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STANDARDISATION REQURIEMENTS FOR SENSORS – WORKSHOP JULY 2024

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Standardisation requirements for sensors – workshop July 2024

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ABSTRACT

Report on a sensor standardisation workshop held in July 2024 at NPL. The 1-day workshop focussed on the standardisation of aerosol and gas sensors covering the following application areas: air quality, fugitive emissions, workplace, and indoor monitoring. The morning consisted of short presentations covering the recently launched publicly available specification (PAS 4023) and ‘setting the scene’ for each of the application areas listed above. The afternoon was an opportunity to identify and discuss topics such as: available standards, standardisation needs and potential issues with each area. This report summarises the presentations and discussions held, it will be used to draw up a roadmap for developing standards and related documents.

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Approved on behalf of NPL by
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Abbreviations

BSI	British Standards Institute
CEN	Comité Européen de Normalisation
GAW	Global Atmosphere Watch
LCS	Low Cost Sensor
PAS	Publicly Available Specification
ISO	International Organisation for Standardisation
PM	Particulate Matter
TC	Technical Committee
TS	Technical Standard
WMO	World Meteorological Organisation

EXECUTIVE SUMMARY

Low-cost sensor systems are increasingly being used, seemingly a cost-effective solution. However, sensor system design and use can have a significant impact on the quality of data produced. Standards are an important element to help ensure that stakeholders (from industry regulators to citizens) can have confidence in sensor systems.

A standardisation workshop was instigated by the British Standards Institute (BSI) EH/2. This committee is responsible for the strategy and work programmes to prepare British standards for outdoor, indoor and workplace air quality. The purpose of the workshop (supported by the BSI) was to review current standards and identify future standardisation needs, covering the monitoring of aerosols and gases. This information will be used to develop a roadmap to identify areas of priority, and common and specific needs for each area, to be developed under the auspices of BSI EH/2. The workshop was attended by UK based government agencies, academia and industry (representing sensor system manufacturers).

The recent publication of the PAS 4023 is a first step towards standardisation, there will be further work needed to develop this standard. The following areas require further work:

- A common lexicon of definitions.
- Development of standards and for test chambers.
- Development of documentation such as case studies, guidance as well as standards and test specification, ensuring that they are written for the intended audience in mind. There could be different speeds for developing documents from “quick wins “ such as simple guidance through to full standards.
- Data management, metrological aspects such as quality assurance and control, traceability and auditing are important considerations. Develop a standard template for data outputs such as meta-data.
- To develop common performance standards.

Following the workshop a roadmap will be developed to highlight timelines and priorities that are specific to each area (outdoor, indoor and workplace) and those that are common.

1 INTRODUCTION

1.1 BACKGROUND

The impact of air quality on global human health, the climate and the wider ecosystem is of major international concern. Monitoring of air quality is an essential part of developing strategies to mitigate its impact. Low-cost sensor systems are increasingly being used, seemingly a cost-effective solution. However, sensor system design and use can have a significant impact on the quality of data produced. Standards are an important element to help ensure that stakeholders (from industry regulators to citizens) can have confidence in sensor systems.

A standardisation workshop was instigated by the British Standards Institute (BSI) EH/2. This committee is responsible for the strategy and work programmes to prepare British standards for outdoor, indoor and workplace air quality. The purpose of the workshop (supported by the BSI) was to review current standards and identify future standardisation needs, covering the monitoring of aerosols and gases. This information will be used to develop a roadmap to identify areas of priority, and common and specific needs for each area, to be developed under the auspices of BSI EH/2. The workshop was attended by UK based government agencies, academia and industry (representing sensor system manufacturers).

The Department for Environment, Food and Rural Affairs, National Centre for Atmospheric Science and the Institute of Air Quality Management subsequently held a low-cost sensors symposium that covered a much wider agenda, covering: standardisation, interactions with case studies, best practice, applications and future aspirations. The event was attended by 100 people from citizen scientists, academics, industry and government. NPL presented the findings from the standardisation workshop at this event.

Appendix 1 lists the workshop attendees.

