Performance evaluation of sensors for gaseous pollutants and particulate matter in ambient air

Status of European standardization work

Martine Van Poppel

VITO

Convenor of CEN TC264/WG42

vito

CEN standardization work

EUROPEAN COMMITTEE FOR STANDARDIZATION

- CEN, the **European Committee for Standardization**
- Develops EN standards and TS (Technical Specification)
- Consensus based process
- Documents developed by CEN Technical Body and approved through vote by the CEN national members

- CEN TC 264/WG42
  - TC 264: Air Quality
  - WG42: Ambient Air – Air Quality Sensors

  (thanks to all members for their hard work!)

vito

EU Air Quality Directive

- EU Air Quality Directive: 2008/50/EC
  - Directive on air quality and cleaner air for Europe
  - objectives for AQ limit values and **common methods** to assess AQ
  - PM_{10}, $PM_{2,5}$, NO_2, CO, O_3, SO_2, Pb, Benzene

Fixed sampling points
can be supplemented by
indicative measurements or
objective estimations

- It includes Data Quality Objectives for measurement techniques:
  - Reference monitoring (fixed measurement sampling points)
  - **Indicative measurements**
  - **Objective estimations**

Sensor can play a role here
(but NOT ONLY here)

vito

Towards a uniform test protocol for sensor in EU

- Work of EU TC264/WG42:
  - Main question: Can sensors meet the prescribed data quality objectives (DQO) of the EU Air Quality Directive?

    "Can sensors be used **as indicative measurements or objective estimations**"
  - Output: a protocol describing specific **performance requirements** and **test methods** under prescribed laboratory and field conditions
  - Context: using sensors as indicative measurements and objective estimations in EU reporting

- Work started about 7 years ago…. Where are we now?

vito

Status of standardization work

Air quality — Performance evaluation of air quality sensors

- Part 1 Gaseous pollutants in ambient air (NO_2, NO, CO, SO, O_3, benzene, CO_2)
  - TS ready and available
  - **CEN/TS 17660-1**
- Part 2 Particulate Matter in ambient air
  - In preparation
  - Idea: start from TS gases BUT some particularities…
  - Some issues to be resolved!
  - Expected to be ready for vote June 2023

vito

CEN TC264/WG42

- Focus:
  - Individual sensor systems (calibrated, treated as black box, not sensor n
  - To use sensors in context of EU AQ Directive
  - *Additional: guidance on testing of CO_2 sensors (informative)*

- Protocol:
  - Lab and field tests: different routes are possible
  - Field tests: different location types and seasons/meteorological conditions
  - DQO and performance requirements:
    - response time, linearity, limit of detection, repeatability
    - Long-term drift, cross-sensitivity, T and RH effect and hysteresis
    - Between sampler uncertainty, uncertainty compared to reference (expanded uncertainty), slope/intercept, data capture
  - Test three systems

vito

Data Quality Objectives – sensor systems

DQO	O_3	CO, NO_2, SO_2	PM_{10}, $PM_{2.5}$	
DQO Reference measurements	**U = 15%**	**U = 15%**	**U = 25%**	
DQO Indicative measurements	U = 30%	U = 25%	U = 50%	→ CLASS 1
DQO Objective estimations	U = 75%	U = 75%	U = 100%	→ CLASS 2
	U = 200%	U = 200%	U= 200%	→ CLASS 3

U: expanded uncertainty
Averaging time: period considered by the Limit Value (LV) -> 1h

vito

General principle of evaluation

ACTIVITIES THAT ARE PART OF THIS EVALUATION

PREPARATION

- System configuration
- Calibration procedures, application of calibration factors

PERFORMANCE EVALUATION

- Sensor system operated according to SOP of manufacturer
- Tests performed following the protocol: Pretest, Lab test, Field test
- Evaluation of DQO and performance requirements
- Class 1, 2, 3 awarded

DEPLOYMENT

- Can be used for ‘indicative measurements’ or ‘objective estimations’ or ‘other application’ dependent on performance evaluation result
- Use SOP as defined by manufacturer

