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Ambient air — Standard method for the measurement of the concentration of carbon monoxide by non-dispersive infrared spectroscopy

National foreword

This British Standard is the UK implementation of EN 14626:2012. It supersedes BS EN 14626:2005 which is withdrawn.

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English Version

**Ambient air - Standard method for the measurement of the
concentration of carbon monoxide by non-dispersive infrared
spectroscopy**

Air ambiant - Méthode normalisée de mesurage de la
concentration en monoxyde de carbone par spectroscopie
à rayonnement infrarouge non dispersif

Luftqualität - Messverfahren zur Bestimmung der
Konzentration von Kohlenmonoxid mit nicht-dispersiver
Infrarot-Photometrie

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Foreword

This document (EN 14626:2012) has been prepared by Technical Committee CEN/TC 264 “Air quality”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 2013, and conflicting national standards shall be withdrawn at the latest by February 2013.

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

This document supersedes EN 14626:2005.

The technical changes made since EN 14211:2005 are listed in Annex G of this European Standard.

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1 Scope

This European Standard specifies a continuous measurement method for the determination of the concentration of carbon monoxide present in ambient air based on the non-dispersive infrared spectroscopic measuring principle. This standard describes the performance characteristics and sets the relevant minimum criteria required to select an appropriate non-dispersive infrared spectroscopic analyser by means of type approval tests. It also includes the evaluation of the suitability of an analyser for use in a specific fixed site so as to meet the data quality requirements as specified in Annex I of Directive 2008/50/EC [1] and requirements during sampling, calibration and quality assurance for use.

The method is applicable to the determination of the mass concentration of carbon monoxide present in ambient air up to 100 mg/m³ carbon monoxide. This concentration range represents the certification range for the type approval test.

NOTE 1 Other ranges may be used depending on the levels present in ambient air.

NOTE 2 When the standard is used for other purposes than for measurements required by Directive 2008/50/EC, the ranges and uncertainty requirements may not apply.

The method covers the determination of ambient air concentrations of carbon monoxide in zones classified as rural areas, urban-background areas and traffic-orientated locations and locations influenced by industrial sources.

The results are expressed in mg/m³ (at 20 °C and 101,3 kPa).

NOTE 3 100 mg/m³ of CO corresponds to 86 µmol/mol of CO.

This standard contains information for different groups of users.

Clauses 5 to 7 and Annexes B, C and D contain general information about the principles of carbon monoxide measurement by non-dispersive infrared spectroscopic analyser and sampling equipment.

Clause 8 and Annex E are specifically directed towards test houses and laboratories that perform type-approval testing of carbon monoxide analysers. These sections contain information about:

- type-approval test conditions, test procedures and test requirements;
- analyser performance requirements;
- evaluation of the type-approval test results;
- evaluation of the uncertainty of the measurement results of the carbon monoxide analyser based on the type-approval test results.

Clauses 9 to 11 and Annex F are directed towards monitoring networks performing the practical measurements of carbon monoxide in ambient air. These sections contain information about:

- initial installation of the analyser in the monitoring network and acceptance testing;
- ongoing quality assurance/quality control;
- calculation and reporting of measurement results;
- evaluation of the uncertainty of measurement results under practical monitoring conditions.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 15267-1, *Air quality — Certification of automated measuring systems — Part 1: General principles*

EN 15267-2, *Air quality — Certification of automated measuring systems — Part 2: Initial assessment of the AMS manufacturer's quality management system and post certification surveillance for the manufacturing process*

EN ISO 6142, *Gas analysis — Preparation of calibration gas mixtures — Gravimetric method (ISO 6142)*

EN ISO 6143, *Gas analysis — Comparison methods for determining and checking the composition of calibration gas mixtures (ISO 6143)*

EN ISO 6144, *Gas analysis — Preparation of calibration gas mixtures — Static volumetric methods (ISO 6144)*

EN ISO 6145-6, *Gas analysis — Preparation of calibration gas mixtures using dynamic volumetric methods — Part 6: Critical orifices (ISO 6145-6)*

EN ISO 6145-7, *Gas analysis — Preparation of calibration gas mixtures using dynamic volumetric methods — Part 7: Thermal mass-flow controllers (ISO 6145-7)*

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

EN ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories (ISO/IEC 17025)*

ENV 13005:1999, *Guide to the expression of uncertainty in measurement*

3 Terms and definitions

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

3.1

adjustment

set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured

Note 1 to entry: Types of adjustment of a measuring system include zero adjustment of a measuring system, offset adjustment, and span adjustment (sometimes called gain adjustment).

