Low Cost AQ Sensor Systems Symposium 2024

Enabling best practice & exploring future opportunities

Post Event Overview

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Low Cost AQ Sensor Systems Symposium 2024 was held on the 8th July at Woburn House Conference Centre. It was jointly hosted by Defra, National Centre for Atmospheric Science and Institute for Air Quality Management.

This post event report provides an outline of the days event and an overview of the attendee perspectives captured via Slido throughout the day.

Attendees

Of the 99 attendees registered for the event, 86 joined us on the day from various communities with an interest in low-cost AQ sensor systems. At registration we asked attendees to *identify your primary role from the following category's.*

The representation across these groups at the event can be seen below in Figure 1. Where attendees had selected more than 1 role, all have been included.

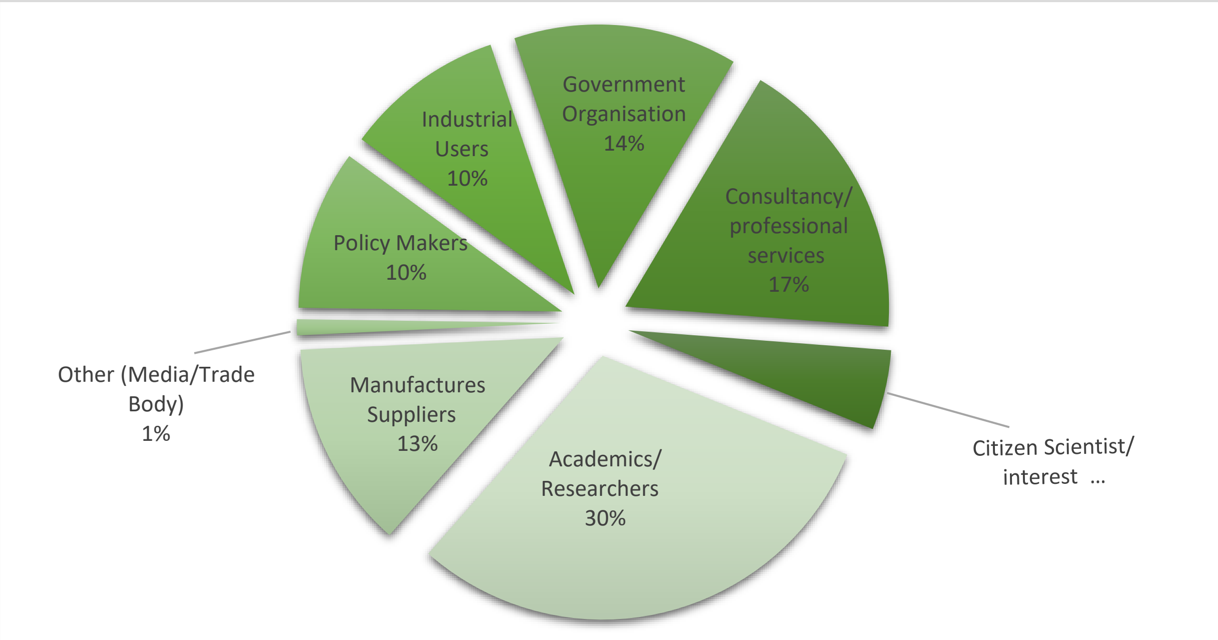


Figure 1: Attendees self-identification across the Code or Practice – Publicly Available Specification 4023 intended audience groups that attended the symposium. Where attendees selected more than one, all have been included.

Talks, Speakers and presentations

Talks, Speakers and Slides from the Symposium can be found in Appendix 1.

Introduction and Welcome

John Newington (Defra) opened the symposium, reflecting on the key work packages that have been completed to date by Defra in building their current evidence base. John touched on Defra's perspectives around what the challenges and opportunities are in this space and what Defra were keen to get out of the day.

Upon arrival, attendees were asked what they were hoping to get out of the days event via the Slido. Focus was around increasing knowledge on the application of low-cost sensors, learning more about best practices and standardisation and on how the data outputs are being used. Full responses captured in Slido can be found in the link in Appendix 1.

Supporting Best Practice

Designing Projects - when and how to use sensors

Dr Pete Edwards (University of York) explored considerations for the practical use of air pollution sensors. From what the question is you are looking to answer, the planning and development through to and data collection. Pete noted the importance of evaluating your approach.

