

PAS 4023:2023

Selection, deployment and quality control of low-cost air quality sensor systems in outdoor ambient air – Code of practice



Department
for Environment
Food & Rural Affairs

bsi.

Publishing and copyright information

The BSI copyright notice displayed in this document indicates when the document was last issued.

© The British Standards Institution 2023.
Published by BSI Standards Limited 2023.

ISBN 978 0 533 21793 3

ICS 13.040.01; 13.020.40; 13.040.20

Not for copying without BSI permission except as permitted by copyright law.

Publication history

First published December 2023

Contents

Foreword	iii
Introduction	v
1 Scope	1
2 Normative references	2
3 Terms, definitions and symbols	3
3.1 Terms and definitions	3
3.2 Symbols	5
4 Performing a measurement campaign	6
4.1 Design of the measurement campaign	7
4.2 Selection of sensor systems	7
4.3 Deployment and maintenance	9
4.4 Quality assurance	15
4.5 Data screening	21
Annexes	22
Annex A (informative)	
Possible monitoring scenarios	22
Annex B (informative)	
Examples of network calibrations	23
B.1 Breathe London Pilot Study methodology	23
B.2 Breathe London ongoing methodology	24
B.3 Methodology deployed for Cheltenham Pororough Council Study	26
Annex C (informative)	
Case studies on improving the comparability of sensor systems	28
C.1 The importance of inter-device comparability	28
C.2 Benefits of co-location calibrations	30
Annex D (informative)	
Sensor technologies and performance issues	32
D.1 Sensor technologies	32
D.2 Performance issues	35
Bibliography	36

List of figures

Figure 1 – Steps to performing a measurement campaign	6
Figure 2 – Sensor system deployment	10
Figure 3 – Sensor system deployed in an area of free air circulation and reduced risk of vandalism ..	11
Figure 4 – Poor deployment location with a wall too close to the sensor system	12
Figure 5 – Poor location with plants too close to the sensor system	12
Figure 6 – Common measurement artefacts and areas for consideration	16
Figure 7 – Example of co-location calibration studies where low-cost sensor systems are monitoring alongside reference instruments at AQ monitoring stations	17
Figure A.1 – Possible monitoring scenarios	22
Figure B.1 – Separation of emission sources	2
Figure B.2 – Evolution of the Breathe London monitoring network.....	25
Figure B.3 – Sensor-system network deployment in Cheltenham.....	26
Figure C.1 – Inter-device comparability	29
Figure C.2 – Data from a low-cost NO ₂ sensor compared with co-located reference measurements under different calibration algorithms and two time-periods.....	31

List of tables

Table 1 – Site deployment information	14
Table B.1 – Summary of Breathe London key performance indicators and outline aims associated with each KPI.....	25
Table B.2 – Demonstration of LDS calibration method	27

Foreword

This PAS was sponsored by the Department for Environment, Food and Rural Affairs (Defra). Its development was facilitated by BSI Standards Limited and it was published under licence from The British Standards Institution. It came into effect on 31 December 2023.

Acknowledgement is given to Nicholas Martin and David Butterfield, of the National Physical Laboratory (NPL), as technical authors, and the organizations that were involved in the development of this PAS as members of the steering group.

- Bureau Veritas
- City of London Corporation
- Clarity Movement Co.
- Council of Gas Detection and Environmental Monitoring (CoGDEM)
- Department for Environment, Food and Rural Affairs (Defra)
- EarthSense Systems Ltd
- Environment Agency
- Environmental Instruments Ltd
- Imperial College London
- London Boroughs of Richmond upon Thames, Merton and Wandsworth
- National Physical Laboratory (NPL)
- Ricardo
- Scotswolds Ltd
- TRL Ltd
- University of Cambridge
- University of Oxford
- University of York

Acknowledgement is also given to the members of a wider review panel who were consulted in the development of this PAS.

The British Standards Institution retains ownership and copyright of this PAS. BSI Standards Limited, as the publisher of the PAS, reserves the right to withdraw or amend this PAS on receipt of authoritative advice that it is appropriate to do so. This PAS will be reviewed at intervals not exceeding two years.

