An interlaboratory comparison of methods for calibration of air temperature contact sensors

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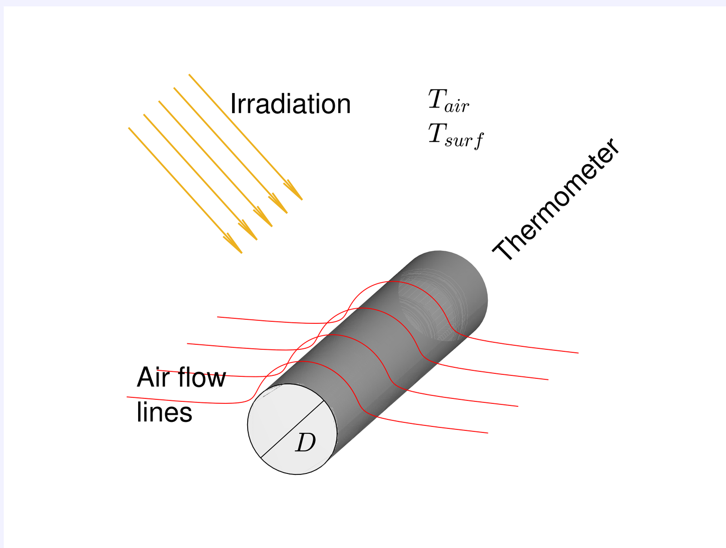
Abstract

To measure air temperature precisely using contact sensors requires that the sensor is (in equilibrium/in adiabatic conditions) with the surrounding air. This is difficult to achieve because heat exchange with the air can only be accomplished through the surface of the thermometer to the nearby air, while radiation may transmit energy to or from faraway objects. To make matters harder, heat exchange across the surface is also affected by the state of the air, such as density, water content and wind speed. To a calibration laboratory this represents a dilemma: should the sensor be calibrated in a liquid bath to obtain the best possible calibration uncertainty, or should it be calibrated in air to more closely resemble the actual use conditions at the cost of a higher calibration uncertainty? As part of a EURAMET project (1459) an interlaboratory comparison (ILC) was launched in 2019 with the aim of establishing a set of best practices for calibration procedures of contact thermometers. 8 different probe models, from 6 different manufacturers, were shipped around Europe to 26 NMIs or DIs, which reported data at air temperatures ranging from -80 °C to +60 °C. In total the ILC provided more than 1600 independent observation points. The sensors were thoroughly characterised prior to and after the circulation. We present two important observations from the aggregate results of this ILC. On the one hand, there is a substantial scatter in the reported reference uncertainty, pointing to a strong variation in the measurement setups and performance. Secondly, the scatter of results show a temperature dependency which is not seen in the reported uncertainties. The standard deviation of this scatter ranges from around 40 mK at 20 °C up to more than 200 mK at -40 °C. This variation is larger than the typical reported uncertainty. We discuss possible implications of this observation.

Why is air thermometry hard?



- sensor dimensions/geometry
- surface finish/emissivity
- air speed v
- condensation/evaporation of water
- air pressure, density, composition
- $T_{surf} - T_{air} \propto \sqrt{D/v}$ [1]
- *Air probes are coupled to other objects*

