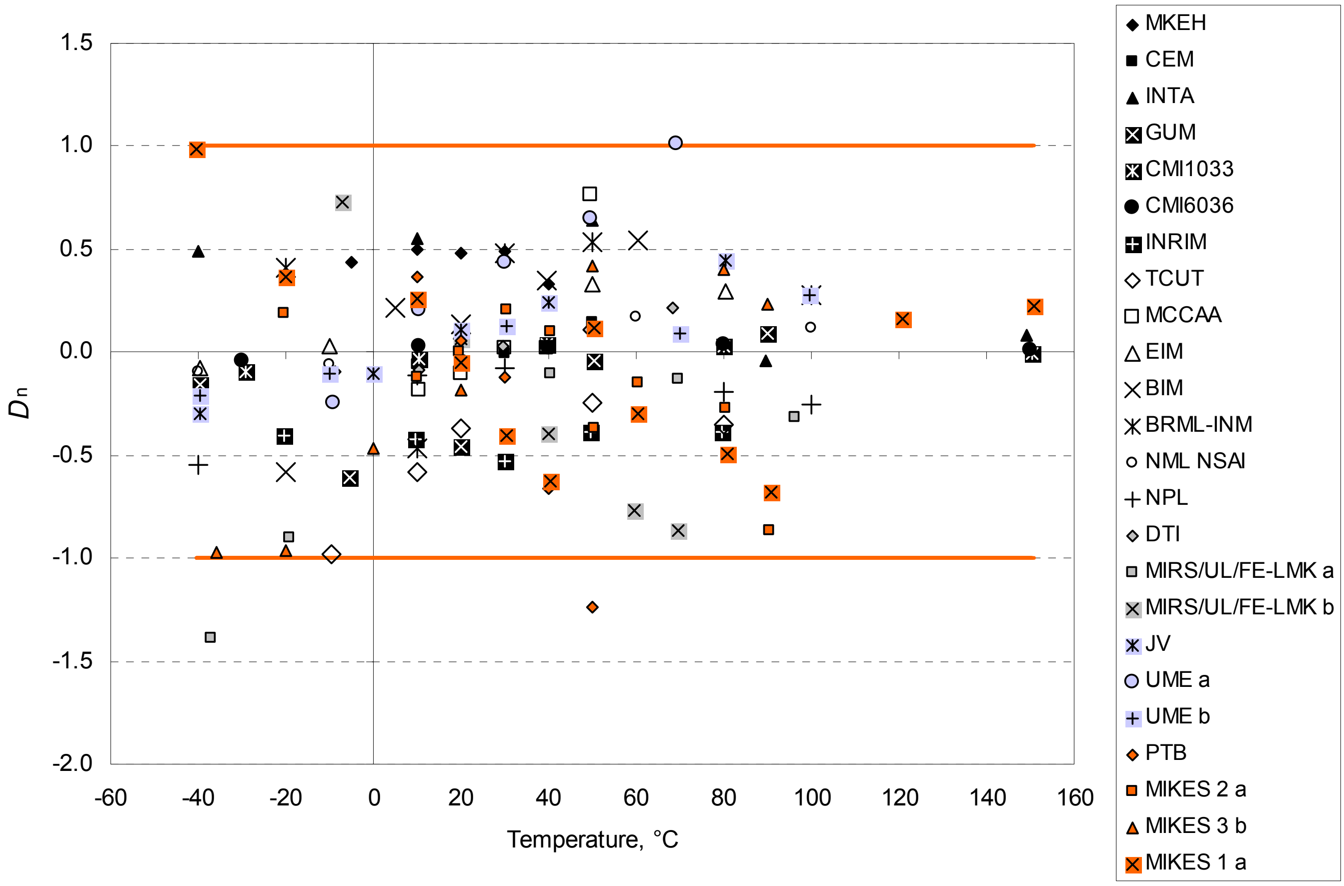


Fig. 4.3 Normalised differences (D_n) of combined air calibration results in comparison part 1 (first seven laboratories in the label list and MIKES 1) and part 2. The mean values of the results between the solid lines are smaller than their expanded uncertainties (k = 2). The letters in MIRS/UL/FE-LMK, UME and MIKES labels refer the calibration setups listed in Table 2. The numbers in MIKES result labels refer to the measurement periods listed in Table 3.

When comparing Fig. 4.2 and Fig.4.3 to each other, we can see that the agreement of the results is better in the latter one. Because the long-term stability of the transfer standard probes were about the same (see Section 2), the better agreement is most probably due to lower sensitivity of ChB1 and ChB2 to environmental conditions (air velocity and thermal radiation).

Table 4 Differences between the results obtained by the laboratories and the corresponding comparison reference functions (d_{BAi}) with the estimated expanded uncertainties (U)).