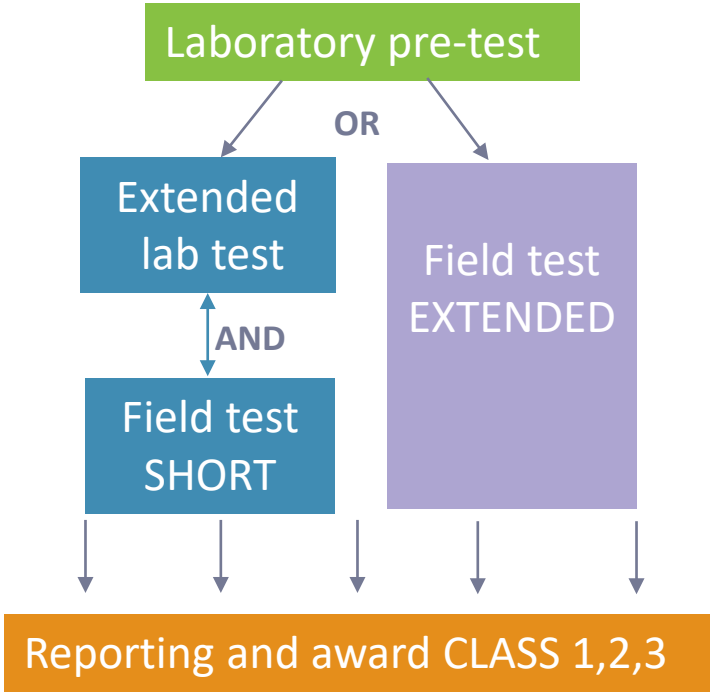
vito

Evaluation protocol for gases – overview

Type of tests:

1. Laboratory pre-test
2. Extended lab test
3. Field tests: short
4. Field tests: extended

Sensor systems tested: 3 replicate



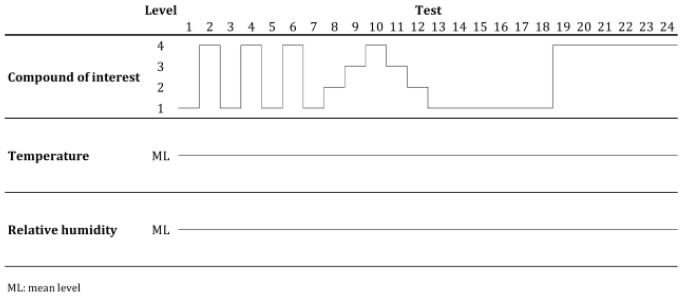
vito

Evaluation protocol for gases – lab pre-tests

- Laboratory pre-tests
  - response time (t_{90} and t_{10})
  - lack of fit (@4 levels)
  - limit of detection, repeatability

  => requirements

- Protocol defines
  - Test levels, length of tests, reading, …



Compound	Span level	Test level
	µg/m³	µg/m³
SO_2	125	0; 75; 125; 200
NO_2	100	0; 40; 100; 140; 200
NO	100	0; 40; 100; 250; 400
O_3	120	0; 60; 120; 180; 240
Benzene	5	0; 5; 25; 45
	mg/m³	mg/m³
CO	2	0; 2; 7; 10

vito

Evaluation protocol for gases – extended lab tests

- Extended lab tests
  - Long-term drift (every 2 weeks over 90 days)
  - cross-sensitivity (at zero and span level)
  - T and RH effect and hysteresis (at zero and span level)

  ⇒ expanded uncertainty of all lab uncertainties

- Protocol defines
  - Interferences to be tested
  - Levels of T, RH to be tested

Interferent	Interferent concentration level	Compound of interest						
		Benzene	O_3	NO_2	NO	SO_2	CO	CO_2
	µg/m³	–	–	–	–	–	–	–
TEX[a]	5	×	–	–	–	–	–	–
O_3	120	–	–	×	×	×	–	–
NO_2	100	–	×	–	×	×	–	–
NO	100	–	×	×	–	×	×	–
SO_2	125	–	×	×	×	–	×	–
	mg/m³	–	–	–	–	–	–	–
CO	2	×	–	–	×	×	–	×
CO_2	750	×	–	–	–	–	×	–

[a] TEX is a combination of toluene, ethylbenzene and at least one xylene.

