SLOVENSKI STANDARD
SIST-TS CEN/TS 17660-1:2022

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Kakovost zraka - Vrednotenje lastnosti senzorskih sistemov za kakovost zraka - 1. del: Plinasta onesnaževala v zunanjem zraku

Air quality - Performance evaluation of air quality sensor systems - Part 1: Gaseous pollutants in ambient air

Luftbeschaffenheit - Leistungsbewertung von Luftqualitäts-sensorsystemen - Teil 1: Gasförmige Schadstoffe in der Außenluft

Qualité de l'air - Évaluation des performances des systèmes capteurs de la qualité de l'air - Partie 1: Polluants gazeux dans l'air ambiant

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Air quality - Performance evaluation of air quality sensor systems - Part 1: Gaseous pollutants in ambient air

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This Technical Specification (CEN/TS) was approved by CEN on 17 October 2021 for provisional application.

The period of validity of this CEN/TS is limited initially to three years. After two years the members of CEN will be requested to submit their comments, particularly on the question whether the CEN/TS can be converted into a European Standard.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
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European foreword

This document (CEN/TS 17660-1:2021) has been prepared by Technical Committee CEN/TC 264 “Air quality”, the secretariat of which is held by DIN.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document is Part 1 of a series of documents published under the general title *Air quality — Performance evaluation of air quality sensor systems*.

Part 1 covers the performance evaluation of air quality sensor systems for gaseous pollutants in ambient air.

Part 2 covers the performance evaluation of air quality sensor systems for particulate pollutants in ambient air.

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to announce this Technical Specification: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

Sensor systems are generally seen as emerging measuring devices for the monitoring of air quality. Sensor systems provide a fast and low-cost alternative to the reference methods as defined in Directive 2008/50/EC on ambient air quality and cleaner air for Europe [1]. Sensor systems could allow for air pollution monitoring at a lower cost and with a higher spatial density than with the reference methods. They also allow for new air pollution applications when coupled with the global positioning system (GPS), global system for mobile communications (GSM) and smartphones including monitoring in complex topographies, at traffic junctions, in street canyons, at remote sites and for citizen science studies; e.g. monitoring around sensitive receptors, schools, or parks.

Sensor systems are making use of one or more low-cost sensors that are based on several principles of operations, e.g. amperometric sensors, metal oxides, optical sensors (infra-red absorption). However, sensor systems share some common features regarding their portability and low-cost compared to traditional reference methods. Typically, sensor systems are able to continuously monitor air pollution, with fast response times ranging between a few tens of seconds and a few minutes.

Currently, the use of sensor systems for air quality monitoring is limited by the occasional low accuracy of measurements that they can achieve. Additionally, there was no unambiguous protocol of evaluation of sensor systems with a structured metrological approach, able to ensure traceability from sensor system measurements to national and international standards. A protocol will enable exhaustive and transparent evaluations of sensor systems that can be an important step to include sensor system measurements into the monitoring of air quality for regulatory and non-regulatory purposes.

The protocol presented in this document applies to sensor systems and supports the requirements of Directive 2008/50/EC. The presented procedure evaluates if the measurement uncertainty defined in Directive 2008/50/EC as data quality objectives for indicative measurements and for objective estimation is met. However, the protocol additionally allows for a less demanding evaluation of the performance of sensor systems for non-regulatory measurements.

The protocol applies to sensor systems as individual measurement devices. This protocol does not apply to sensor systems as nodes in a sensor network. Annex A gives information on the use of sensor systems in sensor networks.

This document defines common procedures and requirements for the evaluation of the performance of sensor systems to facilitate mutual recognition by the relevant bodies or stakeholders and thereby minimise both administrative and cost burdens on manufacturers. It does not describe the roles and responsibilities of manufacturers, test laboratories and relevant bodies under these procedures.

In addition to the gaseous pollutants regulated in Directive 2008/50/EC, carbon dioxide is considered in the scope of this protocol although this compound is not listed in Directive 2008/50/EC. Consequently, there is no data quality objective for carbon dioxide. The World Health Organisation (WHO) has not set any guidelines for carbon dioxide. However, there is a growing interest in monitoring carbon dioxide in ambient air with sensor systems.

1 Scope

This document specifies the general principles, including testing procedures and requirements, for the classification of performance of low-cost sensor systems for the monitoring of gaseous compounds in ambient air at fixed sites. The classification of sensor systems includes tests that are performed under prescribed laboratory and field conditions.

