GREEN DEAL
ORIENTATION PAPER

TC for Thermometry (T)
TC Chair: Dolores del Campo
Version 3.1, 2020-12-03

ORIENTATION PAPER ON CHALLENGES IN THERMOMETRY

The attainment of the aims of the European Green Deal and the development of a climate neutral economy requires concerted efforts within all parts of European industry and society.

Thermometry is the key technology to quantify thermal energy, to minimize thermal heat losses and to control, optimise and to validate new and more efficient ways for energy supply, storage, distribution and consumption. In addition, temperature is one of the most important measured quantities in advanced industrial manufacturing, where reliable thermometry is key to ensure optimised energy use, product quality and minimise carbon emissions. Finally, reliable thermometry is essential to ensure for example safe and effective vaccine and medicine storage and transportation, food storage and processing and is a key “essential climate variable” in the field of meteorology and climate change monitoring.

Although there is a multitude of different temperature measuring methods and sensors commercially available, there are a number of important tasks for which existing solutions are insufficient and suitable temperature measuring systems, traceable to the International System of Units (SI), have to be developed. The aim of this paper is to collate some of the challenges thermometry and associated quantities are facing in fulfilling the objectives set by the European Green Deal. They could be summarized in two main issues which impact in the different policy areas established by the EU.

1. Improving the Efficiency of Energy Supply and Industrial Use

1.1 Self-validating drift-free sensors

Long term research is needed to develop *in-situ* traceable monitoring of temperature – sensors are then always right – i.e. no drift enabling industrial processes to run optimally. This is a key enabling technology required to facilitate autonomous production. This requires self-validating thermal sensors and ultimately practical primary thermometers e.g. wide range Johnson Noise or small-scale Doppler Broadening thermometers.

1.2 Distributed temperature sensing and sensor networks

There is an increasing demand for distributed temperature sensing e.g. in heat or fuel storage tanks, electrical grids, power transformers, solar power plants, monitoring of sources for geothermal energy use or specific industry applications. This can be realized either by an integration of several sensors in one thermometer with a length of few centimetres up to several thousand meters or a smart combination of individual sensors to form a network.

Such approaches can be realized either by fibre-optic approaches or a network of smart classical thermometers connected via IoT techniques. The metrological characterization of different fibre-optic techniques is urgently required.

Finally, with increasing moves to digitization in industrial production it is essential that the impact of sensor and software-related uncertainties on process control and hence product quality need to be investigated, quantified and validated.

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

1.3 Surface temperature measurement methods

Reliable determination of surface temperatures is essential to optimise the energy efficiency and product yield of a wide range of industrial processes. This requires, for non-contact IR and thermal imaging approaches:

- real time in-situ evaluation of emissivity,
- in-situ real time evaluation of thermal radiation sources,
- real time correction algorithms for emissivity and reflected thermal radiation,
- traceability in situ through deployment of reference sources in processes.
- In addition, more novel surface thermometry methods need to be developed on a widescale: in particular alternative methods for determining surface temperatures that are *non-thermal radiance* based– e.g. phosphor thermometry (spot and imaging) – to immediately mitigate for emissivity and reflected thermal radiation – this is a developing field and needs work on background metrology before more widespread dissemination and
- improved contact thermometers to reduce the influence of the thermal boundary layer e.g. by the development and validation of small diameter fibre-optic thermometers with corrected for thermal expansion and whose measurement method is independent of strain related phenomena.

1.4 Improved methods for gas temperature measurements

Current measurement techniques for gas temperature have serious limitations due to their heat capacity, thermal radiation exchange with the environment, stem conduction or maximum operation temperature. Needs for further improvements are e.g. in sensors for optical industries, precision engineering, meteorology and atmospheric research, humidity measurements or applications regarding combustion processes.

New developments in photonic thermometry, spectroscopic gas thermometry and acoustic gas thermometry offer promising options for significant improvements of gas temperature measurements.

1.5 Special applications

- Thermometers for high EMV-compatibility for monitoring and control of electrical generators and transformers, microwave processing and other industrial applications.
- Sensors for explosion-protected applications, e.g. hydrogen fuel stations.
- Development and characterization of improved thermoelectric materials for energy harvesting.
- Thermal monitoring of radioactive waste is essential for long term (decadal) safe storage. This includes containers, interim stores and ponds as well as long term geological storage repositories facility. Suitable radiation resistant sensors and sensing methods are required for long-term reliable traceable measurements of single-point temperatures, surfaces of containers and key points within storage facilities e.g. determining temperature distributions and gradients.
- In-line measurement of material water content in production lines (e.g. in drying), use of combined measurement methods to improve uncertainty.
- Material moisture measurement such as concrete, wood, etc.

2. Improvements in Climate Monitoring

Local and global climate temperature trends are directly associated, caused and causing at the same time, changes in numerous areas of the ecosystem: examples include marine biology (and associated fishing and sea-based food production), vegetation (and associated agricultural and farming economy), precipitation, extreme events, geology (glaciers and rock stability in the mountains).

The thermometry community, in general, plays an important role in supporting WMO and associated institutions (GCOS, GOOS, Global Cryosphere Watch etc.) regarding best practice guides, improved instruments & calibration services, measurement uncertainty evaluations and metrological aspects in the establishment of climate reference stations and networks. Furthermore there are additional needs, described in the following sections, that required further actions.

2.1 Ocean temperature measurements

The ocean absorbs more than 90 % of the excess heat which is attributed to greenhouse gas emissions. Therefore, the measurement of the temperature distribution and of long-term changes of the ocean temperature with uncertainties below 2 mK is one of the most important requirements for the monitoring and modelling of climate change. There is a need for:

- Further developments of thermistor-based temperature sensors and calibration methods for oceanography up to a depth of 6000 m with smallest possible measurement uncertainties (< 1mK) for periods of about 5 years,
- fibre-optic temperature measurement methods for local monitoring of temperature profiles,
- acoustic thermometry (ToF) for long-distance interpolation and measurements in polar regions (below ice),
- oceanographic instrumentation for drift-free practical primary thermometry (e.g. Johnson noise, acoustic, refractive index)
- reduced uncertainties in the measurand definition and measurements of the Sea Surface Temperature (SST), also to improve the comparison among in-situ and remote sensing
- support of oceanographic organisations and researchers to achieve smallest possible uncertainties by calibration services (up to high pressures), calibration and application guides and the determination of measurement uncertainties

2.2 Atmospheric measurements

Measurements of the air temperature and humidity are essential for meteorology and climate studies. These include ground-based weather stations, balloon-borne (e.g. radiosondes) and aircraft in-situ systems, ground-based remote sensing (GNSS-PW, Lidar). Further R&D activities are required:

- To include and to evaluate the data quality and uncertainty of reference and baseline stations,
- to produce a practical definition of air temperature and prepare guidelines for standard procedures for the calibration of thermometers in air,
- to further minimise and quantify environmental uncertainty contributions such as solar radiation, wind, condensation effects, or the influence of pressure (upper atmosphere),

- further development and validation of acoustic and other methods for remote sensing.

2.3 Soil, rocks, permafrost

Accurate on site measurements of ground temperature are fundamental to understand heat propagation and its effects on land. Studies started and still require advances for:

- testing and recommending methods to reduce uncertainty in measurements of temperature in rocks, to better predict risks of instability and falls, especially in high mountains,
- improving measurements of in-situ soil surface and near-surface temperature, to increase comparability with remote sensing land observations,
- reducing uncertainties below 0.02 °C and recommending best practices in permafrost temperature and temperature profiles measurements, to better detect active layers depths and its evolution as an effect and indicator of climate change.