Figure 1, standardisation workshop attendees

1.2 SCOPE

The British Standards Institute (BSI) committee EH/2 consists of the following areas:

- EH/2/1 Stationary Source Emissions.
- EH/2/2 Workplace Atmospheres.
- EH/2/3 Ambient Atmospheres.
- EH/2/4 General aspects.
- EH/2/5 Emissions to internal environments.

EH/2 mirrors the activities of International Standards for standardisation (ISO) TC146 (air quality) and European Committee for standardisation CEN TC 264 (air quality) and aims to provide leadership into these committees.

EH/2 are reviewing the future needs for low-cost sensor standards, and to identify and align pre normative research. The committee instigated a workshop (hosted by NPL) to identify current standards and future needs, including representatives from EH/2/1 to EH/2/5 (listed above), industry, government agencies and academia.

The 1-day workshop focussed on the standardisation of aerosol and gas sensors covering the following application areas: air quality, fugitive emissions, workplace, and indoor monitoring. The morning consisted of short presentations covering the recently launched publicly available specification (PAS 4023) and ‘setting the scene’ for each of the application areas listed above. The afternoon was an opportunity to identify and discuss topics such as: available standards, standardisation needs and potential issues with each area. The day concluded by identifying priority topics to focus future work. The workshop covered topics at a top level; it is envisaged future workshops and meetings will be need to discuss details.

The aims of the workshop were as follows:

- Define what sensors are and their role across the different areas.
- Review recent and current standardisation activities and drivers.
- Look at common needs and specific requirements.
- Look to input into a road map of priority areas of UK interest in standards.
- Provide means to steer and coordinate EH/2 activities.

The information gathered from the workshop will then be used to draw up a roadmap of the standardisation needs. This report contains a summary of the topics discussed at the workshop and a preliminary roadmap (which is open for discussion) which will be disseminated to EH/2 committee members, workshop attendees and those invited but could not attend.

Appendix 2 provides a list of known existing documents and standards – as of July 2024.

1.3 WORKSHOP PLANNING

The workshop was planned with help from EH/2 (Rid Robinson) and the subgroup chairs EH/2/1 – stationary source emissions (Rupert Standring), EH/2/2 – workplace air (Peter Stacey), EH/2/3 – ambient air (Brian Stacey) and EH/2/5 – indoor air (Caroline Widdowson) and HSE (Joanna Macnamara). This included defining out the scope and agenda for the workshop, identification of existing standards and invitees and preparation and delivery of presentations.

2 WORKSHOP

2.1 PRESENTATIONS

Workshop “setting the scene” presentations:

- Developing a code of practice for the use of low-cost sensors in ambient air monitoring. BSI PAS 4023:2024.
  Speaker: Valerio Ferracci (Air Quality and Aerosol Metrology Group, NPL).

  Highlights:
  This is an initial step towards the standardisation of low-cost sensors for air quality, covering sensor selection and deployment. It has been adopted by local authorities across the UK. There is ongoing work to:
  - *Assess the calibration and correction methods of Low Cost Sensor (LCS) co-location with reference instruments.*
  - *Investigate approaches to hybrid network calibrations.*
  - *Develop standard methods to validate the operation and data output from sensor systems.*
  - *Allow the full exploitation of advantages of LCS globally.*

- Sensor systems in ambient air quality monitoring.
  Speaker: Brian Stacey (EH/2/3 Ambient Air).

  Highlights:
  - *Standardisation is needed so that end users can be confident of the quality of data from sensor systems. Performance metrics to consider (not exhaustive): calibration, repeatability, drift, effect of movement, comparison with reference data, interference etc.*
  - *There are many sensor system providers. Ricardo run (unofficial) colocation studies at 4 locations across the UK. These studies are used to evaluate sensor system performance which provides the following benefits: assisting in the choice of sensor system for applications; an opportunity for suppliers to improve their systems and provide valuable insights into performance such as variability between “identical” systems, understanding of sensor limitations etc.*
  - *Looking to the future: volume of data will be a challenge, ongoing quality control critical for seasonality and regionality variations in data verification. CEN Technical specifications will help quantify performance, work done by Cambridge to calibrate sensors may be useful.*

- Air quality standards from a CEN TC264 WG 42 perspective.
  Speaker: David Harrison (Bureau Veritas).