Note 2 to entry: Adjustment of a measuring system should not be confused with calibration, which is a prerequisite for adjustment.

[SOURCE: JCGM 200:2012 (VIM) [2]]

Note 3 to entry: In the context of this standard, adjustment is performed on measurement data rather than on the analyser.

3.2

ambient air

outdoor air in the troposphere, excluding workplaces as defined by Directive 89/654/EEC, where provisions concerning health and safety at work apply and to which members of the public do not have regular access

[SOURCE: 2008/50/EC[1]]

3.3

analyser

measuring system that provides an output signal which is a function of the concentration, partial pressure, flow or temperature of one or more components of a gas mixture

3.4

availability of the analyser

fraction of the time period for which valid measuring data of the ambient air concentration is available from an analyser

3.5

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

Note 1 to entry: A calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

Note 2 to entry: Calibration should not be confused with adjustment of a measuring system, often mistakenly called “self-calibration”, nor with verification of a calibration.

Note 3 to entry: Often, the first step alone in the above definition is perceived as being calibration.

[SOURCE: JCGM 200:2012 (VIM) [2]]

Note 4 to entry: In the context of this standard, calibration is a comparison of the analyser response to a known gas concentration with a known uncertainty when the information obtained from the comparison is used for the successive adjustment (if needed) of the analyser.

3.6

certification range

concentration range for which the analyser is type-approved

3.7

check

verification that the analyser is still operating within specified performance limits

3.8

combined standard uncertainty

standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances or co-variances of these other quantities weighted according to how the measurement result varies with changes in these quantities

[SOURCE: ENV 13005:1999]

3.9

coverage factor

numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty

[SOURCE: ENV 13005:1999]

3.10

designated body

body which has been designated for a specific task (type approval tests and/or QA/QC activities in the field) by the competent authority in the Member States

3.11

detection limit

smallest concentration of a measurand that can be reliably detected by a specific measurement process

Note 1 to entry: The detection limit is calculated as $3,3 \times (s_z/B)$ where s_z is the standard deviation of analyser response at zero measurand concentration (see 8.4.5) and B is the slope of the calibration function [3].

3.12

expanded uncertainty

quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand

Note 1 to entry: The fraction may be viewed as the coverage probability or level of confidence of the interval.

Note 2 to entry: To associate a specific level of confidence with the interval defined by the expanded uncertainty requires explicit or implicit assumptions regarding the probability distribution characterised by the measurement result and its combined standard uncertainty. The level of confidence that may be attributed to this interval can be known only to the extent to which such assumptions may be justified.

[SOURCE: ENV 13005:1999]

Note 3 to entry: For the purpose of this standard the expanded uncertainty is the combined standard uncertainty multiplied by a coverage factor $k=2$ resulting in an interval with a level of confidence of 95 %.

3.13

fall time

difference between the response time (fall) and the lag time (fall)

3.14

independent measurement

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

Note 1 to entry: The largest value of response time (rise) and response time (fall) are intended.

3.15

individual measurement

measurement averaged over a time period equal to the response time of the analyser

Note 1 to entry: The largest value of response time (rise) and response time (fall) are intended.

Note 2 to entry: This definition differs from the meaning of the concept "individual measurement" in Directive 2008/50/EC [1].

3.16

influence quantity

quantity that is not the measurand but that affects the result of the measurement

[SOURCE: ENV 13005:1999]

3.17

interferent

component of the air sample, excluding the measured constituent, that affects the output signal

3.18

lack of fit

maximum deviation from the linear regression line of the average of a series of measurement results at the same concentration

3.19

lag time

time interval from the moment at which a step change of sample concentration occurs at the inlet of the analyser to the moment at which the output reading reaches a level corresponding to a predefined change of the stable output reading

3.20

limit value

level fixed on the basis of scientific knowledge, with the aim of avoiding, preventing or reducing harmful effects on human health and/or the environment as a whole, to be attained within a given period and not to be exceeded once attained

