Consultative Committee for Thermometry (CCT)

President: Dr Yuning Duan		Executive Secretary: Dr Susanne Picard

1. Executive summary

The CCT covers metrology linked to temperature, humidity and thermophysical quantities[1]. The CCT strategy was updated in 2017 and its recent activity has been focused on the redefinition of the kelvin. New key comparisons are not expected in the near future, only repeats.

A precise and accurate knowledge of temperature is important in science, technology and industry where precision and pushed limits are targeted. Temperature and humidity metrology play important roles in climate studies, whereas thermophysical quantities represent essential information to balance costs linked to energy consumption. Although thermometry is regarded by some as a mature science, it faces new challenges.

2. Scope of the CCT

The CCT gives advice to the CIPM on all scientific matters and issues that influence metrology in the fields of temperature, humidity and thermophysical quantities. It acts as the focus and network for this diverse community, to develop common aims and collaboration among national metrology institutes (NMIs) and designated institutes (DIs) in Member States of the BIPM or with other relevant bodies. The CCT assures continuity and reliable precision of a common international temperature scale and promotes best practice. It also identifies and organizes key comparisons in its fields to establish global comparability of measurements and traceability to the SI, and assures the degree of quality of reported data.

3. Activities and achievements since the last meeting of the CGPM

The CCT and the redefinition of the kelvin

The kelvin is presently defined by the temperature of the triple point of water – the temperature where ice, water and water vapour coexist. This temperature is realized using a glass or quartz cell containing water. Improvement of the associated uncertainty has been achieved by a better understanding of the influence from the isotopic composition of the water; an outcome of the international key comparison CCT-K7. Nevertheless, the definition is still linked to a device that puts limitations on precision and realization of extreme low or high temperatures.

The CCT met in June 2017. The redefinition of the kelvin by the Boltzmann constant was its focus; the CCT played an important role in coordinating this achievement. This new definition is based on an invariant constant and is not only universally accessible but will allow improved precision in the future as well as providing a stable reference in itself for future generations. Substantial progress has been achieved by a large number of metrology institutes. The different techniques and realizations applied to determine the Boltzmann constant $\boldsymbol{k}$ with a high precision, a constant that links temperature to energy, are the basis of obtaining a robust value. A range of very different approaches have successfully been exploited to contribute to this common goal: precise determination of the speed of sound; techniques

[1] Thermophysical quantities describe thermal behaviour in matter, such as thermal conduction or thermal insulation.

taking advantage of the thermal properties of the dielectric constant; measuring temperature related electric noise or determining the Doppler broadening of optical frequencies

International collaboration between the institutes involved was indispensable to get a clear picture of the results. The set objectives of:

- a relative standard uncertainty of the adjusted value of k less than 1×10^{-6}, and
- a determination of k based on at least two fundamentally different methods, of which at least one result for each have a relative standard uncertainty less than 3×10^{-6}

were fulfilled. Furthermore, for the first time, the uncertainty of the Boltzmann constant is smaller than the uncertainty of the applied temperature scale, an additional indication that the time is appropriate for a redefinition. The CODATA special adjustment in 2017 provided the exact value:

$$k = 1.380\ 649\ 10\text{-}23\ \text{J/K}.$$

The preparation for the new definition of the kelvin has been accomplished by establishing a new *Mise en Pratique*[2] on how the new definition may be realized. It contains a main document completed with a number of appendices with detailed technical information on the primary standards and guidance on how to realize the kelvin via the Boltzmann constant and evaluate the associated uncertainty. This document is not only a guide but represents the current uppermost level of thermometry as well as decades of experience. It also represents an excellent outcome by the CCT.

The temperature scale ITS-90 is presently not affected by the redefinition. An electronic *Guide to the realization of the ITS-90*[3] was completed in 2017. It is available on the BIPM website and is a unique manual for thermometrists and has been realized within the auspices of the CCT

A focus issue on the Boltzmann constant was published by *Metrologia*[4] in 2015.

The different primary instruments developed for the determination of the Boltzmann constant are now used to measure thermodynamic temperature over a wide range of temperatures to determine the difference to the present temperature scale ITS-90. This phase is expected to last until the mid-2020s and will stimulate the need for a new temperature scale.

