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Report

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Study of the need for improved traceability for air temperature measurements – summary report

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Department for **Innovation, Universities** & **Skills**

Study of the need for improved traceability for air temperature measurements – summary report

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SUMMARY

The following is a concise summary of findings and recommendations arising from a review conducted as part of Deliverable 2 of Project SI10, NMS Programme for Materials and Thermal Metrology 2007-10

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1 BACKGROUND

Measurements of temperature in air (and other gases) account for a large proportion of all temperature measurements made. Applications include air conditioning; refrigeration; meteorology; climate research; processing, storage and testing of diverse products; and monitoring of environments generally.

In particular, relative humidity (RH) is a function of temperature, so RH measurements are only meaningful in the context of the air temperature. All humidity generation and standards depend critically on the accuracy of air (gas) temperature measurements.

2 ISSUE

Some temperature sensor types are known to vary in performance when used to measure gas temperature, where heat transfer can depend on gas movement, sensor immersion depth and radiative exchange with surroundings. A calibration in one environment may not be fully applicable in another environment without extra considerations. This can lead to measurement errors which can be significant for users aiming for low measurement uncertainty.

3 STUDY

Sectors to which air temperature measurement is of importance were identified and current instrumentation, practical use and calibration techniques were reviewed.

User needs were investigated by approaching a selection of existing NPL humidity and air temperature calibration customers, TMAN (Humidity) Club members, thermometer suppliers; and through them identifying the needs of other users of temperature measurements in industry. Information was gathered by telephone and face to face conversations, and by e-mail from approximately 20 contacts, using a proforma set of questions.

4 SUMMARISED FINDINGS – CURRENT NEEDS AND STATE OF THE ART

4.1 TECHNICAL ISSUES

Most comments were focused on a moderate temperature range, within the span –100 °C to +100 °C – this being the range of demand for most accurate air temperature measurement. (However it is recognised that considerable problems arise in gas temperature measurements at more extreme temperatures).

Whenever thermometers undergo electrical self heating, stem heat conduction or radiative heating from surroundings, these prevent the sensor from attaining (and therefore indicating) the local temperature. Such error depends partly on the ability of the medium to remove excess heat from the sensor. Where the medium is gas, heat transfer is generally worse than in the stirred liquid bath that is the default calibration medium: in air, sensors are likely to over-read compared to that calibration environment. The effect can be much less than 0.1 °C but sometimes several tenths of a degree at moderate temperatures. In proximity to highly differing temperatures (e.g. near a furnace) radiative errors can be considerably more.

Conventional temperature calibration in a liquid bath is attractive because of the small uncertainties that are sometimes offered. Where calibration in air is relevant and available, it typically carries larger uncertainties. These include some allowance for worse performance in air. (The same allowance is needed when using air sensors calibrated in liquid, but users may not know this or account for it.)

One obstacle to recreating thermal conditions is the use of wells to accommodate air temperature sensor within liquid baths. Recently some laboratories have used "Fluorinert" liquids to directly immerse sensors (even bare electronics) for temperature calibration. While this can provide good thermal contact, heat dissipation would still not be the same as that in air (i.e. probably misleadingly better).

Some air temperature sensors are not configured for calibration in a liquid bath.
Sometimes heating arises from other sensors in the same probe housing (for example in a combined relative humidity and temperature probe).

Some types of air temperature instrument are less prone to error because of operating principle, shielding, or aspiration (drawing gas though).

4.2 USER NEEDS AND PRACTICES

Sensitivity to the medium of use is a concern for users who cannot tolerate uncertainty of several tenths of a degree in their temperature measurements. Examples are listed below in Table 1.

While some cases are highlighted in the table, there are a wide variety of other examples encompassing chemical engineering, various areas of metrology, fuel gas transportation, stack emission monitoring, and others. Many of these feature gases other than air, where the same concerns apply. Conversely there are many less-demanding applications where air temperature measurements and underpinning calibrations are already fully adequate.

Table 1: Areas where temperature measurements in air are required with low uncertainties, or where the air conditions critically affect the applicability of calibrations.