[SOURCE: 2008/50/EC [1]]

3.21

long term drift

difference between zero or span readings over a determined period of time (e.g. period of unattended operation)

3.22

monitoring station

enclosure located in the field in which an analyser has been installed to monitor concentrations of one or more ambient air pollutants

3.23

parallel measurements

measurements from different analysers, sampling from one and the same sampling manifold, starting at the same time and ending at the same time

3.24

performance characteristic

one of the parameters assigned to equipment in order to define its performance

3.25

performance criterion

limiting quantitative numerical value assigned to a performance characteristic, to which conformance is tested

3.26

period of unattended operation

time period over which the drift complies with the performance criterion for long term drift

3.27

repeatability (of results of measurement)

closeness of the agreement between the results of successive individual measurements of carbon monoxide carried out under the same conditions of measurement

Note 1 to entry: These conditions include:

- a) the same measurement procedure;
- b) the same observer;
- c) the same analyser, used under the same conditions;
- d) at the same location;
- e) repetition over a short period of time.

3.28

reproducibility under field conditions

closeness of the agreement between the results of simultaneous measurements with two analysers in ambient air carried out under the same conditions of measurement

Note 1 to entry: These conditions are called field reproducibility conditions and include:

- a) the same measurement procedure;
- b) two identical analysers, used under the same conditions;

- c) at the same monitoring station;
- d) the period of unattended operation.

3.29

response time

time interval from the instant at which a step change of sample concentration occurs at the inlet of the analyser to the instant at which the output reading reaches a level corresponding to 90 % of the stable output reading

3.30

sampled air

part of ambient air that is transferred through the sampling inlet and sampling system for subsequent measurement

3.31

sample gas temperature

temperature of the sampled gas at the sample inlet

Note 1 to entry: The term 'gas' may refer to a test gas used in type-approval testing or to ambient air transferred to the analyser.

3.32

sampling system

the assembly of components needed to transfer ambient air to the analyser

3.33

short-term drift

difference between zero or span readings at the beginning and end of a 12 h period

3.34

standard uncertainty

uncertainty of the result of a measurement expressed as a standard deviation

[SOURCE: ENV 13005:1999]

3.35

surrounding temperature

temperature of the air directly surrounding the analyser

3.36

type approval

decision taken by a designated body that the pattern of an analyser conforms to specified requirements

3.37

type approval test

examination of two or more analysers of the same pattern which are submitted by a manufacturer to a designated body including the tests necessary for approval of the pattern

3.38

uncertainty (of measurement)

parameter associated with the result of a measurement that characterises the dispersion of the values that could reasonably be attributed to the measurand

[SOURCE: ENV 13005:1999]

4 Abbreviated terms

FEP perfluoro-ethylene-propylene

MFC mass flow controller

PTFE polytetrafluoroethylene

5 Principle

5.1 General

This standard describes the method for measurement of the concentration of carbon monoxide in ambient air by means of non-dispersive infrared spectroscopy. The requirements, the specific components of the infrared analyser and its sampling system are described. A number of performance characteristics with associated minimum performance criteria are given for the analyser. The actual values of these performance characteristics for a specific type of analyser shall be determined in a so-called type approval test for which procedures have been described. The type approval test comprises a laboratory test and a field test. The selection of a type-approved analyser for a specific measuring task in the field is based on the calculation of the expanded uncertainty of the measurement method. In this expanded uncertainty calculation, the actual values of various performance characteristics of a type-approved analyser and the site-specific conditions at the monitoring station are taken into account (see 9.6). The expanded uncertainty of the method shall not exceed 15 % for fixed measurements or 25 % for indicative measurements, as specified in Annex I of Directive 2008/50/EC [1]. Requirements and recommendations for quality assurance and quality control are given for the measurements in the field (see 9.4).

5.2 Measuring principle

The attenuation of infrared light passing through a sample cell is a measure of the concentration of CO in the cell, according to the Lambert-Beer law. Not only CO but also most hetero-atomic molecules will absorb infrared light; in particular water and CO₂ have broad bands that can interfere with the measurement of CO. Different technical solutions have been developed to suppress cross-sensitivity, instability and drift in order to design continuous monitoring systems with acceptable properties. For instance:

- measuring IR absorption of a specific wavelength (4,7 µm for CO);
- dual-cell monitors, using a reference cell filled with clean air (compensation for drift);
- gas-filter correlation, “measuring” over a range of wavelengths.