Strategy

In 2012, the CCT carried out a significant analysis of its accomplishments since the introduction of the CIPM MRA and a forecast of its impact. This analysis was updated and published in 2017[5]. The CCT strategic plan provides a global picture of the present and future needs in thermal metrology. No thermometry activities are carried out at the BIPM; the strategic plan is of relevance to the NMIs, DIs and their stakeholders.

Dominant areas for stakeholders' needs are within the energy sector, climate and global warming, high-value manufacturing, health and safety, electronics and materials industry, science and research.

No increase in the number of key comparisons is presently expected. The comparison phase within thermometry is mature and is dominated by repeats of key comparisons.

[2] https://www.bipm.org/utils/en/pdf/si-mep/MeP-K-2018.pdf
[3] https://www.bipm.org/en/committees/cc/cct/guide-its90.html
[4] http://iopscience.iop.org/journal/0026-1394/page/Focus_on_the_Boltzmann_Constant
[5] https://www.bipm.org/utils/en/pdf/CCT-strategy-document.pdf

There are seven Working Groups within the CCT today. In addition, the CCT is supported by a number of Task Groups, which have a limited duration depending on achievement of the objective and/or time.

Comparisons and working groups

Several comparisons within the CCT have been completed since the 25th meeting of the CGPM (2014). Notably, the first key comparison in humidity was completed and the results were published in 2015. The first supplementary comparison within the CCT on the cross-disciplinary field of thermophysical quantities was also concluded and the final report was published in 2016. Repeat comparisons are in progress, notably on the realization of ITS-90 using Standard Platinum Resistance Thermometers. A repeat of the realization of the triple point of water is planned to start in 2019. The CCT has identified seven key comparisons, listed in the table below.

The CCT is assisted by working groups to deal with matters on key comparisons, calibration and measurements capabilities (CMCs), and strategy, and supported by the working groups for contact and non-contact thermometry, humidity and environment. Recent outcomes of the working groups are summarized in the 2017 CCT Strategy document[5]. Task Groups that had accomplished their objectives for the *Mise en Pratique* and the redefinition of the kelvin were closed in 2017. A new task group was created on emerging technologies (CCT-TG-CTh-ET). It will explore new possibilities for self-calibrating and small size devices. These have been made possible by exploring quantum physics, which is likely to modify the landscape of thermometry. The group is tasked with making a survey of this field and will report to the CCT at its next meeting, which is expected to be held in 2020.

SET OF CCT KEY COMPARISONS		**REPEATS**	
CCT-K1	Realization of the ITS-90 from 0.65 K to 24.6 K		
CCT-K2	Realization of the ITS-90 from 13.8 K to 273.16 K		
CCT-K3	Realization of the ITS-90 from 83.8 K to 933.4 K	**CCT-K9**	Realization of the ITS-90 from 83.8 K to 692.7 K
CCT-K4	Comparison of local realizations of AL and Ag freezing-point temperature		
CCT-K5	Realization of the ITS-90 from 961 °C to 1 700 °C	**CCT-K10**	Realization of the ITS-90 from 961 °C to 3 000 °C
CCT-K6	Humidity: Dew and frost point temperatures (−50 °C to 20 °C)	**CCT-K8**	Humidity: dew point temperatures (30 °C to 95 °C)
CCT-K7	Water triple point cells	**CCT-K11**	Repeat foreseen in 2019

Interaction with international bodies

Since 2015, the CCT, via the Working Group for Environment (CCT-WG-Env), has been represented on the CIMO Expert Teams (Commission for Instruments and Methods of Observation) of the World Meteorology Organization. There has been reciprocal input in the CCT working group.

Active exchanges are made with the International Association on Properties of Water and Steam (IAPWS) on issues related to humidity.