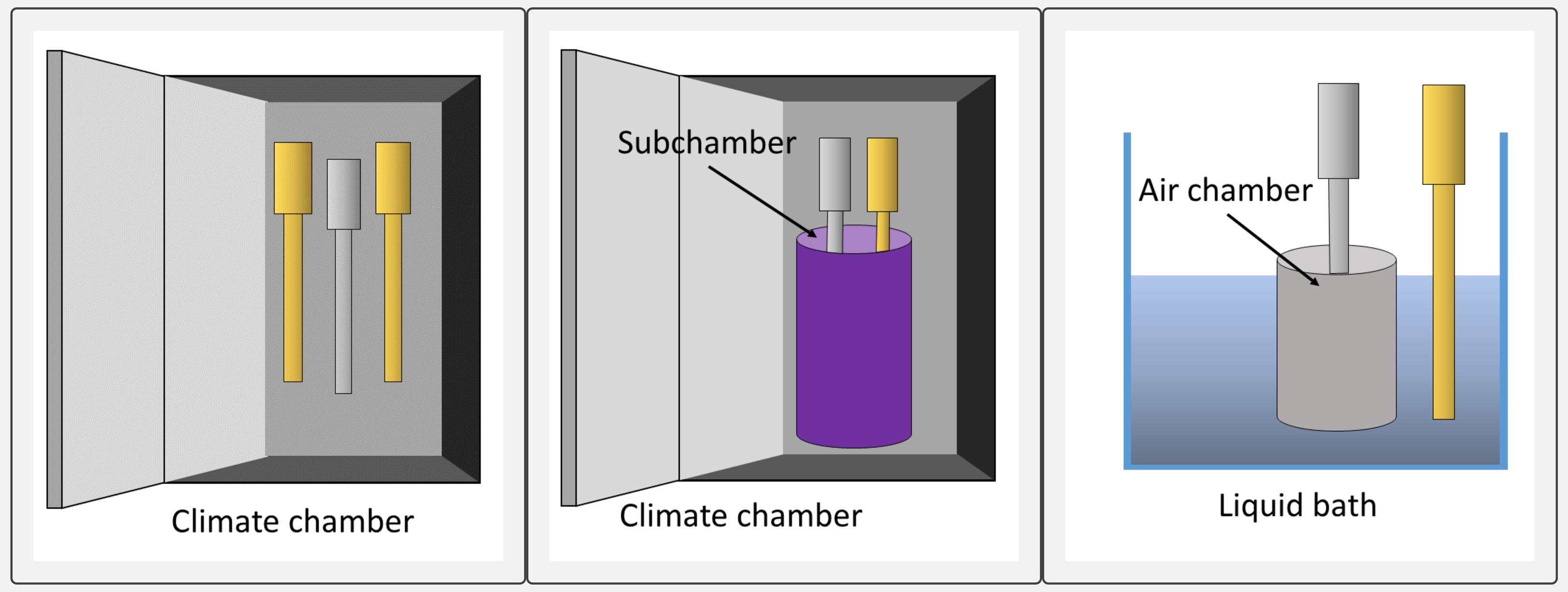
Overview of the ILC

- Launched in 2019.
- Part of Euramet project 1459.
- Goals are (i) to explore different strategies for air thermometer calibrations, (ii) to serve as foundation for a guideline.
- Supports newly formed task group in BIPM-CCT (CCT-TG-Env-AirT).

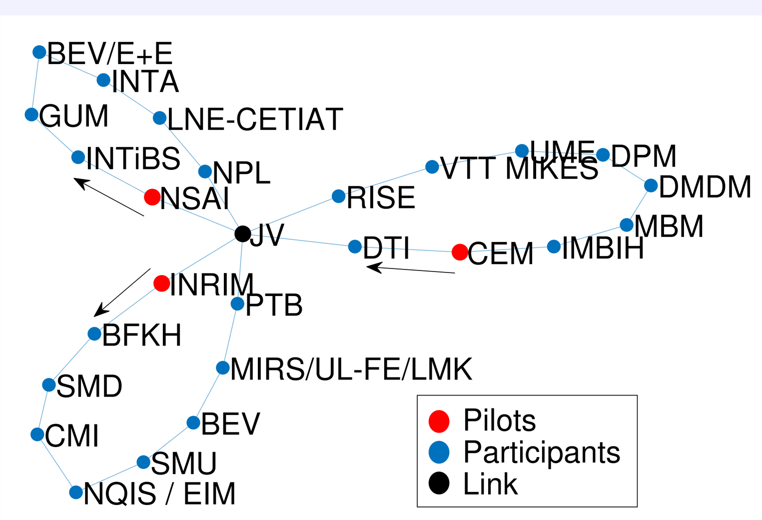
Key numbers:

Participants:	26
Setups:	29
Datapoints (in total):	1642
Datapoints (consensus):	1192
Distinct setups:	3
Circulated probes:	23
Probe models:	8
Data points:	6/8

Three main setup types



Topology



Probe dimensions

Model	Ø / Length [mm]
BEV E+E	6 / 230
Calpower NS	3 / 80
MBW	3 / 40
Physicus PT100/10	5 / 117
Vaisala TMP1	6 / 130
Wika	
-CTP5000-170B	6 / 350
-TR60 special	7.76 / 44
	19.7 / 62