  Highlights:
  - *Technical Specification TS 17660-1:2021 Performance evaluation of air quality sensor systems - gases.*
    Requires many field and laboratory tests, but with options to reduce the number of tests. Certification is being held up by the need to accredit test laboratories to ISO 17025.
  - *Technical Specification TS 17660-2:2024 to be published later this year. Performance evaluation of air quality sensor systems - Particle Matter (PM).*

  - *Currently only technical specifications have been written, the next step is to apply for funding to undertake experiments to validate whether the contents of these specifications need modification prior to publishing them as full standards.*
  - *European Directive 2008/50/EC is in the process of being superseded. The new directive has different uncertainty thresholds and limit values. The Technical Specifications will need modifying to maintain the link between the documents and legislation.*

- Air quality Particulate Matter (PM) sensors in the workplace
  Speaker: Delphine Bard (EH/2/2 Workplace Air)

  Highlights:
  - *The workplace is a challenging environment.*
  - *In general sensors developed for environmental settings often operate as "black boxes", there is a need for more tailored workplace devices.*
  - *Sensors can provide large datasets.*
  - *Continuous use can lead to data drift and need for change in correction factor.*
  - *Sensors may need replacement for long term use.*
  - *There are ethical considerations with regard to workplace sensors.*
  - *There needs to be accuracy and precision criteria for sensor devices for both qualitative and quantitative applications, and understanding the performance of sensors is an ongoing area of research.*
  - *Qualitative data just as valuable as quantitative data.*
  - *Practical guidelines, standardisation and standards are important.*
  - *At present low-cost sensors should not be used for compliance purposes, such as checking for adherence to workplace exposure limits.*

- Sensors for fugitive emissions monitoring
  Speaker: Andy Connor (Environmental Emissions Group, NPL)

  Highlights:
  - *Wide range of emissions need to be detected and/or quantified, ranging from fugitive diffuse emissions over large areas to point source emissions from known sources. Understanding the characteristics of the emissions source (as much as possible), for example concentration range, is important for selecting the most appropriate monitoring method.*
  - *Low-cost sensors are currently used in leak detection instruments. Understanding the performance of instruments can be challenging as the sensor is normally installed within a black box system.*
  - *Low-cost sensors are being considered to complement other techniques to cover the monitoring of large areas.*

2.2 DISCUSSIONS

Appendix 1 lists current standards and documents that are relevant to the areas identified in section 1.2. The following provides a list of all the points raised during discussions:

The discussion points have been divided up to into the following themes:

- Definition of a sensor.
- Test chambers.
- Documentation.
- Data management.
- Sensor availability and selection and performance.

i) Definition of a sensor

There is no clear meaning and agreement in many areas.

A low-cost sensor is generally regarded as “lower-cost” and used as a continuous measuring device. The scope of this workshop is “*sensor systems”,* i.e. an integrated system consisting of the sensor (convert gas or particulate concentration into an electrical signal), data sampling and processing functions, power supply and data reporting (e.g. display or remote output to a database). The system could be integrated with other monitoring systems and/or collocated with a reference instrument.

Are the definitions in current documents adequate, for example: technical specification (CEN/TS 17660) and PAS 4023?

Consider a review of current definitions and provide a standard lexicon of terms?

ii) Test chambers for sensor systems

Standards / guidance are needed for test chambers to ensure they are fit for purpose. Such document(s) should include a common expression of performance standard, not necessarily a design standard. This is a high priority need.

iii) Documents, best practice guides, standards and case studies

What regulations, additional standards or guidelines, toolkits are needed?

Information such as guidance documents, toolkits, best practice guides, example case studies are all needed – as well as standards. Anonymous case studies may be useful for gathering information and helping to understand where there have been issues, things have gone wrong or gathering lessons learnt.

Case studies may provide information that is easier for stakeholders and actors to relate to. Collating case studies could then be used to help develop standards / best practice guides that are more fit for purpose and user friendly. Consider a case study template that could be attached to existing standards such as the PAS. A “national” document to

support the recent PAS could develop this quickly, then look into developing this into an ISO so that BSI EH/2 could take a lead on.

There may be need for a different “speed/detailed” approach to developing such documents, from a “quick win” such as awareness documents or simple guidance documents to full standards.