Lab.	d_{BAi}	$U(d_{ABi})$	d_{BAi}	$U(d_{ABi})$	d_{BAi}	$U(d_{ABi})$	d_{BAi}	$U(d_{ABi})$	d_{BAi}	$U(d_{ABi})$
	-5 °C		10 °C		20 °C		30 °C		40 °C	
MKEH	0.027	0.062	0.024	0.048	0.018	0.037	0.018	0.037	0.015	0.046
	10 °C		20 °C		30 °C		40 °C		50 °C	
CEM	-0.015	0.240	-0.011	0.240	-0.002	0.240	0.007	0.240	0.035	0.240
	-40 °C		10 °C		50 °C		90 °C		150 °C	
INTA	0.024	0.049	0.024	0.043	0.022	0.034	-0.002	0.058	0.008	0.095
	-40 °C		-5 °C		20 °C		50 °C		90 °C	
GUM	-0.018	0.114	-0.031	0.050	-0.029	0.062	-0.002	0.042	0.007	0.070
	-30 °C		10 °C		40 °C		80 °C		150 °C	
CMI1033	-0.014	0.148	-0.004	0.109	0.005	0.139	0.007	0.263	-0.002	0.372
	-30 °C		10 °C		40 °C		80 °C		150 °C	
CMI6036	-0.008	0.170	0.004	0.115	0.002	0.117	0.007	0.176	0.003	0.279
	-20 °C		10 °C		30 °C		50 °C		80 °C	
INRIM	-0.014	0.035	-0.015	0.035	-0.018	0.035	-0.015	0.039	-0.015	0.039
	-10 °C		10 °C		20 °C		50 °C		80 °C	
TCUT	-0.092	0.094	-0.055	0.094	-0.035	0.094	-0.026	0.104	-0.041	0.118
	10 °C		20 °C		30 °C		40 °C		50 °C	
MSA	-0.032	0.174	-0.018	0.174	0.004	0.174	0.003	0.174	0.134	0.174
	-40 °C		-10 °C		20 °C		50 °C		80 °C	
EIM	-0.020	0.260	0.007	0.260	0.019	0.200	0.067	0.200	0.100	0.340
	-20 °C		5 °C		20 °C		40 °C		60 °C	
BIM	-0.088	0.151	0.027	0.127	0.022	0.159	0.041	0.119	0.065	0.120
	-20 °C		10 °C		30 °C		50 °C		100 °C	
INM [a]	0.029	0.070	-0.028	0.061	0.015	0.031	0.022	0.041	0.045	0.160
	-40 °C		-10 °C		30 °C		60 °C		100 °C	
NML [b]	-0.019	0.200	-0.010	0.182	0.003	0.186	0.028	0.160	0.043	0.360
	-40 °C		10 °C		30 °C		80 °C		100 °C	
NPL	-0.044	0.080	-0.009	0.080	-0.006	0.080	-0.015	0.080	-0.020	0.080
	-10 °C		10 °C		30 °C		50 °C		70 °C	
DTI	-0.010	0.112	-0.003	0.040	0.001	0.045	0.008	0.075	0.028	0.129
	-40 °C		-20 °C		40 °C		70 °C		100 °C	
MIRS a [c]	-0.140	0.100	-0.091	0.100	-0.010	0.100	-0.017	0.130	-0.051	0.160
	-7 °C		20 °C		40 °C		60 °C		70 °C	
MIRS b [c]	0.037	0.051	0.004	0.061	-0.032	0.080	-0.077	0.100	-0.104	0.120
	-40 °C		0 °C		20 °C		40 °C		80 °C	
JV	-0.041	0.137	-0.013	0.131	0.015	0.131	0.032	0.131	0.059	0.133
	-10 °C		10 °C		30 °C		50 °C		70 °C	
UME a [d]	-0.018	0.071	0.015	0.073	0.032	0.073	0.047	0.073	0.073	0.073
	-40 °C		-10 °C		30 °C		70 °C		100 °C	
UME b [d]	-0.020	0.095	-0.010	0.095	0.012	0.096	0.009	0.096	0.026	0.096
	10 °C		20 °C		30 °C		40 °C		50 °C	
PTB	0.008	0.022	0.001	0.022	-0.003	0.022	-0.014	0.022	-0.038	0.031
	-40 °C		10 °C		40 °C		80 °C		150 °C	
MIKES 1a [e]	0.099	0.100	0.021	0.080	-0.025	0.040	-0.030	0.060	0.068	0.300
	-36 °C		-20 °C		20 °C		50 °C		90 °C	
MIKES 3b [e]	-0.040	0.041	-0.030	0.031	-0.007	0.041	0.017	0.041	0.012	0.051

[a] INM = BRLM-INM
[b] NML = NML NSAI
[c] MIRS = MIRS/UL/FE-LMK
[d] see the system description in Table 2
[e] see system description in Table 2 and measurement description in Table 3 only five points covering the whole range are shown here

4.3 Results Obtained with the Thermohygrometer

In the analysis of results obtained with the transfer standard thermohygrometer (HMT), we focus in the correlation with the results obtained with the PRTs (presented in the previous section) in order to identify potential effects specific to RH/T probes. Similarly to Section 4.1, a comparison reference function was determined for the HMT results by means of weighted nonlinear least square fitting in the $\Delta t_i = t_{\mathrm{ind}\ i} - t_{\mathrm{R}\,i}$ data ($t_{\mathrm{ind}\ i}$) is the temperature reading of the HMT reported by laboratory i). Difference values calculated with Eq. 3 were then compared to the corresponding differences for the pairs of ChA and ChB1/ChB2. Fig. 4.4 shows that most of the results agree within ±0.1 °C. However, a clear trend towards extremes of measurement ranges can be identified in the results of many laboratories. This is probably related to the heat conduction along the HMT probe.

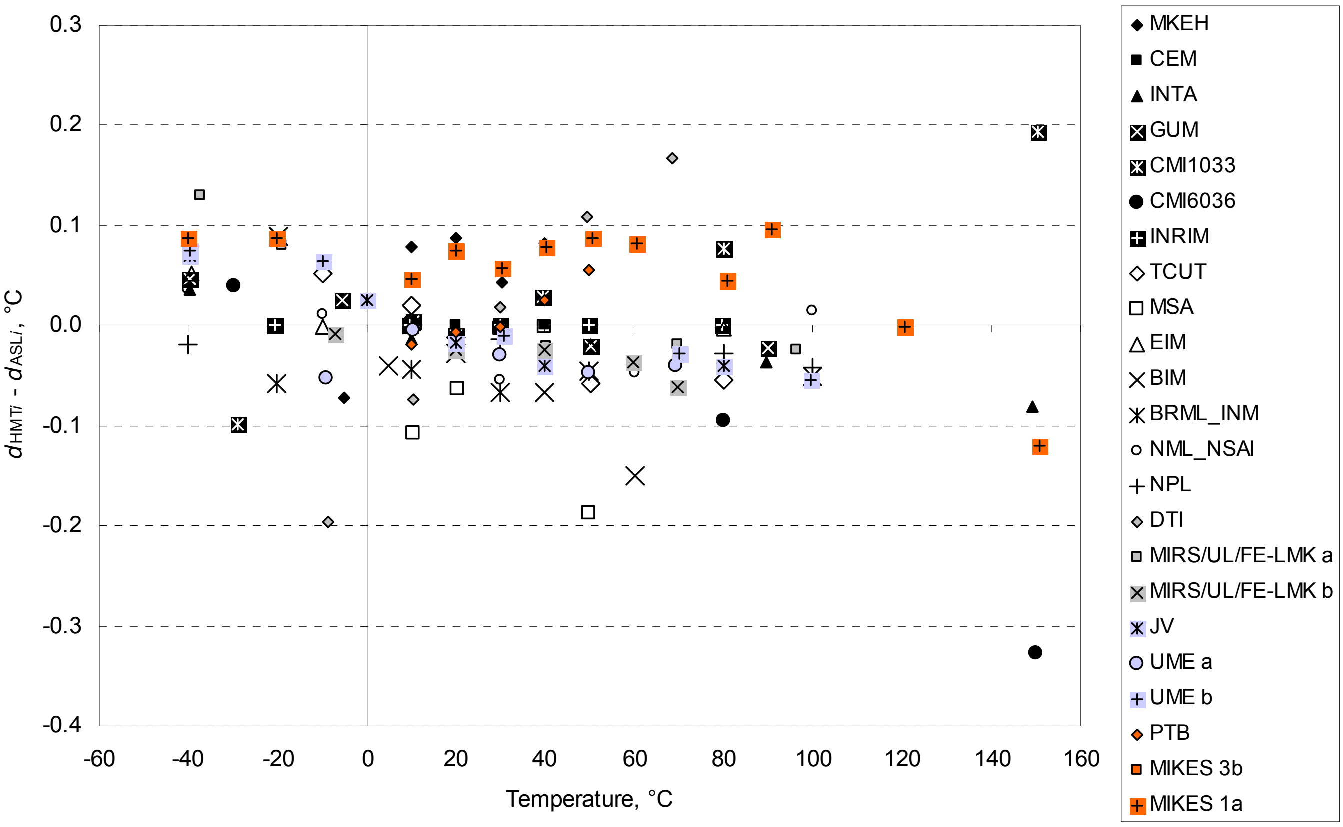


Fig. 4.4 Correlation between the results obtained with the HMT ($d_{\mathrm{HMT}\ i}$) and the PRTs ($d_{\mathrm{ASL}\ i}$) applying Eq. (3). The letters in MIRS/UL/FE-LMK, UME and MIKES labels refer the calibration setups listed in Table 2. The numbers in MIKES result labels refer to the measurement periods listed in Table 3.