Special attention shall be paid to infrared radiation absorbing gases such as water vapour, carbon dioxide, nitrous oxide and hydrocarbons.

The concentration of carbon monoxide is measured in volume/volume units (if the analyser is calibrated using a volume/volume standard). The final results for reporting are expressed in mg/m³ using standard conversion factors (see Clause 10).

5.3 Type approval test

The type approval test is based on the evaluation of performance characteristics determined under a prescribed series of tests. In this European Standard, test procedures are described for the determination of the actual values of the performance characteristics for at least two analysers in a laboratory and the same analysers in the field, operated in parallel in both cases. The type approval laboratory tests shall not include the sampling inlet, sampling system and external data acquisition system, but shall include analyser sampling line and filter. The type approval field test may include a sampling inlet and a sampling system. However, the influence of these components on the test results shall be minimised by proper maintenance.

A designated body shall perform these tests. The evaluation for type approval of an analyser is based on the calculation of the expanded uncertainty in the measuring result based on the numerical values of the tested performance characteristics and compared with a prescribed maximum uncertainty.

The type approval of an analyser and subsequent QA and QC procedures provide evidence that the defined requirements concerning data quality laid out in Annex I of Directive 2008/50/EC [1] can be satisfied.

Appropriate experimental evidence shall be provided by:

- type approval tests performed under conditions of intended use of the specified method of measurement, and
- calculation of expanded uncertainty of results of measurement by reference to ENV 13005.

5.4 Field operation and quality control

Prior to the installation and operation of a type approved analyser at a monitoring station, an expanded uncertainty calculation shall be performed with the actual values of the performance, obtained during the type approval tests, and the site-specific conditions at that monitoring station. This calculation shall be used to demonstrate that the type-approved analyser meets the requirements for all applicable limit values under the actual conditions present at that specific monitoring station.

After the installation of the approved analyser at the monitoring station, its correct functioning shall be tested.

Requirements for quality assurance and quality control are given for the operation and maintenance of the sampling system, as well as for the analyser, to ensure that the uncertainty of subsequent measurement results obtained in the field is not compromised.

6 Sampling

6.1 General

Depending on the installation of the infrared analyser at a monitoring station, a single sampling line for the analyser may be chosen. Alternatively, sampling can take place from a sampling system consisting of a common sampling inlet with a sampling manifold to which other analysers and equipment may be attached. Conditions and layout of the sampling system will contribute to the uncertainty of the measurement; to minimise this contribution to the expanded uncertainty, requirements for the sampling equipment are given in the following sub-clauses.

NOTE In Annex B, different arrangements of the sampling equipment are schematically presented.

6.2 Sampling location

The location where the ambient air shall be sampled and analysed is not specified as this depends strongly on the category of a monitoring station (such as measurements taken in e.g. a rural area or background area). Criteria on sampling points on a micro scale are given in Annex III of Directive 2008/50/EC [1].

6.3 Sampling system

6.3.1 Construction

The sampling system shall include a sampling inlet and may include the following components:

- a sampling line or manifold;
- a particle filter placed between the sampling line or manifold and the analyser;
- a sampling pump in case a sampling manifold is used.

The sample inlet shall be constructed in such a way that ingress of rainwater into the sampling line or manifold is prevented. The sampling line or manifold shall be as short as practical to minimise the residence time.

In the case where a sampling manifold is used, an additional pump is necessary with sufficient capacity to fulfil the sampling requirements stated in the previous sub-clauses (see also 6.5 and Annex D).

The material of the sample inlet as well as the sampling line or manifold can influence the composition of the sample. In practice, the best materials, such as polytetrafluoroethylene (PTFE), perfluoro-ethylene-propylene

(FEP), borosilicate glass or stainless steel, shall be used. The influence of the material of the sampling inlet and line or manifold on the measured concentrations of CO due to losses shall be $< 2,0 \%$.

NOTE This value can be achieved when the quality assurance and quality control requirements (see Clause 9) are followed.