Any document needs to be clear about who it is pitched to: for example, academia, citizen science, industry regulators etc.

Look for commonalities across industry sectors at user level, for example calibration.

Example case studies:

- AQ Mesh: https://www.aqmesh.com/case-studies/aqmesh-case-studies/

- WMO GAW 293 report, case studies: https://library.wmo.int/viewer/68924/?offset=#page=40&viewer=picture&o=bookmark&n=0&q=

iv) Data management

Need to consider data reporting standards (the content, format and quality).
How is data packaged - how can this be standardised?
There is no common way of recording what the sensor system was doing (i.e. meta data).
Investigate a simple template for data reporting.

Are there existing reporting standards that could be used. For example, in the US, there could be suitable examples to follow. US have done well at this (apparently).

Importance of quality checks before data is used / transferred for use.
Need to QA/QC checked data in published work in journals.

There needs to be traceability in data collection, and auditing too.

v) Sensor availability and selection and performance

Commercial industry tend to drive the design of low cost sensors, sensors are typically purchased off the shelf. Therefore, they may not necessarily be designed for their intended application and there is often a need to tailor them (or tailor a system around them) for specific use cases. What guidance is needed for this?

Sensor selection for PM2.5, more options are needed. Need to adapt sensor systems to specific application needs.

Capture range of user needs and requirements and identify common needs.
What performance is needed?
Is there a common set of performance characteristics?

Build a database and case studies (use of sensors) to survey range of sensors used and their performance. Ensuring performance is fit for use can be an issue.

Is there a minimum (basic) performance for sensors. Precision is important.
What are the basic or common QA needs?

Build up correct factors for different environments.

Need a list of case studies to build a map of sensor systems across all of communities and type of use.

e.g. What ranges, compounds - for workplace monitoring

e.g. speciation for air quality
what are the bounds of acceptability, based on performance requirements.

What are the minimum performance requirements for indoor / outdoor measurements? Standard / common guidance methodology for calibrating a system?

Can we build a common framework? What are aspects to watch out for?
Common need for guidance and instruction - basics of QA/QC. See EPA toolkit. Action / user groups will be using these sensors – so they need the guidance to use them effectively. What kind of tool kit can they use - needs to be centralised?

Encourage people to upload data to a central point. Guidance on sensor selection.

Common AQ for sensors in use. Common performance requirements?

What are the performance requirements that we have / don't have?

Whether a sensor system needs to measure multiple species is an important consideration

Factors that are common across all areas:

- Data management: Importance of QA/QC before data is used or transferred for use.
- Sensor availability and selection and performance:
    - To identify a common set of performance requirements and quality assurance for sensors in use. Is there a common set of needs in terms of performance for sensors?
    - Methodology for calibrating a sensor.
- Test chambers: common expression of performance and guidance for use of test chambers.
- Documents: Common guidance. Need for case studies and tool kits.

3 CONCLUSIONS

The recent publication of the PAS 4023 is a first step towards standardisation, there will need to be further work to develop the standard such as methods to validate operation and output data and assess calibration and correction methods.

There are many sensor network performance metrics to consider, for example drift over time. Colocation studies have been proven to be useful to evaluate, improve and assist in the choice of sensor systems.

Technical specification and standards to need to keep up with legislation. There can be challenges such as funding and ensuring the test sites are accredited to the applicable standards such as ISO17025.

The workplace is a challenging environment. There is a need for more tailored sensor systems. There are ethical considerations with regard to workplace sensors too. There needs to be accuracy and precision criteria for sensor devices for both qualitative and quantitative applications.

Development of a set of common definitions (lexicon) would be useful.

The metrological aspects of sensor systems are important such as quality control and assurance, traceability and auditing as well as the describing the performance of sensor in a standard way.

It was recognised that information pitched at appropriate levels of complexity and relevance is needed for the wide range of stakeholders including citizen scientists, industry regulators, academics and manufacturers. Such documentation includes: case studies and good practice guides as well as full standards and technical specifications. Case studies and good practice guide could potentially be generated and published within shorter times scales compared to standards and technical specifications, therefore they could provide a “quick win” in terms providing impactful information.