This PAS is not to be regarded as a British Standard. It will be withdrawn in the event it is superseded by a British Standard.

The PAS process enables a code of practice to be rapidly developed in order to fulfil an immediate need in industry. A PAS can be considered for further development as a British Standard, or constitute part of the UK input into the development of a European or International Standard.

Information about this document

This publication can be withdrawn, revised, partially superseded or superseded. Information regarding the status of this publication can be found in the Standards Catalogue on the BSI website at bsigroup.com/standards, or by contacting the Customer Services team.

Where websites and webpages have been cited, they are provided for ease of reference and are correct at the time of publication. The location of a webpage or website, or its contents, cannot be guaranteed.

Copyright is claimed in the definition at 3.1.3. The content has been reproduced with the permission of the Joint Committee for Guides in Metrology (JCGM). Copyright remains with JCGM. All rights reserved.

Copyright is claimed in the definitions at 3.1.6, 3.1.11, and 3.1.12. The content has been reproduced with the permission of the European Committee for Standardization (CEN). Copyright remains with CEN. All rights reserved.

Use of this document

As a code of practice, this PAS takes the form of recommendations and guidance. It is not to be quoted as if it were a specification. Users are expected to ensure that claims of compliance are not misleading.

Users may substitute any of the recommendations in this PAS with practices of equivalent or better outcome. Any user claiming compliance with this PAS is expected to be able to justify any course of action that deviates from its recommendations.

It has been assumed in the preparation of this PAS that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

Presentational conventions

The provisions of this document are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is “should”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

The word “should” is used to express recommendations of this PAS. The word “may” is used in the text to express permissibility, e.g. as an alternative to the primary recommendation of the clause. The word “can” is used to express possibility, e.g. as a consequence of an action or an event.

Notes and commentaries are provided throughout the text of this document. Notes give references and additional information that are important but do not form part of the recommendations. Commentaries give background information.

Where words have alternative spellings, the preferred spelling of the Shorter Oxford English Dictionary is used (e.g. “organization” rather than “organisation”).

Contractual and legal considerations

This publication has been prepared in good faith, however no representation, warranty, assurance or undertaking (express or implied) is or will be made, and no responsibility or liability is or will be accepted by BSI in relation to the adequacy, accuracy, completeness or reasonableness of this publication. All and any such responsibility and liability is expressly disclaimed to the full extent permitted by the law.

This publication is provided as is, and is to be used at the recipient’s own risk.

The recipient is advised to consider seeking professional guidance with respect to its use of this publication.

This publication is not intended to constitute a contract. Users are responsible for its correct application.

Compliance with a PAS cannot confer immunity from legal obligations.

Introduction

Recent developments in air quality monitoring have resulted in new sensor systems that potentially provide an informative low-cost addition to reference methods. Such sensor systems are expected to allow air pollution monitoring to be performed at a lower cost and with a higher spatial density than is possible with the current reference methods. They also allow for new source apportionment and calibration methodologies, when coupled with spatial information, to provide a much better understanding of an individual's or group's exposure to air pollutants.

The potential advantages of low-cost air quality sensor systems include the following:

- small footprint making them easily deployable in the urban environment;
- larger area coverage than fixed point measurements if a network approach is implemented and improved spatial and temporal resolution; and
- potential of continuous calibration through co-location with reference style analysers and a network calibration.

For these advantages to be exploited, it is important that robust quality assurance is performed on the data produced.

This PAS has been developed to provide recommendations and guidance to users to:

- select sensor systems appropriate for their monitoring needs;
- deploy sensors in a way that promotes representative sample collection; and
- undertake the quality assurance (QA) processes to generate good quality data from these systems.

Additional information is also provided in four annexes as follows:

- Possible monitoring scenarios (Annex A);
- Examples of network calibrations (Annex B);
- Case studies on improving the comparability of sensor systems (Annex C); and
- Sensor technologies and performance issues (Annex D).