The sampling line or manifold may be moderately heated to avoid condensation. Condensation may occur in the case of high ambient temperature and/or humidity.

The influence on the measured concentrations of the pressure drop along the sampling inlet and line or manifold and the particle filter shall be $\leq 1,0 \%$.

6.3.2 Particle filter

A particle filter shall be placed between the sampling line or manifold and the inlet of the analyser. The filter shall retain all particles likely to alter the performance of the analyser. It shall be made of PTFE. The material of the filter housing shall be chemically inert to carbon monoxide.

The filter may be internal to the analyser (see 7.7) or external. In case the analyser contains a built-in filter, an external filter is not necessary.

NOTE 1 A pore size of the filter of $5 \mu\text{m}$ usually fulfils this requirement.

NOTE 2 Suitable materials for the filter housing are for example PTFE, stainless steel, or borosilicate glass.

The particle filter shall be conditioned before used in measurements. The filter shall be changed periodically depending on the dust loading at the sampling site (as indicated in 9.7). The filter housing shall be cleaned at least every six months. Overloading of the filter may cause loss of carbon monoxide by adsorption on the particle matter and may increase the pressure drop in the sampling line.

6.3.3 Loss of carbon monoxide

Depending on the location of the particle filter, the sampling system can be contaminated by deposition of dust. This can induce losses of carbon monoxide. The sampling system shall be cleaned (as stated in 9.4.1) with a frequency which is dependent on the site-specific conditions.

6.3.4 Conditioning

The sampling system and the particle filter shall be conditioned (at initial installation and after each cleaning) to avoid temporary decreases in the measured carbon monoxide concentrations by sampling ambient air for a period of at least 30 min at the nominal sample flow rate. Conditioning may also be done in the laboratory before installation.

These conditioning periods shall not be included in the calculation of the availability of the analyser during the type approval test (see 8.5.7).

NOTE Conditioning during field operation is considered a part of normal maintenance. Consequently, the concentrations measured during conditioning need not be included in the calculation of data capture, and eight-hourly averages.

6.4 Control and regulation of sample flow rate

The sample flow rate into the analyser shall be maintained within the specifications of the manufacturer of the analyser.

NOTE The flow rate into the infrared analyser is usually controlled by means of restrictors.

6.5 Sampling pump for the manifold

When a sampling manifold is used, a pump (or similar device, e.g. a blower) is necessary for sampling ambient air and suction of the sampled air through the sampling manifold. The inlet of the sampling pump for the sampling manifold shall be located at the end of the sampling manifold (see Annex B). The sampling pump or fan shall have sufficient rating to ensure that all analysers connected to the manifold are supplied with the required amount of air and to ensure that the residence time fulfils the requirement given in 6.3.3. To verify the functioning of this pump, it is recommended to install a flow alarm system. An example of a sampling manifold is given in Annex B.

The influence of the pressure drop induced by the manifold sampling pump on the measured concentration shall be $\leq 1,0$ %.

7 Analyser equipment

7.1 General

In Annex C, schematic diagrams are given of two types of non-dispersive infrared analysers.

The non-dispersive infrared analyser consists of the principal components that are described in 7.3 to 7.6.

7.2 Interferents

7.2.1 General

As various gases absorb infrared radiation, interference from these gases can occur when their infrared absorption bands coincide or overlap the CO infrared absorption bands. The degree of interference varies among individual NDIR analysers. In general, gas correlation spectrophotometers are less sensitive to the influence of interferences (see 5.2).

7.2.2 Water vapour

The primary interferent is water vapour.

NOTE Water vapour interference can be minimised by using one or more of the following measures:

- a) drying the sampled air with use of a semi permeable membrane or a similar drying agent;
- b) maintaining a constant humidity in the sample and calibration gases by refrigeration or saturation and making a volume correction for the constant humidity;
- c) using narrow-band optical filters.

7.2.3 Carbon dioxide

Interference may be caused by carbon dioxide (CO₂).

NOTE The effect of CO₂ interference at concentrations normally present in ambient air is minimal; that is, 340 µmol/mol volume fraction may give a response equivalent to 0,2 µmol/mol volume fraction [4]. If necessary, CO₂ may be scrubbed with soda lime.

7.2.4 Hydrocarbons

Hydrocarbons at concentrations normally found in the ambient air do not ordinarily interfere.