5 Analysis of Effects Specific to Air Temperature Calibrations

5.1 Studies on Results of All Calibration Systems

Covering the results of all laboratories, two approaches were applied to study further the effects specific to air temperature calibrations: 1) comparison of the ChA results obtained in the subchambers to the rest of the results, and 2) comparison of the results obtained for ChA in air to liquid at each laboratory. The outcomes of the first approach showed that no effect related to use of a subchamber could be identified in the results.

A summary of results obtained with the second approach is given in Fig. 5.1. Squares and triangles show the difference $\Delta t_{\mathrm{air}\ i} - \Delta t_{\mathrm{liquid}\ i}$ determined at +10 °C and +80 °C, respectively. Although all laboratories performed calibrations in liquid at these two temperatures, some of them did not include these points to their air calibration scheme as shown in Table 3. In these cases, the $\Delta t_{\mathrm{air}\ i}$ values were derived for this study by linear interpolation. These results are marked in the figure with open squares and triangles.

Comparing these results with the corresponding differences d_i (see Section 4.1) determined at all measurements points of all participants ("ChA all temp" in Fig. 5.1) we can find a good correlation. This supports the assumption that the scatter of results in Fig. 4.1 is mainly due to differences in thermal conditions in different air calibration systems. However, we could not identify correlations between the results of Fig. 5.1 and the system descriptions in Table 2

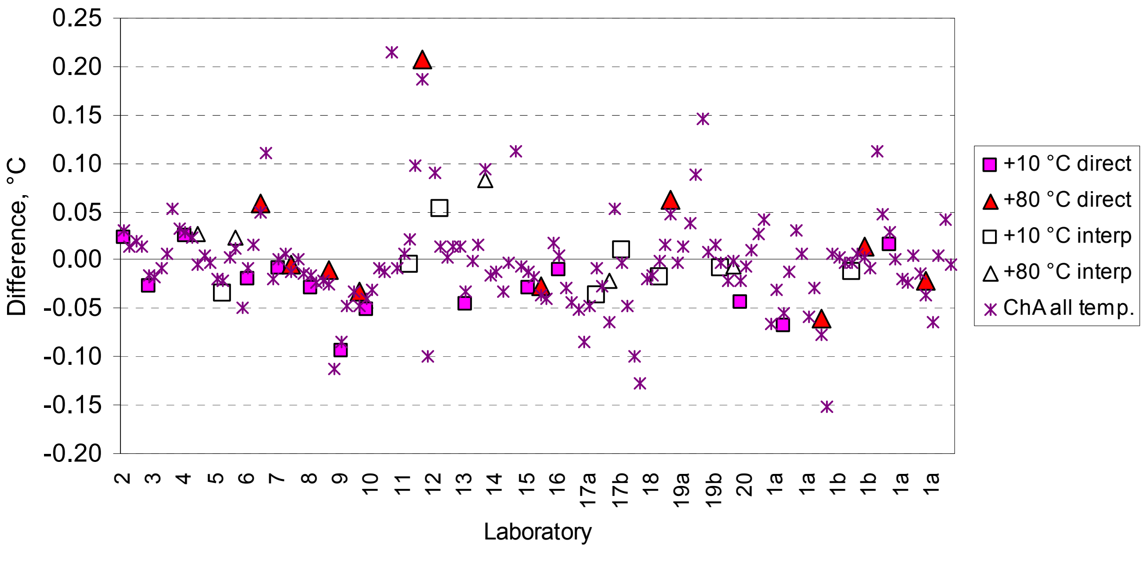


Fig. 5.1 Difference between calibrations in air and liquid. Squares and triangles show the difference $\Delta t_{\mathrm{air}\ i} - \Delta t_{\mathrm{liquid}\ i}$. Open marks show results based on linear interpolation in $\Delta t_{\mathrm{air}\ i}$ values. Crosses show Δt_i values determined in air at all measurements points of all participants. The laboratory numbers refer to Table 1.

5.2 Difference Between Two Types of PRTs

The simultaneous measurements with ChA and ChB1 in the comparison part 1 allow us to investigate directly the effect of different fluid medium on thermometers with about the same length but different diameter and surface. For this purpose we calculated the difference between the thermometer probes in calibrations in liquid and air, respectively, for each calibration system at each temperature point. As shown in Fig. 5.2, the variation in ChB1 - ChA correlates fairly well with the variation of Δt_i values ("ChA all temp." in Fig. 5.2), which supports the original assumption that ChA is more sensitive to changes in heat transfer conditions than ChB1.