In addition, there are opportunities for international communication at the The TEMPMEKO conference, the most of which was held in Zakopane (Poland) in 2016,

Meeting of the CCT in 2017

The CCT met on 1 and 2 June 2017 at the BIPM, preceded by Working Group and Task Group meetings. A number of NMIs that were neither members or official observers of the CCT, but which were from Member States of the BIPM attended as an observer: INM (Colombia), INTiBS (Poland), NIS (Egypt) and SASO-NMCC (Saudi Arabia). The chairperson from each technical committee for thermometry within the RMOs was invited to attend. The CMI (Czech Republic) presented their request to become member of the CCT, which was approved by the CIPM in 2017.

A list of actions and decisions is available[6] and the proceeding of the meeting have been published[7].

4. Outlook in the short and long term

Precise and accurate knowledge of temperature is important in all scientific fields where precision and pushed limits are targeted. The redefinition of the kelvin will notably stimulate the establishment of a new temperature scale; a particularly important task for the CCT.

Credible thermal design for production control in the metallurgical and ceramic industries relies on thermophysical quantity data related to transfer and storage of heat (thermal conductivity, heat capacity and thermal diffusivity). Improvements in thermal insulation represent huge cost reductions world-wide and a reduction of global energy consumption.

Reaching an SI-based definition of relative humidity represents a big challenge where a significant user community is involved. Furthermore, developments in the humidity field are required to support industrial measurements in diverse gases such as carbon dioxide, hydrogen and fuel gas mixtures.

In the longer term, increasing computer power through quantum computing is a potential growth industry requiring accurate temperature measurement at very low temperatures.

Climate and meteorology are priority areas. Temperature and humidity are fundamental quantities involved in a wide range of climate change investigations. Comparability for meteorological observations and traceability to international measurement standards must be improved.

New technology allows the production of small-sized thermometry devices, opening the door to new applications. The CCT anticipates this progress.

The CCT is facing several challenges. For the scientific community, the future redefinition of the kelvin is clear and consistent but appears abstract to most of the user community; there is a challenge in how to make this concept more accessible, for example to schoolchildren and students.

[6] https://www.bipm.org/cc/CCT/Allowed/Summary_reports_and_strategy/CCT_A_and_D_2017.pdf

[7] https://www.bipm.org/utils/common/pdf/CC/CCT/CCT28.pdf

Comparisons to accomplish traceability are made by circulating sensitive devices or reference materials. This process is unavoidably time consuming and transport problems are regularly encountered. Other problems are linked to customs procedures or regulatory and safety issues.

Finally, thermometry is regarded by many people as “old” science and fewer students are attracted to this academic area today. There is real concern over how to maintain existing know-how in this particular discipline, not only in the metrology sector but also in the manufacturing sector, as this is fundamental to high-precision science and technology. The onus is on the thermometry community to communicate more clearly the importance of the discipline.

Annex: CCT Data

CCT was set up in 1937

President: Dr Yuning Duan
Executive Secretary Dr Susanne Picard

Membership 24 members and 1 observer

List of CCT members and observers http://www.bipm.org/en/committees/cc/cct/members_cc.html

Meetings since the 25th CGPM meeting: 1–2 June 2017

Full reports of the CCT meetings: http://www.bipm.org/en/committees/cc/cct/publications_cc.html

Seven Working Groups: http://www.bipm.org/en/committees/cc/cct/working_groups.html

Key Comparisons (WG-KC)
CMC Coordination (WG-CMC)
Strategic Planning (WG-SP)
Contact Thermometry (WG-CTh)
Non-Contact Thermometry (WG-NCTh)
Humidity (WG-Hu)
Environment (WG-Env)

Five Task Groups: http://www.bipm.org/en/committees/cc/cct/working_groups.html

Emerging Technologies (TG-CTh-ET)
Guide to Thermometry (TG-GoTh)
Themophysical Quantities (TG-ThQ)
Non-Contact Thermometry CMCs (TG-NCTh-CMC)
Non-Contact Thermometry HTFP Uncertainties (TG-NCTh-HTFPU)

CCT Comparison activity	Completed	In progress	Planned [2019-2022]
CCT key comparisons (and supplementary comparisons)	14 + (1)	9 + (2)	1
BIPM comparisons[8]	0	0	0
CCT pilot studies	3	0	3
CMCs	2688 CMCs for thermometry are registered in the KCDB (1 Sep 2018)		

[8] One of the completed CCT comparisons was piloted by the BIPM.