Developing standards and guidance for test chambers are needed to ensure they are fit for purpose.

Standards, guidance and template for data quality control and assurance are needed.

A landscape that describes the various user needs and requirements and identify common needs in terms of low costs sensor and sensor network performance is needed.

4 NEXT STEPS

1. This report will be sent to representatives of the different areas EH/2/1 to EH/2/5 and workshop attendees (and those invited) for feedback on its general content and whether any specific areas or issues are incorrectly documented, missing or to highlight anything new.

2. Start to build two roadmaps that identify low-cost sensor system needs and priorities over immediate, medium term and long term timelines:
   - General (cross cutting) roadmap applicable to all areas EH/2/1 to EH/2/5 to be led by NPL. Figure 2 illustrates an example general roadmap. The timescales / priorities shown are given in no particular order, they are to be discussed and agreed.
   - Specific roadmap within each area (if required) – to be led by chairs of relevant areas.

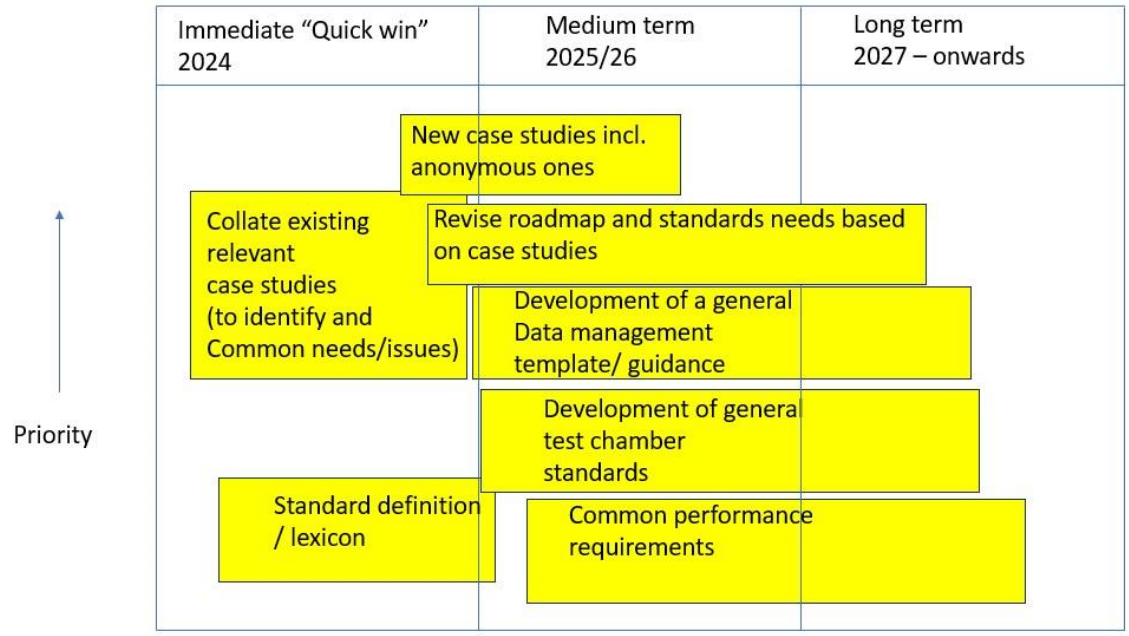

Figure 2, general roadmap example.

5 APPENDIX 1

Attendance list

Name	Organisation
Andy Connor	National Physical Laboratory (NPL)
Rod Robinson	NPL
Valario Ferrachi	NPL
Jacob Shaw	NPL
Standring, Rupert	Environment Agency (EA)
Stratford, Tania	EA
Joannna Macnamara	British Standards Institute (BSI)
Caroline Widdowson	Markes International
Zaheer Nasar	Cranfield University
Keith Mower	Building Research Establishment
Delphine Bard	Health and Safety Executive (HSE)
Brian Stacey	Ricardo
Owen Butler	HSE
John Saunders	HSE
Miranda Loh	Institute of Occupational Medicine
Davene Chatter-Singh	DEFRA
Lekan Popoola	University of Cambridge
David Harrison	Bureau Veritas
Lindus De Roo	Vito
Beth Lloyd	Bureau Veritas
Yuging Dai	Birmingham University
Juncheng Qian	Birmingham University
David Green	EarthSense
Sharadha Kariyawasam	Vortex IoT
David Johnson	South Coast Science
Agnieszka Carvalho	TSI
Bruno Beloff	South Coast Science