The procedure described is applicable to the determination of the mass concentration of air pollutants. The pollutants that are considered in this document are the gaseous pollutants regulated under Directive 2008/50/EC (O_3, $NO/NO_2/NO_x$, CO, SO_2 and benzene) in the range of concentrations expected in ambient air.

This document provides a classification that is consistent with the requirements for indicative measurements and objective estimation defined in Directive 2008/50/EC. In addition, it provides a classification for applications (non-regulatory measurements) that require more relaxed performance criteria.

This document applies to sensor systems used as individual systems. It does not apply to sensor systems as part of a sensor network. However, for some applications (e.g. in cities) sensor systems are deployed as part of a sensor network. Annex A gives information on the use of sensor systems as nodes in a sensor network.

This document gives guidance on the testing of CO_2 sensor systems in Annex B since, although not listed in Directive 2008/50/EC, CO_2 is an interesting indicator as proxy for activities involving combustion processes or for CO_2 evaporation from soil or water.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN ISO 14956:2006, *Air quality — Evaluation of the suitability of a measurement procedure by comparison with a required measurement uncertainty (ISO 14956:2002)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
ambient air
outdoor air in the troposphere where provisions concerning health and safety at work apply and to which members of the public do not have regular access

[SOURCE: Directive 2008/50/EC]

Note 1 to entry: This does not include workplaces defined by Directive 89/654/EC.

3.2
sensor
individual sensor
chemical cell or physical unit that produces an analytically useful signal by detecting or measuring the analyte

3.3
sensor system
sensor node
single integrated set of hardware that uses one or more sensors to detect and/or measure a chemical concentration or quantity that is able to supply real time measurements

Note 1 to entry: The term "instrument" has a very similar definition, but many researchers are typically referring to a reference grade device when using the word "instrument".

Note 2 to entry: All the tests that are intended in this document are designed for sensor systems only.

Note 3 to entry: Sensor systems contain a number of common components in addition to the basic sensing or analytical element that is used for detection. Common core components and functions can include:

— sensing element or detector (actually the sensor);

— sampling capability (active or passive sampling);

— power systems, including batteries;

— analogue to digital conversion;

— signal processing;

— local data storage;

— data transmission;

— housing or casing.

3.4
class 1 sensor system
measuring device delivering data that are at minimum consistent with the data quality objectives of indicative measurements

Note 1 to entry: The term "indicative measurement" refers to the definition in Directive 2008/50/EC and not to the performance of the sensor system.

3.5
class 2 sensor system
measuring device delivering data that are at minimum consistent with the data quality objectives of objective estimations

Note 1 to entry: The term "objective estimation" refers to the definition in Directive 2008/50/EC and not to the performance of the sensor system.

3.6
class 3 sensor system
measuring device delivering data that comply with a relaxed target measurement uncertainty, but are not formally associated with any mandatory data quality objective

Note 1 to entry: Relaxed target measurement uncertainty are given in Table 3.

3.7
exposure chamber
volume that can be sealed with controlled conditions of temperature, humidity and test gas volume fraction, used for performing the test on the sensor system

3.8
averaging period
period of time for which a limit value is associated

Note 1 to entry: For this document, the averaging period for field measurements is default to 1 h if the averaging period in Directive 2008/50/EC is greater than 1 h.

3.9
independent measurement
measurement that is not influenced by a previous individual measurement, by separating two individual measurements by at least four response times

3.10
individual measurement
measurement averaged over a time period equal to the response time of the sensor system

[SOURCE: adapted from EN 14211:2012, 3.15]

Note 1 to entry: This definition differs from the meaning of the concept “individual measurement” in Directive 2008/50/EC.

3.11
cold start
initial start after a shutdown or a long maintenance

Note 1 to entry: While the durations can vary, typically a cold start follows a shutdown of at least 48 h (2 days or more).

3.12
warm start
restart after a short maintenance period of typically 1 h

3.13
hot start
restart after a shutdown period of a few minutes

3.14
shelf life
maximum storage period before use as stated by the manufacturer

3.15
zero gas
gas or gas mixture used to produce the zero response of a given analytical procedure or measuring device for a given range of content

[SOURCE: ISO 7504:2015, 4.6]

3.16
calibration
operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

[SOURCE: JCGM 200:2012, 2.39]

Note 1 to entry: A calibration can be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it can consist of an additive or multiplicative correction of the indication with associated measurement uncertainty. Calibration should not be confused with adjustment of a measuring system, often mistakenly called "self-calibration", nor with verification of calibration.