Area	Main temperature range and uncertainty needed (U_{95})	Currently used	Limitations/problems
Meteorology and climate research	-100 °C to +80 °C ±0.1 °C or better in some cases	Platinum resistance thermometers (PRTs)	Aircraft environment, multiple challenges of high air speeds, altitude, droplets, icing, sample rate
Humidity measurements	-60 °C to +100 °C ±0.1 °C and upwards	Conventional or miniature-component (or on-chip) PRTs, thermistors, thermocouples, band gap sensors	Use of “bare” components, contamination, possible condensation. Error of 0.1 °C in temperature causes error of 0.6 percent of RH value, at room conditions.
Humidity primary standards and calibration labs	-100 °C to +100 °C ±0.01 °C and upwards	PRTs	Presence of condensed water, range of airflow and pressure
Close-control metrology labs (e.g. dimensional)	20 °C to 23 °C ±0.05 °C and upwards	PRTs, thermistors	Disparity seen between air temperatures and block-mount temperatures
Climatic test chambers (product testing)	-100 °C to +100 °C, ±0.1 °C to ±0.2 °C, or more	PRTs, thermocouples, thermistors	Response time, condensation, variable airflow, some thermal radiation
Fundamental thermometry standards using gas medium (e.g. acoustic thermometry)	Various ranges. Near 0 °C may require better than 0.1 mK	PRTs	Expertise in top-level labs typically overcomes heat transfer problems and sensor/calibration limitations.

4.3 FURTHER COMMENTS ON THE FINDINGS

The range where the most accurate air temperature measurements are needed is typically near room temperature.

Users with critical needs are high level metrology labs, product testing labs, and climate researchers.

Relative humidity instrument suppliers saw pressure for smaller air temperature uncertainties, but it is difficult to say whether driven by competition, rather than true user need.

Laboratories offering temperature calibration in air often do this as part of their humidity or other services, not necessarily handled with mainstream temperature calibrations.

The provision and implementation of calibrations is variable. Certain users and suppliers reported being fully able to achieve the uncertainties they want, and to fulfil customer needs (and wishes). However there were examples of users demanding the smallest calibration uncertainty while not necessarily understanding the added uncertainty in applying the measurement in their chosen medium. PRT calibrations in air at with uncertainty as small as 15 mK are supplied by at least one UKAS lab, yet it is known that customers demanding this are not taking the care to use the same operating current (so self-heating will change). In such calibrations, there is no convention of reporting or varying the air flow.

National laboratories across Europe have identified a need to investigate consistency of their temperature calibrations in air, and a EURAMET cooperation in research (Project 1061) has already been formalised between 18 national institutes.

5 WHAT USERS NEED

In order to support valid temperature measurements in air and other gases, with the uncertainties required by users, the following would be desirable:

- Sensing techniques appropriate for air or gases, with advice on selection
- Good measurement practices, including radiation shielding, and consideration of self-heating, immersion of and heat flow generally…
- Measurement traceability relevant to the requirement and conditions of measurement, with
    - Suitable uncertainties
    - Measured airflows relevant to conditions of use …
    - (For PRTs) operating current reported, with recommendation on current to be applied in use.
- Advice on estimating uncertainties due to change of medium between calibration and use
- Guidance on uncertainty analysis for temperature measurement generally. (Some good guidance exits - see for example UKAS M3003.)

6 RECOMMENDATIONS

The NMS could support valid temperature measurements by:

- Carry out and report (publish) practical study on air temperature measurement and calibration for commonly used sensors, with respect to air flow, heat leaks, and radiation
- Provision of improved air temperature calibrations, with fuller reporting of calibration conditions relevant to the applicability of the calibration results

- Guidance on selection and use of sensors for measuring air temperature.

Already in place are:

- Calibration of air temperature sensors in air provided at NPL and some other laboratories
- Air temperature session already part of NPL regular training course “Humidity measurement and calibration”
- TMAN meeting “Measuring the temperature of the earth” planned for June 2009
- NPL has joined EURAMET P1061. Active UK contribution to depend on NMS funding extending/diverting to cover this work.

7 COLLABORATION/CO-FUNDING OPPORTUNITIES

- Discussion/teaming opportunities with instrument companies, calibration labs, other high level users, and bodies such as the Society of Environmental Engineers. With instrument companies, collaboration might include loan/discount of equipment in return for project data and acknowledgement
- Existing expertise in various areas across NPL
- EURAMET cooperation
- Reading University and others with research interests in air temperature measurement.