The talk focused on findings from Quant – The Quantification of Utility of Atmospheric Network Technologies. Outlining the importance of sensor calibrations and how these can be impacted by changes at sensor locations. The talk underlined the value of understanding the precision of the model of sensor being used, especially when using multiple devices in a network.

Pete took us through case studies on: reducing sensor bias by understanding seasonal changes in ozone; low-cost sensor network case study during Covid Lockdown; and an application in source apportionment.

Publicly Available Specification: Journey to getting here and where next

Dr Davene Chatter-Singh (Joint Air Quality Unit) shared the journey Defra and the British Standards Institute (BSI) had taken to get the **Code of Practice – Publicly Available Specification (PAS) 4023** (COP- PAS4023) published. Reviewing the steps taken to develop the fast-track standard and the steering group inputs.

We reflected on the content of the COP- PAS 4023 and Davene shared the current activities around marketing, publicity and engagement activities that were taking place as part of the first cycle of the BSI fast-track standard review process.

Disseminating Lessons Learnt

Nat Easton (Clean Air Programme) presented the work being undertaken by the Clean Air Programme in this space. Nat shared current aims around developing best practice tools and guidance that are in an accessible and useable format for Local Authorities.

During the interactive sessions Nat sought feedback from Local Authorities around what they would like to see.

What is Standardisation and why do we need it?

Progress on Standardisation: Outcomes from the technical meeting

Andy Connor (National Physical Laboratory) gave an outline of current sensor standardisation before providing an overview of a Technical Sensor Standardisation workshop hosted by National Physical Laboratory on 2nd July.

Andy detailed the aims of the technical workshop and the topics discussed. These included: exploring different approaches; basis guidance to full standards; common methods/ templates for reporting data and meta data; sensor performance and data quality; importance of QA/QC traceability in data; need for test chambers that are fit for purpose; and adapting sensors to specific needs.

Future Look

Low-cost sensor source apportionment and data science - Unveiling the hidden information from low-cost sensor data

Dimitrios Bousiotis (University of Birmingham) explored current limitations of monitoring networks across the UK and the opportunities low-cost sensor technology brings to improve monitoring. Dimitrios led us though several case studies reflecting on different applications: at Selly Oak Birmingham estate to see the hyperlocal air quality variations; the application of machine learning to fill gaps in measurement data; their use in source identification and apportionment; and an application at a construction site.

Dimitrios also reflected on case studies on hyperlocal pollution sources along 2 main roads; and indoor air quality at a school.

Indoor Air Quality – Insights of their application

Evangelia Chatzidiakou (University of Cambridge) spoke on understanding indoor air quality with sensor technologies and digital science as part of the work being undertaken through Ingenious (Understand**ING** the sourc**E**s, tra**N**sformations and fate of ind**O**or air poll**U**tant**S**).

This projects aim is to Understand Air Pollution in Homes. Focusing on Bradford, Evangelia shared data from various instruments (low cost and reference grade), comparing the differences and similarities in ambient and indoor baselines. We focused in on a case study where measurements were taken in a kitchen over a 2-week period and the impact of fuel poverty and overheating.

Evangelia talked through the projects application of a conceptual model to understand air changes, sources and loss rate coefficients.

Key findings from Ingenious indicate that while indoor air quality exposure varies significantly between participants, outdoor generated particulate matter is a significant component of indoor exposure for all participants.

International Perspective – Learning from others

Lekan Popoola’s talk was split into 2 components. Through the first half Lekan gave a brief overview on the international perspective of low-cost sensor application. We worked through case studies on: tools for mapping fire and smoke across America feeding into Air Quality index and large incidents; a low-cost method for ambient Black Carbon using cellular phone images; and global and local scale monitoring tools for environmental inequality and justice. Lekan concluded the first part focusing on emerging new research and application frontiers.

The second part of this presentation Lekan reflected on the World Meteorological Organization GAW no.293 report: Integrating Low-cost Sensor Systems and Networks to Enhance Air Quality Applications. This report, which Lekan was a contributing author, was published in June 2024. The talk provided a comprehensive outline of the report's contents, which focuses on network level use of low-cost sensors. There are chapters on: air quality reconstruction, source identification and attribution; AQ patterns & trend for environmental justice, health studies and personal exposure monitoring; forecasting, data quality & disclosure; to Air Quality monitoring network design; and AQ monitoring network operations.