Overview of ILC (cont'd)

Measurement method and reporting

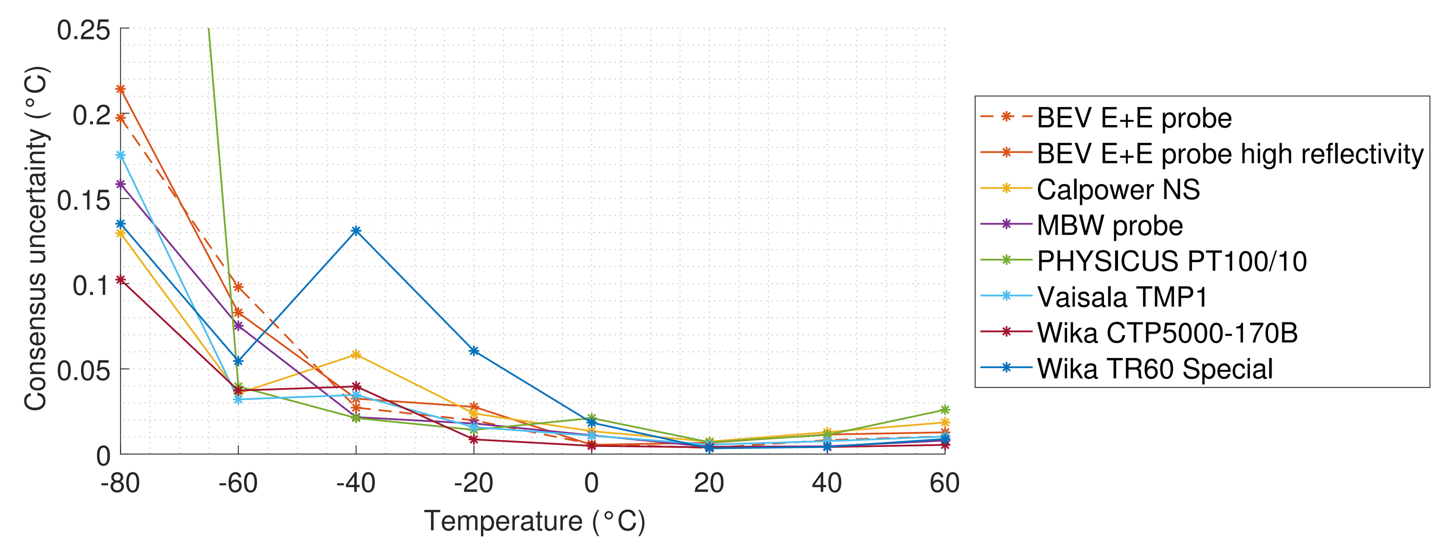
Method	Comparison with local reference Measured in stable air No restrictions on equipment
Main data	Reference air temperature *U*nit *u*nder *t*est (UUT) resistance Uncertainties
Required metadata	Reference probes, readout devices Chambers/facility description Traceability of reference(s)