Note 2 to entry: This document does not describe the process of calibration of sensor systems.

3.17
drift
continuous or incremental change over time in measurement, due to changes in properties of a sensor system

Note 1 to entry: The drift is related neither to a change in a quantity being measured nor to a change of any recognized influence quantity.

3.18
memory effect
effect of previous values of the measurand on the current measurement results

[SOURCE: EN ISO 9169:2006, 2.1.21]

Note 1 to entry: Memory effect can be quantified by the difference between the upscale and downscale measurements starting from fixed lower and upper measurement values.

3.19
detection limit
limit of detection
measured quantity value, obtained by a given measurement procedure, for which the probability of falsely claiming the absence of a component in a material is β, given a probability α of falsely claiming its presence

Note 1 to entry: IUPAC recommends default values for α and β equal to 0,05.

Note 2 to entry: The abbreviation LOD is sometimes used.

Note 3 to entry: The term "sensitivity" is discouraged for "detection limit".

[SOURCE: JCGM 200:2012, 4.18]

3.20
repeatability of results of measurements
repeatability
closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement

Note 1 to entry: These conditions are called repeatability conditions.

Note 2 to entry: Repeatability conditions include:

— the same measurement procedure;

— the same observer;

— the same measuring instrument, used under the same conditions;

— the same location;

— repetition over a short period of time.

Note 3 to entry: Repeatability can be expressed quantitatively in terms of the dispersion characteristics of the results.

[SOURCE: VIM:1993, 3.6]

3.21
selectivity of a measuring system
selectivity
property of a measuring system, used with a specified measurement procedure, whereby it provides measured quantity values for one or more measurands such that the values of each measurand are independent of other measurands or other quantities in the phenomenon, body, or substance being investigated

[SOURCE: JCGM 200:2012, 4.13]

Note 1 to entry: In chemistry, the measured quantities often involve different components in the system undergoing measurement and these quantities are not necessarily of the same kind.

Note 2 to entry: In chemistry, selectivity of a measuring system is usually obtained for quantities with selected components in concentrations within stated intervals.

3.22
sensitivity of a measuring system
sensitivity
quotient of the change in an indication of a measuring system and the corresponding change in a value of a quantity being measured

Note 1 to entry: Sensitivity of a measuring system can depend on the value of the quantity being measured.

Note 2 to entry: The change considered in a value of a quantity being measured must be large compared with the resolution.

[SOURCE: JCGM 200:2012, 4.12]

3.23
stability of a measuring instrument
stability
property of a measuring instrument, whereby its metrological properties remain constant in time

[SOURCE: JCGM 200:2012, 4.19]

Note 1 to entry: Stability can be quantified in several ways, e.g. in terms of the duration of a time interval over which a metrological property changes by a stated amount, or in terms of the change of a property over a stated time interval.

3.24
uncertainty of measurement
measurement uncertainty
uncertainty
non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used

Note 1 to entry: Measurement uncertainty includes components arising from systematic effects, such as components associated with corrections and the assigned quantity values of measurement standards, as well as the definitional uncertainty. Sometimes estimated systematic effects are not corrected for, but instead, associated measurement uncertainty components are incorporated.

Note 2 to entry: The parameter may be, for example, a standard deviation called standard measurement uncertainty (or a specified multiple of it), or the half-width of an interval, having a stated coverage probability.

Note 3 to entry: Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from series of measurements and can be characterized by standard deviations. The other components, which may be evaluated by Type B evaluation of measurement uncertainty, can also be characterized by standard deviations, evaluated from probability density functions based on experience or other information.

Note 4 to entry: In general, for a given set of information, it is understood that the measurement uncertainty is associated with a stated quantity value attributed to the measurand. A modification of this value results in a modification of the associated uncertainty.

[SOURCE: JCGM 200:2012, 2.26]

3.25
combined standard measurement uncertainty
standard measurement uncertainty that is obtained using the individual standard measurement uncertainties associated with the input quantities in a measurement model

[SOURCE: JCGM 200:2012, 2.31]

3.26
expanded measurement uncertainty
expanded uncertainty
product of a combined standard measurement uncertainty and a factor larger than the number one

Note 1 to entry: The factor depends upon the type of probability distribution of the output quantity in a measurement model and on the selected coverage probability.

Note 2 to entry: The term “factor” in this definition refers to a coverage factor.