Interactive Sessions

The Symposium had 2 interactive sessions: the first to understand what is needed to support best practice and improve knowledge around standardisation in different communities; and the second a showcase of low-cost sensor applications through a mingle and circulate session focused on poster case studies. Through these interactive sessions the co-hosts posed several questions which attendees answered via Slido. The high-level, reoccurring points are captured below, the full Slido output can be found in Appendix 1.

What is needed to support best practice and improve knowledge around standardisation in different communities

1. **Code of Practice – Publicly Available Specification (PAS) 4023 was published in December 2023. When did you become aware of its publication and from who?**
   35% of the respondents indicated that they become aware of the COP-PAS 4023 as part of this event, either through its publicity or from the talks given. Most of the respondents were in 2024, perhaps suggesting they were unaware of the public consultation that took part in 2023.

2. **To help you meet your monitoring objectives, what pollutants do you think are most useful for sensor measurements?**
   Table 1 outlines the measurands inputted. Particulates (considering all metrics) accounted for more than 43% of the inputted values, followed by NO_2 at 29% and greenhouse gas collectively at 9%.

3. **What are the questions you are trying to answer with the use of low-cost sensors?**
   Respondents focus was around understanding the hyper local variation in pollutant concentrations and trends to help identify sources. Furthering knowledge of their contribution to varying temporal profiles through to longer term trends; evidencing the effectiveness of interventions through to use in modelling verification. Sensors are being used as part of engagement campaigns to help raise awareness and behavioural change, a key driver being 'how to improve public health'.

4. **What are the barriers that are preventing you achieve best practice?**
   The underlying responses centralised around a wish to uplift knowledge and confidence in best practice of QA/QC. Barriers included black boxed AQ sensors with limited data/resources to verify manufactures/suppliers selling

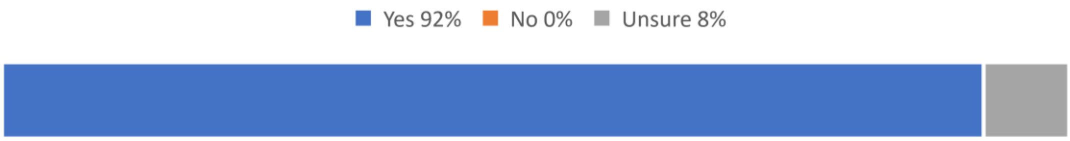
Table 1: Output from Question 2 of the interactive session.

Measurand	Count
Particle Mass	6
PM_{10}	4
$PM_{2.5}$	9
Particle Number	1
PM_1	1
Black Carbon	1
Dust	1
Ultra fine Particulate (UFP)	1
Ammonia	1
H_2S	2
CH_4	1
GHG	1
CO_2	3
Decibels (dB)	1
Deg	1
Bioaerosols	1
tVOCs/VOC	2
Benzene	1
SO_2	2
CO	2
NO_X	1
NO_2	15
O_3	3
LDSA – Lung Deposition Surface area	1

claims. Other difficulties focused on time and resource constraints, with a lack of information available of what is an appropriate scale of cost with increasing QAQC complexity. Other obstacles were around logistics and practicalities of connecting to mains powers, maintaining internet connection and facilitating co-location with reference instruments.

1. **What support around quality assurance do you need to give you the confidence in the quality of your data?**

2. **Would a knowledge hub/interactive space to share knowledge, lessons learned and data sharing be of use to sensor users?**



5. **If you could have 1 question answered today around standardisation or best practice – what would it be?**
There was a broad range of questions asking about: if there is a possibility of having a national impartial testing facility? If sensor performance results are/could be actively shared? What on-device and post collection data processes occur and whether they can be transparent? Whether there is a repository of case studies available? What is acceptable precision, accuracy and how do you determine appropriate QA/QC procedures for your study? And where to go for advice on standardisation and best practice?