6 APPENDIX 2

6.1 AIR QUALITY

1. PAS 4023:2024
   PAS 4023:2023 | 31 Dec 2023 | BSI Knowledge (bsigroup.com)
   Select and deploy sensors
   Published
   Publicly Available Standard

2. CEN/TS 17660-1:2021 – published Jan 2022
   Performance testing of sensors (gases)
   Published
   Technical standard

3. CEN/TS17660-2 to be published in Oct 2024
   Performance testing of sensors (pm)
   To be Published
   Technical standard

6.2 INDOOR AIR

4. ASTM D8405-21: Standard Test Method for Evaluating PM2.5 Sensors or Sensor Systems Used in Indoor Air Applications D8405 Standard Test Method for Evaluating PM2.5 Sensors or Sensor Systems Used in Indoor Air Applications (astm.org)

6.3 WORKPLACE AIR

5. under CEN TC 137 WG3 - prCEN/TS XXXXX:XXXX/ WI 137087 - Workplace exposure — Direct-reading low-cost particulate matter sensors for measuring airborne NOAA — Guidelines for application

6. CEN/TR 16013-1:2010. Workplace exposure - Guide for the use of direct-reading instruments for aerosol monitoring - Part 1: Choice of monitor for specific applications.

7. CEN/TR 16013-2:2010. Workplace exposure - Guide for the use of direct-reading instruments for aerosol monitoring - Part 2: Evaluation of airborne particle concentrations using Optical Particle Counters

8. CEN/TR 16013-3:2012. Workplace exposure - Guide for the use of direct-reading instruments for aerosol monitoring - Part 3: Evaluation of airborne particle concentrations using photometers.

9. BS ISO 21501-1:2009 - Determination of particle size distribution — Single particle light interaction methods Part 1: Light scattering aerosol spectrometer

10. British Occupational Hygiene Society - Technical Guide Series No. 15 (2nd Edition) TECHNICAL GUIDE ON DIRECT-READING DEVICES FOR AIRBORNE AND SURFACE CHEMICAL CONTAMINANTS By Peter Walsh1 , Paul Evans2 , Steve

Lewis3, Bob Old4 , Leigh Greenham5 , Jean-Philippe Gorce1 , Penny Simpson1 and Barry Tyle1

11. Working life exposome toolkit
    About — EPHOR Project (ephor-project.eu)
    Miranda Loh (who is to be invited to the workshop) will be able to provide more information on the EPHOR project which aims to develop a working life exposome toolkit. The development of guidance on the use of low-cost sensors in the workplace is one of the 'tools' being developed, and this has involved a co-design aspect, involving occupational hygienists, health and safety practitioners etc in the process.

12. Scottish Environmental Protection Agency: Guidance on the use of low-cost sensors in the workplace – under development

13. Mineral Products Association: Real Time Dust Measurement – "Strategy for use of real time monitoring equipment in Workplace Atmospheres"

6.4 OTHER

14. Air sensor toolbox - USA
    Test centre for the performance of air sensor monitoring systems – US EPA
    Includes a number of guides, for example: standard operating procedures, deployment of sensors
    https://www.epa.gov/air-sensor-toolbox/evaluation-emerging-air-sensor-performance#related_links

15. AQ-SPEC, air quality sensor performance centre, South coast AQMD, USA
    https://www.aqmd.gov/aq-spec

    Test centre to evaluate the performance of commercially available "low-cost" air quality sensors in both field and laboratory settings, and provides guidance on sensor technology and data interpretation.