The sensor systems are based upon several principles of operation, including:

- electrochemical for NO_x , NH_3 , SO_2 , CO and O_3 ;
- light scattering optical particle counter for PM_{10} , $\text{PM}_{2.5}$ and PM_1 ; and
- non-dispersive infrared (NDIR) for CO_2 .

The sensor systems can also continuously monitor air pollution, with fast response times ranging between a few tens of seconds to a few minutes, but presently with a reduced measurement accuracy (higher uncertainty) and lower precision.

NOTE 1 The term “low cost” refers to the initial purchase price of a single air quality sensor system and is not an indicator of measurement accuracy. The cost is dependent on the number of pollutant sensors employed and users implementing a large network of systems. The cost of necessary co-location deployments, quality checking and adjustment can be substantial. Examples of these costs are sensor replacement, installation, removal, consent issues/legal, power access, co-location charges and data processing. Most importantly, the purchase price might not account for additional ongoing charges for access to the measurement data. Whilst the UK has performance standards for reference quality instruments, and guidance for monitoring under Local Air Quality Management (LAQM) application, there is no formal code of practice for the evaluation, deployment and use of low cost sensors and networks composed of these sensors.

NOTE 2 Although “low-cost” air quality sensor systems have advanced significantly, they are currently no validated published documentary standards against which to judge their performance and therefore cannot be used for official compliance reporting against limit values. PD CEN/TS 17660-1, however, provides information on how to test the performance of these types of sensor systems for gaseous species.

1 Scope

This PAS provides recommendations for the selection, deployment, maintenance and quality assurance of low-cost air quality sensor systems as standalone units or as part of a network, for the measurement of outdoor ambient air as suited to their application and desired purpose. This includes systems that are static in position and semi-permanent in placement.

This PAS covers air quality sensor systems which measure one or more of the following gaseous or particulate pollutants:

- nitrogen dioxide (NO₂);
- oxides of nitrogen (NO_x);
- nitric oxide (NO);
- ozone (O₃);
- sulfur dioxide (SO₂);
- carbon monoxide (CO);
- carbon dioxide (CO₂); and
- particulate matter (PM₁₀, PM_{2.5} and PM₁) in outdoor ambient air.

This PAS is intended for use by those aiming to monitor and report on air quality through the implementation of low-cost air quality sensor systems, including public makers, local authorities, environmental health officers, citizen scientists, industrial users, sensor system manufacturers and suppliers, academics, researchers, and those with an interest in air quality quantification and improvement.

NOTE 1 The PAS would be beneficial to those involved in delivering Local Air Quality Management (LAQM). Technical guidance on measurements for LAQM purposes is given in TG22 [1].

This PAS does not cover:

- statutory legal reporting of data against theoretical air quality objectives;
- passive diffusive tubes, e.g. Palmes diffusion tubes;
- pumped sorption tubes;
- total volatile organic compound (VOC) low-cost sensors;
- single hydrocarbon/VOC low-cost sensors;
- sensors providing an indoor air quality index (IAQ);

NOTE 2 This PAS acknowledges the use of sensors for measuring indoor air quality but provides no formal guidance or recommendations for making occupational health measurements or other indoor air measurements.

- portable hand-held or wearable sensor systems;
- sensor systems used in mobile applications, both ambient and indoor air;
- the provision of intellectual property for the air quality sensor system specific technologies or specific products;
- the collection format and storage of data obtained from the sensor system, including any human interventions, such as for the analysis and interpretation of results;
- access to the data and the data format;
- making reliable measurements in confined spaces, including subways, tunnels or underground railways; and
- the use of air quality sensor systems for compliance monitoring and reporting, including demonstrating adherence to pollutant limit values or targets enshrined in legislation.

NOTE 3 Examples of such legislation include the Air Quality Standards Regulations 2010 [2], the Air Quality Standards (Scotland) Regulations 2010 [3], the Air Quality Standards (Wales) Regulations 2010 [4], the Air Quality Standards (Northern Ireland) Regulations 2010 [5] and the Environmental Targets (Fine Particulate Matter) (England) Regulations 2023 [6].