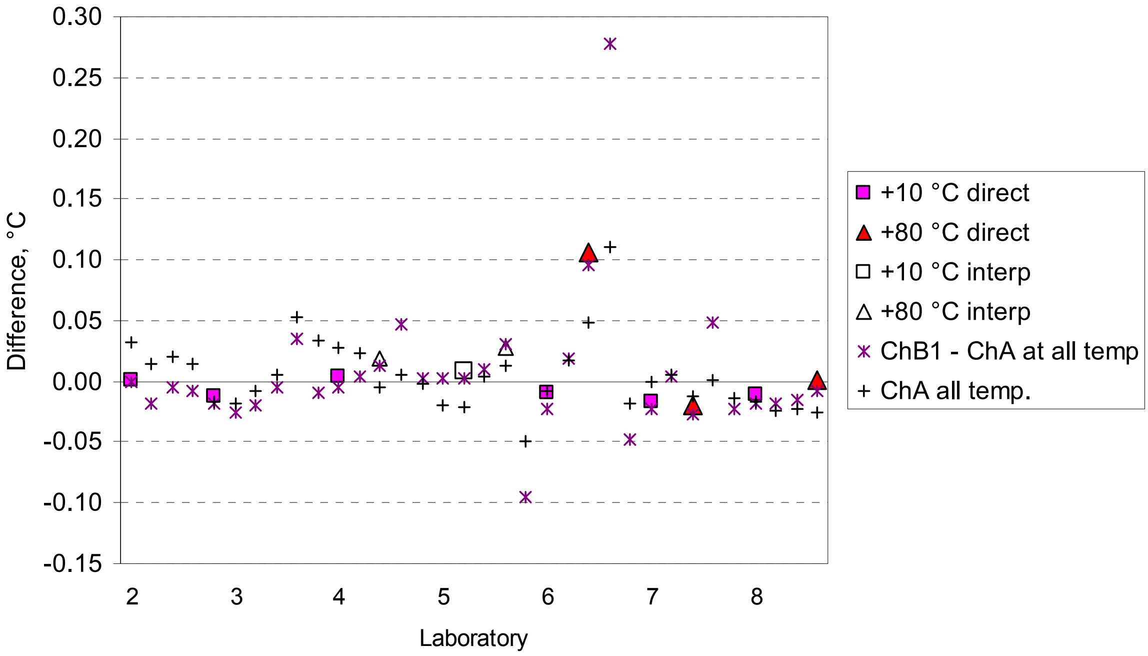


Fig. 5.2 Difference between ChB1 – ChA determined in air and liquid, respectively. Open marks show results based on linear interpolation in the results of calibrations in air. Cross and plus marks show ChB1 – ChA and Δt_i values, respectively, determined in air at all measurements points of the comparison part 1 participants. The laboratory numbers refer to Table 1.

5.3 Additional intralaboratory studies

Additional information about the effect of variations in heat transfer conditions in air temperature calibrations was looked from measurements at MIRS/UL/FE-LMK and additional measurements at MIKES. The Thunder 2500 humidity generator with a copper insert at MIRS/UL/FE-LMK provides a stable and homogeneous temperature field in a small volume for calibrating air temperature sensors. In the second system wooden black box of about 10 litres located in a large temperature controlled chamber prevents radiation heat transfer with walls of the chamber and reduces temperature oscillations. A fan maintaining air flow through the box reduces temperature gradients and maintains air flow around the thermometer under calibration. Five thermistors and industrial

PRTs were used to determine the temperature in the copper insert and the wooden box, respectively.

As shown in figure 5.3, the difference ChA - ChB2 is fairly insensitive to temperature in both calibration systems. The magnitude of the difference is about the same but with opposite sign. Also the difference ChA - HMT is fairly insensitive to temperature in the system b but highly sensitive in the system a. Because ChA, ChB2 and HMT are of very different kinds as air thermometers, we can conclude that the linear trend in the system b results in Fig. 9 is mainly due to the determination method of the reference temperature. On the other hand, HMT was significantly affected by a parasitic heat loss in the system a. The effect was largest in the extremes of the temperature range.

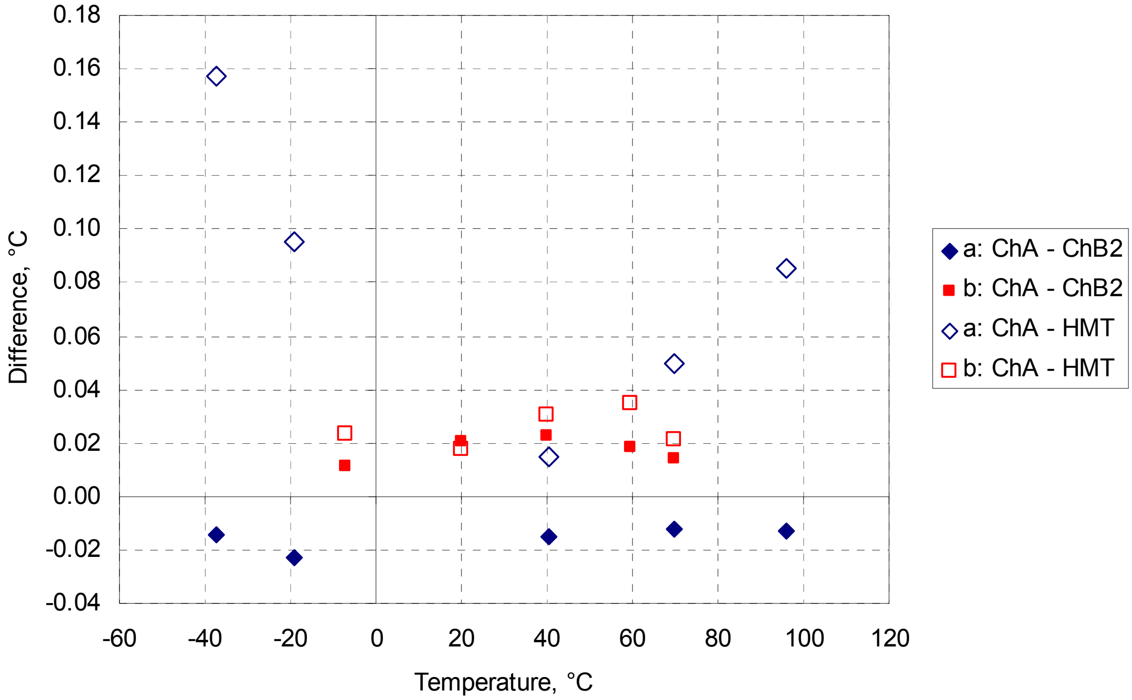


Fig. 5.3 Differences between the transfer standards in the calibrations performed at MIRS/UL/FE-LMK. The system identifications refer to Table 2.

MIKES performed additional measurements for a direct comparison of calibrations in an ordinary climatic chamber (Heraeus-Votsch HC 4020 with inner volume 180 l, air speed about 2 m/s) and a subchamber (inner volume 0.2 l, air speed about 0.004 m/s) located inside the climatic chamber. Only ChA and HMT were used in these measurements. The air temperature in the subchamber and the climatic chamber was determined with two thin Pt-100 thermometers (diam. 1.6 mm) and a Pt-100 thermometer (diam. 3.2 mm) equipped with a ventilated radiation shield, respectively.

Fig. 5.4 shows that the subchamber reduces parasitic heat transfer at high temperatures with both instruments. The results for HMT in the subchamber show an offset compared to results of climatic chamber in the range below 40 °C. Because the offset is negative this cannot be due to self heating. The thin PRTs used as the reference in the subchamber were also calibrated in the climatic chamber together with ChA. The difference to the reference thermometer in the climatic chamber was 0.05 °C at -30 °C and less than 0.02 °C at the other points. This proves that the discrepancy in ChA results at high temperature in Fig. 5.4 is not related to the reference thermometers.