Show Case of low-cost sensor applications

Users from citizen scientist, academics, industry, professional users through to government showcased a varied application of low-cost sensors through poster on the day. You can see the case studies showcased in Appendix 2. As part of this session we posed 5 questions via Slido. The full output can be found in Appendix 1.

1. **What are your thoughts around the variety of posters today, what would you like to see in addition to the case studies that will help you?**
   Respondents were very positive with the interesting variety of low-cost sensor application, notably across a range of users

   There was asks around having a further knowledge and understanding of aspects of network project delivery. For example, understanding the decision-making process as to the methods selected.

2. **Are there any case study examples that you were hoping to see that are not here today?**
   Respondents suggested specific examples of low-cost sensors that would be good examples for collective learning, through to specific aspects (eg QAQC, project budget profiles and more lessons learned). There was positive recognition that Local Authorities have a large knowledge base in the application of low-cost sensors, and respondents were keen to see more case studies showcasing this.

3. **What stood out for you in the case studies provided?**
   There was a broad range of responses, covering many of the posters. The Rail Safety and Standards Board (RSSB) was mentioned repeatedly as an interesting and informative case study. One respondent commented on the synergies with other government priorities including noise, health and climate change.

4. **Do you have any other comments you'd like to add?**
   A positive recognition for the authors of the posters which were from a good range of different user applications.

5. **What is one key action you would like to see coming from today's discussions**
   Comments centralised around uplifting knowledge. Be that how to engage with residents around the data produced; independent evaluation on sensors to help in selecting and purchasing a system and guidance around the sensors available. More case studies, help sheets, and a secure platform for collaboration with other network managers.

   Other comments focused on bring together sensor information/data to improve granularity of the Air Quality picture, and taking a more holistic approach to indoor and outdoor air.

Select Group- Targeted Discussion Session

At registration, there was an option for attendees to put themselves forward to be part of a select group for the Targeted Discussion. This ran immediately after the symposium with the aim of reflecting on the earlier sessions in the day and investigate next steps that various user groups need to take to maximise the benefit from this technology.

The Select Group split into 5 facilitated theme group discussions targeted around the themes listed below. The participants were split across groups to ensure even split of various user groups.

Theme 1.	Future proofing current standards and approaches
Theme 2.	Enabling Best Practice, the role of different groups (academic, government, manufacturers), and what is needed to support each of those.
Theme 3.	Understanding where the viability sits for manufacturers/suppliers and network managers
Theme 4.	Opportunities for novel/different applications, typically in academia and supporting their transfer to the real world
Theme 5.	Data, Machine Learning and AI

The perspectives from the targeted discussion will be pulled together and an output will be consulted on with the select group before outputs are shared from this session.

Defra, NCAS and IAQM would like to give a very big thank you to the speakers, those that showcased their case studies and all the attendees who shared their perspectives on the day.

We hope you found the Symposium beneficial, built connections, feeling more connected in the Low-cost Air Quality Sensor Systems community.

We look forward to working with you as we further explore the opportunities from this technology.

Appendix 1: Talks, Speakers and Slides from the Symposium

Session and Talks		Speaker	Link to slides	Case Studies
Introductions		**John Newington** Head of Evidence, Air Quality and Industrial Emissions Defra	PDF	-
Supporting best practice	**Designing Projects**: when and how to use sensors**.**	**Pete Edwards** University of York	PDF	• Reducing sensor bias by understanding seasonal changes in ozone • Low-cost sensor network case study during Covid Lockdown An application in source apportionment
	Publicly Available Specification: Journey to getting here and where next	**Dr Davene Chatter-Singh** Joint Air Quality Unit	PDF	• Possible Monitoring Scenarios • Examples of Network Calibrations – Breathe London and Local Authority case study methodologies summarised • Case Studies UK QUANT University of York case study demonstrating sensor system comparability. Sections C1 and C2 provide detail of the importance of inter device comparability and the benefits of co-location calibrations • Different Sensor Technologies and Performance Issues
	Disseminating Lessons Learnt	**Nat Easton** University of Southampton	PDF	-
What is standardisation and why do we need it?	**Progress on Standardisation –** outcomes from technical meeting	**Andy Connor** National Physical Laboratory	PDF	-
	Interactive Session - what is needed to support best practice and improve knowledge around standardisation in different communities	**All attending** **Kieran Laxen** – **IAQM** and **Sarah Moller - NCAS**	PDF	-
Showcase of low cost sensor applications	**Interactive Session -** networks and research via a mingle and circulate session focused on the posters case studies.	**All attending** **Kieran Laxen – IAQM** and **Sarah Moller - NCAS**		• See Appendix 2: Showcase of Low-cost Sensor Application
Future look	**Low Cost Sensor Source Apportionment and Data Science:** Unveiling the hidden information from low-cost sensor data	**Dimitrios Bousiotis** Pope Group/University of Birmingham	PDF	• Selly Oak Birmingham estate hyperlocal air quality variations. • The application of machine learning to fill gaps in measurement data and their use in source identification and apportionment. • Application at a construction site. • Hyperlocal pollution sources along 2 main roads • Indoor air quality at a school**.**
	Indoor Air Quality – Insights of their application	**Evangelia Chatzidiakou** University of Cambridge	PDF	• participants measurements in a kitchen over a 2-week period and the impact of fuel poverty and overheating