16. Similar to AQ-SPEC, France.
    Air labs Microsensor Challenge
    https://airlab.solutions/en/projets/challenge-microcapteurs-edition-2023-189

17. Other ASTM standards (American Society for Testing and Materials)
    Develop and deliver voluntary consensus standards.
    Atmospheric Analysis Standards (https://www.astm.org/products-services/standards-and-publications/standards/atmospheric-analysis-standards.html)
    List of some areas (and standards) that might be relevant (not exhaustive):
    - Ambient Atmospheres and Source Emissions
      D8406-22 Standard Practice for Performance Evaluation of Ambient Outdoor Air Quality Sensors and Sensor-based Instruments for Portable and Fixed-point Measurement

      D8559-24 Standard Specification for Ambient Outdoor Air Quality Sensors and Sensor-Based Instruments for Portable and Fixed-Point Measurement

    - Indoor Air

D8405 (listed above)

- Meteorology
- Quality Control
- Workplace Air Quality

New specifications:
- ASTM WK74812. New Specification for Ambient Air Quality Sensors and Other Sensor-based Instruments. https://www.astm.org/workitem-wk74812
- ASTM WK74360. New Test Method for Evaluating CO2 Indoor Air Quality Sensors or Sensor Systems Used in Indoor Applications. https://www.astm.org/workitem-wk74360
-

18. **Sensor networks** (guidance) : ISO/IEC 29182-2:2013:

    ISO/IEC 29182-2:2013(en), Information technology — Sensor networks: Sensor Network Reference Architecture (SNRA) — Part 2: Vocabulary and terminology

    Produced by ISO/IEC JTC 1.

    Scope: This part of ISO/IEC 29182 is intended to facilitate the development of international standards in sensor networks. It presents terms and definitions for selected concepts relevant to the field of sensor networks. It establishes a general description of concepts in this field and identifies the relationships among those concepts. It may also be used as guidance for development of other parts of ISO/IEC 29182 and any other sensor network related standard.

    The purpose of the ISO/IEC 29182 series is to

    - provide guidance to facilitate the design and development of sensor networks,
    - improve interoperability of sensor networks, and
    - make sensor networks plug-and-play, so that it becomes fairly easy to add/remove sensor nodes to/from an existing sensor network.

19. Proceedings of a low-cost sensor workshop in 2016, https://www.gla.ac.uk/media/Media_499205_smxx.pdf.

    Focused on the opportunities and challenges of using low-cost sensor technology to monitor air quality and how this emerging technological opportunity could help to engage citizens.

    The workshop concluded that in order to overcome key barriers in the development and use of low-cost sensors, there is a clear need to improve sensor performance and implement standards.

    The emergence of “Big data” raises questions on how data is shared, analysed, modelled, by whom, and where?

20. Guidance for test chambers, ISO standard (David H to supply details).

21. RESET Air. The RESET Air Standard is a data standard for air quality monitoring.

https://www.reset.build/standard/air

The RESET Air Standard defines the requirements for collecting indoor air quality data via continuous monitoring of an interior space or building, with the goal of standardizing indoor air quality data.
There is a RESET certification scheme.

22. Healthy building certifications (indoor air quality)

- WELL Building standard.

  Establishes requirements in buildings that promote clean air and reduce or minimize the sources of indoor air pollution.

  https://standard.wellcertified.com/air

- UL Verified Healthy Building Mark Certification scheme.
  https://www.ul.com/services/verified-healthy-buildings

- FITWEL. https://www.fitwel.org

Further details and comparison between these schemes:
https://www.sanalifewellness.com/blog/comparing-healthy-building-certifications-well-fitwel-and-ul-verified-healthy-building

23. CoGDEM
Council of Gas Detection and Environmental Monitoring
https://www.cogdem.org.uk/

24. The National Institute for Occupant Safety and Health (NIOSH)
Manual of Analytical Methods (NMAM)
https://www.cdc.gov/niosh/nmam/default.html

Measuring respirable aerosols using real time optical monitors. Low-cost sensors are mentioned.

25. IAQM Guidance for monitoring construction dust
https://iaqm.co.uk/wp-content/uploads/2013/02/Construction-Dust-Guidance-Jan-2024.pdf

26. MCERTS and low-cost sensors: does certification guarantee real world performance?

https://www.ricardo.com/en/news-and-insights/insights/mcerts-and-low-cost-sensors-does-certification-guarantee-real-world-performance

27. World Meteorological Organisation
Global Atmosphere Watch (GAW) 293 WMO report on low-cost sensors
Integrating Low-cost Sensor Systems and Networks to Enhance Air Quality Applications