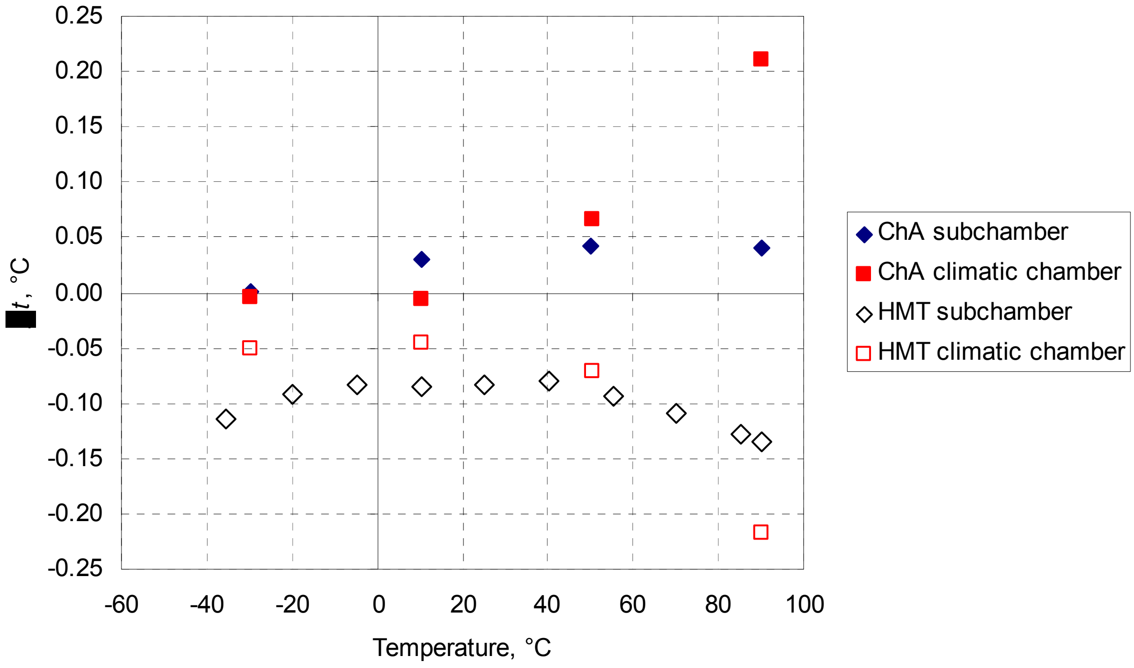


Fig. 5.4 Difference between the transfer standards (ChA and HMT) and the reference temperature measured at MIKES in the climatic chamber with and without the subchamber (marked with diamonds and squares, respectively).

6 Discussion

In this work we investigated correlations between variations in calibration results and calibration environments. The correlation with differences in the reference thermometer probes and their locations in the calibration volumes in the compared calibration systems was not thoroughly studied. Outcomes of such study would probably explain only some of the differences between the laboratories and trends indentified in their results. Heat transfer effects specific to each sensor under calibration and its installation in the calibration system induce always variations in calibration results. Figures 4.2 and 4.3 show that the laboratories involved with this comparison have well taken this into account in their uncertainty estimations.

When selecting transfer standards, the thermometer probe ChA was chosen to represent a thermometer with high sensitivity to thermal conditions in the calibration systems whereas ChB1 and ChB2 represented typical PRTs used in air temperature measurements. Including a thermohygrometer with fairly long and massive probe in the transfer standard set, we wanted to reveal errors specific to RH probes. The results presented in Section 5 show that these objectives were reached. In most cases where effects related to variations in heat transfer were identified, it was not possible to determine the actual dominating error source.

7 Conclusion

Calibrations of thermometers in air with various types of setups were compared to each other in this work. We investigated error sources specific to measurements in air instead of liquid and studied how realistic are the uncertainty estimations done by the participating metrology institutes. The obtained results demonstrated well the effects of variations in the heat transfer conditions in air calibrations. Radiation shielding was shown to reduce the effect of variations in the surface quality of thermometers under calibration but it may increase errors related to convective and conductive heat transfer and self heating depending on the velocity profile inside the shield. Differences between calibrations in air and liquid were typically within ±0.05 °C at 10 °C and 80 °C but significantly larger differences were found in wider temperature range. The analysis of the equivalence between the laboratories showed that the uncertainty estimations were mostly realistic.

References

1. S. Bell, R. Benyon, N. Böse, M. Heinonen, Int. J. Thermophys. 29, 1537 (2008)
2. V. Fernicol et al., A European roadmap for humidity and moisture (EURAMET 2012), http://www.euramet.org/fileadmin/docs/Publications/roadmaps/TC_T_Humidity_Roadmap_2012_text.pdf. Accessed 13 June 2013
3. S. Friederici, E. Tegeler, in Proceedings of 9th International Symposium on Temperature and Thermal Measurements in Industry and Science, vol. 2, ed. by D. Zvizdic (LPM/FSB, Zagreb, 2005), pp. 795-800
4. E. Renaot, et al., Int. J. Thermophys. 29, 991 (2008)
5. M. J. Ballico, M. K. Nguyen, U. Norranim, Metrologia 44, Tech. Suppl., 03005 (2007)
6. IEC 60751 (1995-07), ISO 1995
7. D. W. Marquardt, J. Soc. Ind. Appl. Math. 11, 431 (1963)

Annexes

1. Instructions for Part 1 of the comparison:
   P1061 Phase 1 Instructions_v1.pdf
2. Instructions for Part 2 of the comparison:
   P1061 Phase 2 Instructions_v4_091110.pdf
3. Summary of the results reported by the participants:
   P1061 Final Report_v2_Annex3.xls

EURAMET P1061

COMPARISON OF AIR TEMPERATURE CALIBRATIONS

Instructions for the part 1
version 1

Martti Heinonen

Espoo 2009

Contents

1 Background

It was agreed in the EURAMET TC-T Meeting in Delft in April 2008 that MIKES will co-ordinate a comparison of air temperature calibrations. The main objective of the project is to investigate the reliability and equivalence of calibration methods used by NMIs in calibrating air thermometers, i.e. thermometers that are used for measuring air temperature and are also calibrated in air (not immersed in a liquid bath). The focus of this project is in the errors due to self-heating and thermal radiation. The results can also be benefitted in developing RH CMC review protocol

Because there were 18 countries expressing interest in taking part in the comparison, strict limits were set for time periods for each participant. It was also decided to split the project in two parts: The first one will be carried out with three participants. After this first loop, it will be decided if any modification is needed to the measurement scheme or the instruments. The results of this first part will be reported and published only in relative to each other, i.e. in such way that the same instruments can be used in the second part without loosing the impartiality.

In this paper, instructions are given for the first part of the project. Final project protocol will be written after completing the first part.

2 Organization

2.1 Method

In this project the effects specific to air temperature measurements and calibrations are studied by comparing calibrations performed by the participants with facilities of different types.