	International Perspective - learning from others	**Lekan Popoola** University of Cambridge		• Tools for mapping fire and smoke across America feeding into Air Quality index and large incidents. • a low-cost method for ambient Black Carbon using cellular phone images. • global and local scale monitoring tools for environmental inequality and justice.

Appendix 2: Showcase of Low Cost Sensor Application

Title	Author	Affiliation Company Authority	Sensor Systems
Air Quality Monitoring with Low Cost Sensors at the UCL Institute for Environmental Design and Engineering	**Emma Gibbons**	UCL Institute for Environmental Design and Engineering	PDF
Evaluating the Performance of Low-Cost Sensors within Railway Settings	**Connor Albutt-Wilkinson and Philbert Chan**	Rail Safety and Standards Board (RSSB)	PDF
Automatic Urban & Rural Network (AURN) Low Cost AQ Sensor Co-Locations	**Becki Cooke**	Environment Agency	PDF
Using Air Quality Monitoring to Improve Air quality Across Oxfordshire Schools		EarthSense	PDF
Empowering Change: Air quality awareness and education through Low-Cost Sensor applications	**Marta O'Brien**	University of Reading/ Defra	PDF
Using Low-Cost Sensors for Air Quality Assessment and Source Apportionment – Part I: Sensors and Materials	**Dimitrios Bousiotis & Francis D. Pope**	University of Birmingham	PDF
Using Low-Cost Sensors for Air Quality Assessment and Source Apportionment – Part II: Data Science and Source Apportionment	**Dimitrios Bousiotis & Francis D. Pope**	University of Birmingham	PDF
Local spatiotemporal dynamics of oak pollen measured by machine learning aided optical particle counters	**Sophie A. Mills, A. Rob Mackenzie & Francis D. Pope**	University of Birmingham & Birmingham Institute of Forest Research	PDF
SAAF HAVA: Citizen Sensing Network	**Stuart Phelps**	RADE [Residents Against Dirty Energy]	PDF
LocalAir: Mapping air pollution using e-scooters	**Sam Gunner & James Thomas**	University of Bristol	PDF
Ricardo and Government of Jersey School Air Quality Study	**David Madle**	Ricardo	PDF
Low Cost Air Quality Sensor Analysis of Hampshire	**Christina Vanderwel, Oliver Simmonds, Zixuan Peng**	University of Southampton, Southampton City Council, Winchester City Council, Eastleigh Borough Council, New Forest District Council	PDF
Worcestershire Real–Time Air Quality Monitor Network: Expanding air quality monitoring across Worcestershire	**Adrian Allman**	Worcestershire Regulatory Services	PDF
LuninAir: Precision Air Quality Data Made Visible	**David Johnson**	South Coast Precision Air Quality Monitors	PDF

Slow the Smoke: A research project to get a better understanding of the sources of air pollution in the Ashley ward, Bristol		Knowle West Media Centre, Bristol City Council and University of Bristol	
MONITORING EFFECTIVENESS OF A GREEN BARRIER IN REDUCING NO2 DISPERSION	**Sioni Hole, Bethan Tuckett-Jones, Sam Carter & Peter Walsh**	WSP	
Low Cost Monitoring at Euston Station Long Term Project for Network Rail		SKANSKA	