vito

Evaluation protocol for gases – field tests

- Field tests:
  - Between sampler uncertainty
  - Data capture

  => requirements
  - expanded uncertainty of field tests

  =>DQO at LV

Compound	Area types		Site types		Step 3 [a] Short field test	Step 4 [a] Extended field test
	urban/suburban	rural	traffic	background	total number of sites	total number of sites
NO_2	×	–	×	×	2	4
NO	×	–	×	×	2	4
O_3	×	×	–	×	2	4
CO	×	–	×	×	2	4
SO_2	×	–	–	×	1	2
Benzene	×	–	×	–	1	2

[a] The numbers in the last two columns indicate the number of required field sites if the sensor system is tested for all area and site types. That means for example when testing a NO_2 sensor system according to Step 4 (extended field test), a total number of 8 field tests shall be carried out (4 in each season)

- Protocol defines
  - Number and type of test sites (area and site type) per pollutant
  - Test conditions:
    - Meteorological conditions: 2 seasons (min 40 days)
    - Concentration levels: "a minimum of 192 h of concentrations higher than 50 % of the average of 98th percentiles of hourly values in the last 5 years "
  - Installation, on-going quality control
  - Correction for slope and intercept

vito

Calculation of uncertainties – field trials

- Between sensor uncertainties (field)
  - Determined per field site
  - For both seasons together

- Expanded uncertainty of field tests at Limit value L:
  - Dataset at different AQMS are evaluated individually
  - Sensor systems are evaluated individually
  - Only a single slope and intercept correction are allowed; (for all systems and sites)

$$U_{\text{field},L} = k \times \sqrt{\left(\frac{R}{n-2} - u(\text{bs},\text{RM})^2\right) + \left[a + (b-1) \times L\right]^2}$$

RANDOM
Residuals of regression line
and correction for between instrument uncertainty
of reference method

BIAS at limit value (L)
Bias between regression line
and perfect agreement
(b=1 and a=0)

vito

Classification of sensor systems for gases

- Classification is based on **DQO** and **performance requirements**

- DQO (as maximum expanded uncertainty):
  - **Class 1**: DQO of indicative measurements
  - **Class 2**: DQO of objective estimations
  - **Class 3**: more relaxed (200%), not linked to Directive, e.g. for research, education, …

  - Evaluation based on DQO at LV (1h), time resolution is 1h if averaging period of LV is larger

- Requirements:
  - response time, lack of fit, repeatability, LOD
  - between sensor uncertainty, data capture

  => More stringent for Class1> Class 2> Class 3

⇒ Classification for each pollutant
⇒ Lowest classification counts over sites/units/req.
⇒ Classification per area/site type is possible

vito

Evaluation protocol for PM

- Based on protocol for gases but some differences!
- First idea : exclude lab test
- Some important issues however:
  - 24h evaluation (limit value) but data will be used on hourly resolution?
  - Ability of sensors to measure PM coarse?
  - Impact of RH on sensor response?
- Field test
  - Test site requirements similar to gases

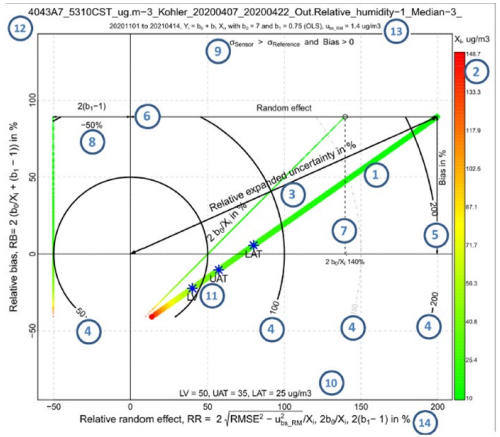
- reporting hourly values also
- Include “coarse” lab test
- Split dataset of field test to observe changes in sensor response f(RH)

vito

Questions – related topics - contact

Poster presentation of **Sinan Yatkin** :

"Modified Target Diagram to check compliance of low-cost sensors with the Data Quality Objectives of the European air quality Directive"



Contact: martine.vanpoppel@vito.be

vito