The comparison is carried out using an ASL F250 thermometer bridge with two Pt 100 probes and an HMT335 thermohygrometer as the transfer standards. The comparison will cover the range -40 °C to +180 °C. Each laboratory will carry out measurements at five measurement points covering the whole air temperature calibration range of the laboratory.

Between August 2008 and January 2009, MIKES carried out several calibrations for the transfer standards in air. The PRTs with the ASL bridge were also calibrated in liquid baths twice.

2.2 Participants

Participants of the first part of the project are:

Table 1 List of participants

Central Office of Measures (GUM)	Poland
Centre for Metrology and Accreditation (MIKES)	Finland
Centro Español de Metrología (CEM) (+Instituto Nacional de Technica Aeroespacial (INTA))	Spain
Hungarian Trade Licensing Office (MKEH)	Hungary

2.3 Scheme

Hungary: weeks 8 to 9 / 2009
Spain: weeks 10 to 12 / 2009
Poland: weeks 13 to 14 / 2009
MIKES: weeks 14 to 15 / 2009

2.4 Measurements

In this project, measurements are carried out in the points: -40, -30, -20, -10, -5, +10, +20, +30, +40, +50, +60, +70, +80, +90, +120, +150, +180 °C. Only MIKES carries out measurements at all of these points.

Calibration in air

Each participant will carry out a full set of **five** point calibration with an ascending order of the points. At three points (maximum, minimum and one in between) measurements are repeated in descending order.

The results of each laboratory will be compared to each other using polynomial fittings.

Each laboratory chooses the five points from the list given above. It is, however, recommendable that the selected points cover the whole range of interest somewhat evenly (your maximum and minimum temperature and 3 points in between) to ensure the reliability of the fittings.

During the calibration in air, a black painted cover is on the PRT A (see Section 3)

Calibration in liquid bath

At each laboratory, the ASL with two PRTs will be calibrated in liquid baths at two points +10 °C and +80 °C before the calibration in air. If there is time within the time slot of a laboratory the bath calibration may be repeated after the calibration in air.

Before the calibration in a liquid bath, a black painted cover is removed from. the PRT A (see Section 3). The cover must not be immersed in a liquid.

The thermohygrometer HMT335 must not be exposed to direct contact with water or other liquids.

3 Transfer standards

3.1 Digital thermometer

An ASL F250 (s/n 1365030997) digital thermometer is used as a resistance bridge in this comparison. It is used with two Pt 100 probes:

Probe A: L=250 mm, d= 2.2 mm; stainless steel covered by thin black painted stainless steel tube (manufacturer: Pentronic)
Probe B: L=230 mm, d= 5 mm (manufacturer: Hart Scientific)

The probe A is connected to the front panel of the ASL bridge but the probe B is connected to the rear panel.

The black cover of the probe A is removed before immersing the probe in a liquid bath by pulling the cover and its handle apart (see fig. 3.1). Before starting measurements in air the cover is re-installed.

Only the resistance readings are recorded.

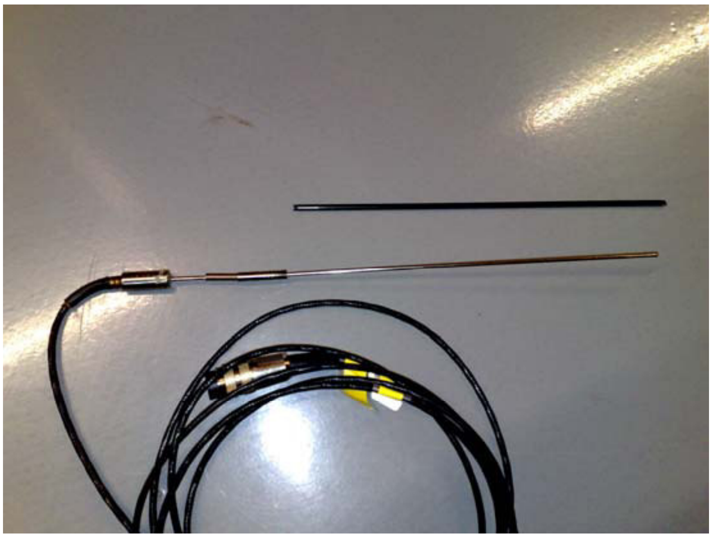


Figure 3.1 The probe A with its cover and when pulled apart from its handle part.

3.2 Thermohygrometer

The probe of the thermohygrometer HMT335 (s/n Z4610004) must not be exposed to direct contact with water or other liquids. Temperature measurements can be carried out in the whole range of this comparison. Although both relative humidity and temperature readings should be recorded, only the temperature readings are for the comparison.

The transmitter body should be kept at room temperature.

A 24 VDC supply is connected to the blue (-) and red (+) wires.

3.3 Package

The thermometer bridge, PRTs and the thermohygrometer are transported in a single wooden transport case. The PRTs are located horizontally below soft material (see figures below).

Figure 3.2 The transport case opened; first layer of soft material removed.

Figure 3.3 The transport case opened; location of mains cable, ASL F250 and HMT335 (with the probe).

Figure 3.4 The transport case opened; location of PRTs.

4 Reporting and analysis

Laboratories will report their results using a specific Excel file delivered by the pilot. The report will include:

- For each measurement point:
    - Local reference value for the air temperature
    - readings of the transfer standards (ASL: resistance; HMT335: temperature and relative humidity)
    - Mean values and corresponding standard deviations are reported.
    - Standard and expanded uncertainties of the reference value and the calibration result are reported.

- For the calibration of the ASL transfer standard using a liquid bath:
    - Local reference value for the liquid temperature
    - readings of the transfer standard (resistance)
    - Mean values and corresponding standard deviations are reported.
    - Standard and expanded uncertainties of the reference value and the calibration result are reported.

- Background information:
    - Description of the test environment and the reference instruments used in the comparison
    - Description how the effects of thermal radiation, self-heating and hysteresis have been taken into account in calculating the results/uncertainty

The results will be compared to each other using curve fittings.

Errors due to thermal radiation and self-heating (+ convective heat transfer) are of special interest.

Each laboratory should send the report file on the results to the coordinator **within 4 weeks after sending the instruments to the next laboratory** (if the dead-line is exceeded, the results will not be included in the final analysis).