Note 3 to entry: Expanded measurement uncertainty is termed “overall uncertainty” in paragraph 5 of Recommendation INC-1 (1980) (see the GUM) and simply “uncertainty” in IEC documents.

[SOURCE: JCGM 200:2012, 2.35]

3.27
coverage factor
number larger than one by which a combined standard measurement uncertainty is multiplied to obtain an expanded measurement uncertainty

Note 1 to entry: A coverage factor is usually symbolized k.

[SOURCE: JCGM 200:2012, 2.38]

4 Symbols and abbreviations

4.1 Symbols

For the purposes of this document, the following symbols apply.

NOTE In the following list, all symbols related to the measurement uncertainty of source contributions are indicated as standard uncertainty, e. g. $u\left(X\right)$. However, in the text expanded uncertainties of the same source contributions can be used, e. g. $U\left(X\right)$.

a	intercept of the regression line
A	average of the values y_i
b	slope of the regression line
b_{a}	average of the slope of the regression line at zero and highest test level
c	intercept of the corrected dataset
C_{a}	average of the values C_i
C_i	i^{th} value of the sensor system response
$\hat{C}_i$	i^{th} value of the concentration estimated using a linear regression
$C_{\mathrm{int,max}}$	maximum concentration of interfering compound
$C_{\mathrm{int,min}}$	minimum concentration of interfering compound
$C_{\mathrm{s,0}}$	average concentration of the measurements at the highest test level at the beginning of the drift period
$C_{\mathrm{s,1}}$	average concentration of the measurements at the highest test level at the end of the drift period
C_{emf,X_1}	value of the sensor system response at tested electromagnetic field level $X_{\mathrm{emf,1}}$
C_{emf,X_2}	value of the sensor system response at tested electromagnetic field level $X_{\mathrm{emf,2}}$
C_{p,X_1}	value of the sensor system response at tested atmospheric pressure $X_{\mathrm{p,1}}$
C_{p,X_2}	value of the sensor system response at tested atmospheric pressure $X_{\mathrm{p,2}}$
C_{wv,X_1}	value of the sensor system response at tested wind velocity $X_{\mathrm{wv,1}}$
C_{wv,X_2}	value of the sensor system response at tested wind velocity $X_{\mathrm{wv,2}}$
$C_{\mathrm{z,0}}$	average concentration of the measurements at zero level at the beginning of the drift period
$C_{\mathrm{z,1}}$	average concentration of the measurements at zero level at the end of the drift period
d	slope of the corrected dataset
$D_{\mathrm{l,s}}$	long-term drift at the highest test level

$D_{\mathrm{l,z}}$	long-term drift at zero level
$D_{\mathrm{l,s,max}}$	maximum long-term drift at the highest test level determined during the 90 days test period
$D_{\mathrm{l,z,max}}$	maximum long-term drift at zero level determined during the 90 days test period
k	coverage factor
L	LV, UAT or LAT currently being assessed
m	number of repetitions at one and the same concentration level
n	number of measuring points; number of measurements
n_{s}	number of replicate sensor systems
r	measurement repeatability; repeatability
R	value of the residual sum of squares resulting from the linear regression;
ρ	residual
$\rho_{\mathrm{c},i}$	residual of each average at each concentration level
$\rho_{\mathrm{c},i,\max}$	maximum residual of individual $\rho_{\mathrm{c},i}$
$s(a)$	square root of the quadratic sum of the standard deviation of the intercepts for the low level plus the standard deviations of the intercepts for the high level of the compounds of interest for temperature and humidity, or the standard deviation of intercepts for test gas
$s(b)$	square root of the quadratic sum of the standard deviation of the slopes for the low level plus the standard deviations of the slopes for the high level of the compounds of interest for temperature and humidity, or standard deviation of the slopes for test gas
s_{r}	standard deviation of repeatability
$s(X_i)$	standard deviation of repeatability of parameter X, given in the performance testing reports of the reference analysers
t	time
t_{90}	response time
t_{f}	response time (fall)
t_{r}	response time (rise)
$t_{n-1,\alpha}$	two-sided Students *t*-factor at a confidence level of $1-\alpha$, with $n-1$ degrees of freedom
$u(a)$	standard uncertainty of the intercept of a regression line
$u(a)^2$	square of the uncertainty of the intercept of the uncorrected dataset
$u(b)$	standard uncertainty of the slope of a regression line
$u(b)^2$	square of the uncertainty of the slope of the uncorrected dataset