Statistics from the ILC

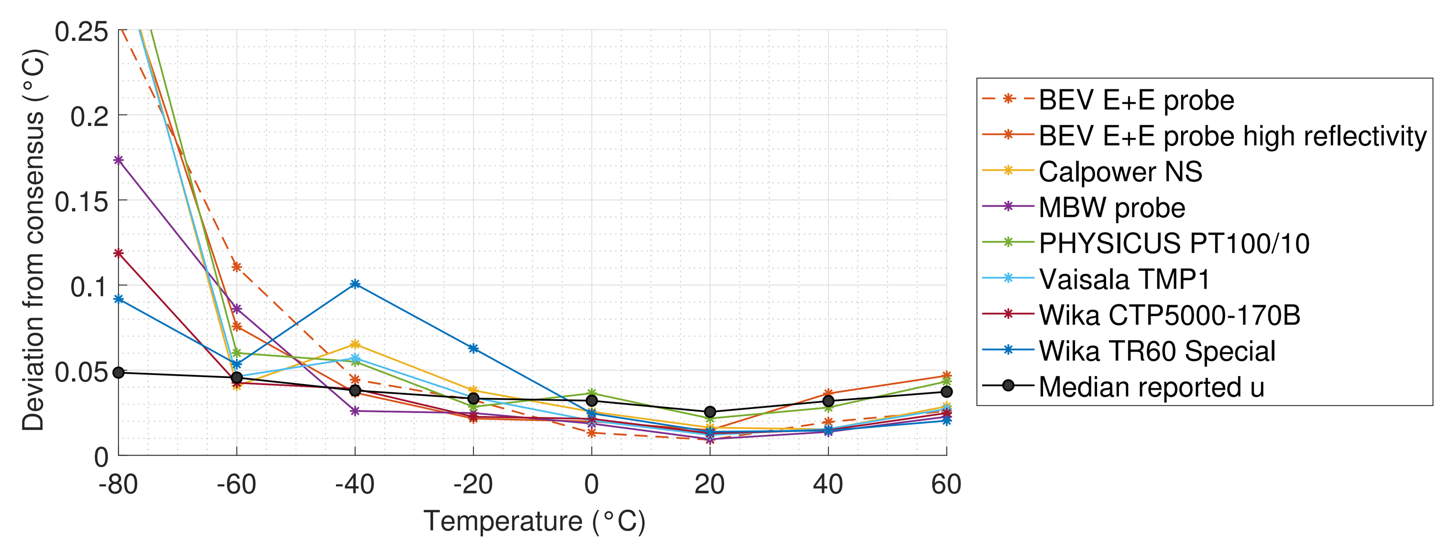
Point [°C]	Count	Best, worst reported u [°C , k=1]		Median δ [°C]	Fraction failed
-80	80	0.002	0.034	0.105	0.13
-60	80	0.003	0.059	0.027	0.16
-40	229	0.004	0.400	0.023	0.15
-20	245	0.003	0.390	0.014	0.14
0	252	0.002	0.275	0.008	0.17
20	252	0.002	0.180	0.005	0.17
40	252	0.003	0.179	0.007	0.11
60	252	0.003	0.177	0.012	0.10

Results

Uncertainty in consensus value



Differences between consensus value and observations



Analysis

Data are analysed using the random effects model (explanation below):

$$r_i = \rho + u_i + \varepsilon_i$$

The DerSimonian-Laird procedure is used to find σ^2 of unknown ε. Features:

- Drift implicit in ε, estimated from scatter in data.
- Possible underestimate of σ^2.

Preprocessing		
Find difference between realised and nominal temperature.	$\Delta_T = \tau - T$	τ: Nominal temperature T: Realised temperature
Use Δ_T to compute corrections to reported resistance using standard $R(T)$ curve.	$\Delta_R = \Delta_T \frac{\delta R}{\delta T}\vert_{T=\tau}$	dR/dT is the sensitivity coefficient of the SPRT reference function [2] with R=100 Ω at 0.01 °C .
Use JV data to link loops.	$L_i = R_{i,JV} - \frac{1}{3}\sum R_{i,JV}$	$R_{i,JV}$ is corrected resistance at JV in loop i.
Main processing		
Uses the random effects model:	$r_i = \rho + u_i + \varepsilon_i$	r_i corrected reported resistance ρ true, unknown resistance u_i reported standard uncertainty ε_i unknown error, variance σ^2
Weighted mean	$\rho = \frac{\sum w_i r_i}{\sum w_i}$	w_i are weights: $w_i = \frac{1}{u_i^2 + \sigma^2}$
Unknown σ from Der Simonian-Laird procedure [3, 4]	$\sigma^2 = \max\{0, \frac{Q-n+1}{\sum \tilde{w}_i + \sum \tilde{w}_i^2 / \sum \tilde{w}_i}\}$	w_i are weights: $w_i = \frac{1}{u_i^2 + \sigma^2}$

Discussion

- Variation in the laboratory setups.
  ⇒ wide and disparate reported uncertainty (mainly due to reference temperature).
- Large fraction of failing cases 10% to 17% (tentative, may change).
- Deviation from consensus depends on temperature with distinct minimum at +20 °C .
  ⇒ Probes optimised for +20 °C ?
  ⇒ Irradiation effects smallest at room temperature?
- At -80 °C and -60 °C few datapoints contribute to high uncertainty in consensus value.

References

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