Espoo 13 February 2009
Martti Heinonen

Contact details

Name of the laboratory	Country	Address	Contact	e-mail
Central Office of Measures (GUM)	Poland	ul. Elektoralna 2, 00-139 Warszawa	Krzysztof Flakiewicz	humidity.KF@gum.gov.pl
Centre for Metrology and Accreditation (MIKES)	Finland	Tekniikantie 1, FI-02151 Espoo	Martti Heinonen	martti.heinonen@mikes.fi
Hungarian Trade Licensing Office (MKEH)	Hungary	Magyar Kereskedelmi Engedélyezési Hivatal, H-1124 Budapest, Németvölgyi út 37-39	Emese Turzó-András	thurzo-a@mkeh.hu
Centro Español de Metrología (CEM)	Spain	Alfar, 2 ; Tres Cantos 28760 SPAIN	Dolores del Campo Maldonado	ddelcampo@cem.mityc.es

EURAMET P1061

COMPARISON OF AIR TEMPERATURE CALIBRATIONS

Instructions for the part 2
version 4

Martti Heinonen

Espoo 2010

Contents

1 Background

It was agreed in the EURAMET TC-T Meeting in Delft in April 2008 that MIKES will coordinate a comparison of air temperature calibrations. The main objective of the project is to investigate the reliability and equivalence of calibration methods used by NMIs in calibrating air thermometers, i.e. thermometers that are used for measuring air temperature and are also calibrated in air (not immersed in a liquid bath). The focus of this project is in the errors due to self-heating and thermal radiation. The results can also be benefitted in developing RH CMC review protocol

Because there were 18 countries expressing interest in taking part in the comparison, strict limits were set for time periods for each participant. It was also decided to split the project in two parts: The first one will be carried out with three participants. After this first loop, it will be decided if any modification is needed to the measurement scheme or the instruments.

The first part was completed in August 2009. It was decided to continue the comparison in the second part without modifications in the scheme. However, due to workload in the participating laboratories the second part was decided to start in January 2010.

In this paper, instructions are given for the second part of the project.

2 Organization

2.1 Method

In this project the effects specific to air temperature measurements and calibrations are studied by comparing calibrations performed by the participants with facilities of different types.

The comparison is carried out using an ASL F250 thermometer bridge with two Pt 100 probes and an HMT335 thermohygrometer as the transfer standards. The comparison will cover the range -40 °C to +100 °C. Each laboratory will carry out measurements at five measurement points covering the whole air temperature calibration range of the laboratory.

Between August 2008 and January 2009, MIKES carried out several calibrations for the transfer standards in air. The PRTs with the ASL bridge were also calibrated in liquid baths twice. Further measurements were carried out in autumn 2009 after completing the first part of the comparison.

2.2 Participants

Participants of the first part of the project are:

Table 1 List of part 1 participants

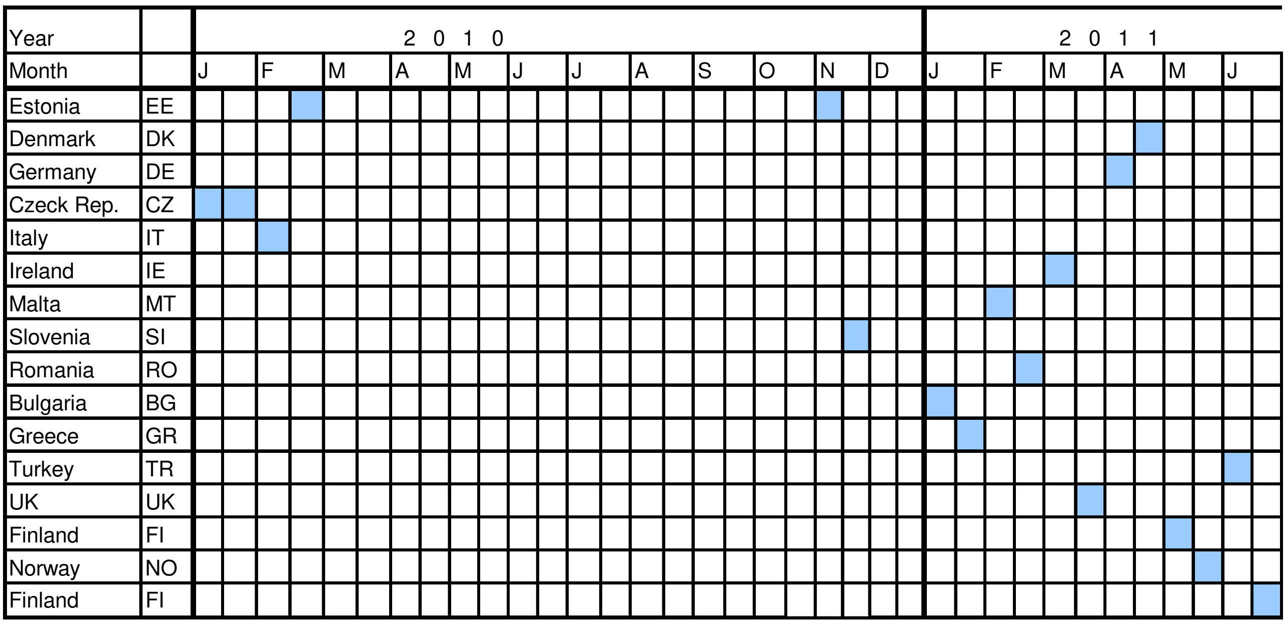
Central Office of Measures (GUM)	Poland
Centre for Metrology and Accreditation (MIKES)	Finland
Centro Español de Metrología (CEM) (+Instituto Nacional de Technica Aeroespacial (INTA))	Spain
Hungarian Trade Licensing Office (MKEH)	Hungary

Participants of the second part of the project are:

Table 2 List of part 2participants

Bulgarian Institute of Metrology (BIM)	Bulgaria
Centre for Metrology and Accreditation (MIKES)	Finland
Czech Metrology Institute (CMI)	Czech Republic
Daniamet-Teknologisk (DTI)	Denmark
Hellenic Institute of Metrology (EIM)	Greece
National Institute of Metrology (INM)	Romania
Istituto Nazionale di Ricerca Metrologica (iNRiM)	Italy
Malta Standards Authority - National Metrology Services (MSA-NMS)	Malta
Metrosert AS	Estonia
National Metrology Laboratory (NSAI NML)	Ireland
National Physical Laboratory (NPL)	UK
Norwegian Metrology Service (JV)	Norway
Physikalisch-Technische Bundesanstalt (PTB)	Germany
Ulusal Metroloji Enstitüsü (UME)	Turkey
University of Ljubljana, Faculty of Electrical Engineering (MIRS/UL-FE)	Slovenia

2.3 Scheme



2.4 Measurements

In this project, measurements are carried out in the points: -40, -30, -20, -10, -5, +10, +20, +30, +40, +50, +60, +70, +80, +90, +100 °C. Only MIKES carries out measurements at all of these points.

Calibration in air

Each participant will carry out a full set of **five** point calibration with an ascending order of the points. At three points (maximum, minimum and one in between) measurements are repeated in descending order.

The results of each laboratory will be compared to each other using polynomial fittings.

Each laboratory chooses the five points from the list given above. It is, however, recommendable that the selected points cover the whole range of interest somewhat evenly (your maximum and minimum temperature and 3 points in between) to ensure the reliability of the fittings.

During the calibration in air, a black painted cover is on the PRT A (see Section 3)

Calibration in liquid bath

At each laboratory, the ASL with two PRTs will be calibrated in liquid baths at two points +10 °C and +80 °C before the calibration in air. If there is time within the time slot of a laboratory the bath calibration may be repeated after the calibration in air.

Before the calibration in a liquid bath, a black painted cover is removed from the PRT A (see Section 3). The cover must not be immersed in a liquid.

The PRT B (see Section 3) is calibrated in a glass tube preventing a direct contact between the PRT cable and bath liquid. It should be tight fitted and the opening should be covered to prevent convection in the tube. The PRT should be immersed with the glass tube as much as possible.

The thermohygrometer HMT335 **must not be exposed** to direct contact with water or other liquids.

3 Transfer standards

3.1 Digital thermometer

An ASL F250 (s/n 1365030997) digital thermometer is used as a resistance bridge in this comparison. It is used with two Pt 100 probes:

Probe A: L=250 mm, d= 2.2 mm; stainless steel covered by thin black painted stainless steel tube (manufacturer: Pentronic)
Probe B: L=25 mm, d= 3 mm

Both probes A and B are connected to the front panel of the ASL bridge.

The black cover of the probe A is removed before immersing the probe in a liquid bath by pulling the cover and its handle apart (see fig. 3.1). Before starting measurements in air the cover is re-installed.

Only the resistance readings are recorded.

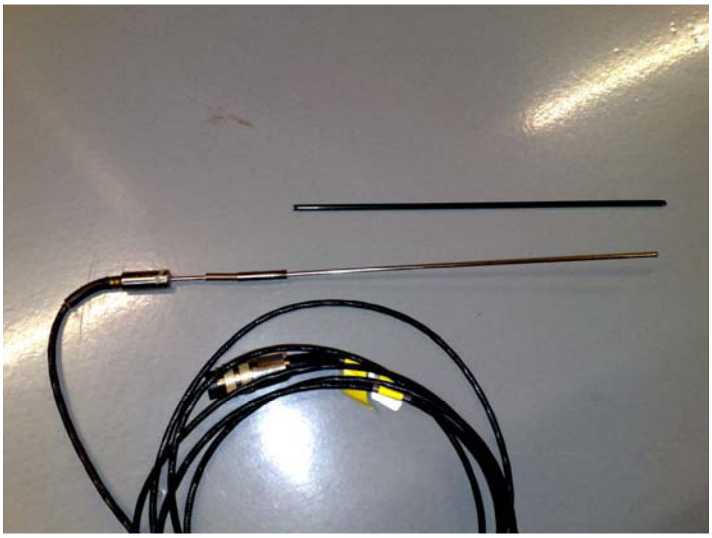


Figure 3.1 The probe A with its cover and when pulled apart from its handle part.

3.2 Thermohygrometer

The probe of the thermohygrometer HMT335 (s/n Z4610004) must not be exposed to direct contact with water or other liquids. Temperature measurements can be carried out in the whole range of this comparison. Although both relative humidity and temperature readings should be recorded, only the temperature readings are for the comparison.

The transmitter body should be kept at room temperature.

A 24 VDC supply is connected to the blue (-) and red (+) wires.

3.3 Package

The thermometer bridge, PRTs and the thermohygrometer are transported in a single wooden transport case. The PRTs are located horizontally below soft material (see figures below).

Figure 3.2 The transport case opened; first layer of soft material removed.

Figure 3.3 The transport case opened; location of mains cable, ASL F250 and HMT335 (with the probe).

Figure 3.4 The transport case opened; location of PRTs.

4 Reporting and analysis

Laboratories will report their results using a specific Excel file delivered by the pilot. The report will include:

- For each measurement point:
  - Local reference value for the air temperature
  - readings of the transfer standards (ASL: resistance; HMT335: temperature and relative humidity)
  - Mean values and corresponding standard deviations are reported.
  - Standard and expanded uncertainties of the reference value and the calibration result are reported.

- For the calibration of the ASL transfer standard using a liquid bath:
  - Local reference value for the liquid temperature
  - readings of the transfer standard (resistance)
  - Mean values and corresponding standard deviations are reported.
  - Standard and expanded uncertainties of the reference value and the calibration result are reported.

- Background information:
  - Description of the test environment and the reference instruments used in the comparison
  - Description how the effects of thermal radiation, self-heating and hysteresis have been taken into account in calculating the results/uncertainty

The results will be compared to each other using curve fittings.

Errors due to thermal radiation and self-heating (+ convective heat transfer) are of special interest.

Each laboratory should send the report file on the results to the coordinator **within 4 weeks after sending the instruments to the next laboratory** (if the dead-line is exceeded, the results will not be included in the final analysis).

Espoo 20 October 2010
Martti Heinonen

Contact details

Please check the delivery address of the next laboratory when receiving the instruments from the previous laboratory.

Name of the laboratory	Country	Contact	e-mail
Bulgarian Institute of Metrology (BIM)	Bulgaria	Sasho Nedialkov	s.nedialkov@bim.government.bg
Centre for Metrology and Accreditation (MIKES)	Finland	Martti Heinonen	martti.heinonen@mikes.fi
Czech Metrology Institute (CMI)	Czech Republic	Jan Otych	jotych@cmi.cz
Daniamet-Teknologisk (DTI)	Denmark	Jan Nielsen	Jan.Nielsen@teknologisk.dk
Hellenic Institute of Metrology (EIM)	Greece	Miltiadis Anagnostou	miltiadis.anagnostou@eim.org.gr
Istituto Nazionale di Ricerca Metrologica (iNRiM)	Italy	Vito Fernicola	v.fernicola@inrim.it
Malta Standards Authority - National Metrology Services (MSA-NMS)	Malta	Joseph Bartolo	joseph-anthony.bartolo@msa.org.mt
Metrosert AS	Estonia	Riho Vendt	riho@metrosert.ee
National Institute of Metrology (INM)	Romania	Mihaela Rujan	mihaela.nedea@inm.ro
National Metrology Laboratory (NSAI NML)	Ireland	Mary White	mary.white@nsai.ie
National Physical Laboratory (NPL)	UK	Stephanie Bell	stephanie.bell@npl.co.uk
Norwegian Metrology Service (JV)	Norway	Ingvild Antonsen	ian@justervesenet.no
Physikalisch-Technische Bundesanstalt (PTB)	Germany	Norbert Böse	Norbert.Boese@ptb.de
Ulusal Metroloji Enstitüsü (UME)	Turkey	Aliye Kartal Dogan	aliye.kartal@ume.tubitak.gov.tr
University of Ljubljana, Faculty of Electrical Engineering (MIRS/UL-FE)	Slovenia	Jovan Bojkovski	jovan.bojkovski@fe.uni-lj.si