NOTE 500 µmol/mol volume fraction of methane may give a response equivalent to 0,5 µmol/mol volume fraction [4].

7.3 Details about analyser equipment

The main parts of the analyser consist of an infrared source, one or two absorption cells, an infrared detector and a chopper wheel for modulation of the infrared radiation to the detector.

In general, the infrared source consists of a heated coil combined with optics for dividing the IR beam into two beams of equal intensity in the case of a dual-cell analyser.

As an example, the infrared detector can be a pneumatic radiation detector that selectively registers radiation from the sample cell and alternately (in the case of a dual-cell analyser). This detector consists of a cell filled with a high concentration of CO connected with a compensating cell (see 5.2).

The infrared source, the absorption cells and detector shall be mounted vibration-free.

The materials used in the analyser shall be inert to corrosion.

7.4 Pressure measurement

The output signal of the analyser is proportional to the density of CO (number of CO molecules) present in the absorption cell and depends on the pressure in the absorption cell. Variations of internal pressure shall be measured and the signal corrected.

The signal shall be corrected also for external pressure and temperature fluctuations. Significant pressure variations are due to synoptic meteorological changes (up to + 3 %) or due to the altitude of the measurement site (about 10 % decrease in pressure for an 800 m rise in altitude).

7.5 Flow rate indicator

A flow rate indicator shall be included in the analyser.

7.6 Sampling pump for the analyser

The sampling pump is situated at the outlet of the analyser, and draws the sample through the analyser. It can be separate or part of the analyser. In any case it shall be capable of operating within the specified flow requirements of the manufacturer of the analyser and pressure conditions required for the NDIR absorption cell.

7.7 Particle filter

An analyser will generally contain an internal particle filter (see 6.3.2). This filter shall be considered an integral part of the analyser in type-approval testing.

8 Type approval of carbon monoxide analysers

8.1 General

The determination of the concentration of carbon monoxide in ambient air shall fulfil the requirement of a maximum uncertainty in the measured values, which is prescribed by Annex I of Directive 2008/50/EC (15 % for fixed measurements or 25 % for indicative measurements). In order to achieve an uncertainty less than (or equal to) this required uncertainty, the infrared spectrometric analyser shall fulfil all the criteria for a number of performance characteristics which are given in this standard. The values of the selected performance characteristics shall be evaluated by means of laboratory tests and field tests. By combining the values of the selected performance characteristics in the expanded uncertainty calculation, a judgement shall be made whether or not the infrared spectrometric analyser meets the criterion of maximum uncertainty prescribed by Annex I of Directive 2008/50/EC (15 % for fixed measurements or 25 % for indicative measurements).

This process of assessment (type approval test) of the values of the performance characteristics comprises laboratory tests and field tests and the calculation of the expanded uncertainty. At least two analysers of the same type shall be tested in the laboratory. Two of these analysers shall be tested during the field test. All analysers tested are required to pass all tests.

The type approval procedure shall fulfil the certification requirements laid down in EN 15267-1 and EN 15267-2. A designated body shall perform the type approval tests. The designated body for the type approval test shall be

accredited for these activities according to EN ISO/IEC 17025. The type approval shall be awarded by or on behalf of the competent authority.

EN 15267-1 specifies the general principles of the product certification of automated measuring systems (AMS) for monitoring emissions from stationary sources and ambient air quality. This product certification consists of the following sequential stages:

- a) performance testing of an AMS;
- b) initial assessment of the AMS manufacturer's quality management system;
- c) certification;
- d) post-certification product-surveillance.

EN 15267-2 covers the supplementary requirements for an AMS manufacturer's management system to EN ISO 9001 [6] for the control of design and manufacturing of AMS. This European Standard also serves as a reference document for auditing the AMS manufacturer's management system.

8.2 Relevant performance characteristics and performance criteria

The performance characteristics which shall be determined during a laboratory and field test, and their related performance criteria, are given in Table 1. Table 1 applies to those ranges that are specified as normative in the scope of this standard. When type-approval tests are performed on analysers with other certification ranges, the performance criteria stated in absolute units such as $\mu\text{mol/mol/K}$ may need to be modified in order to meet the uncertainty criteria in Annex I from Directive 2008/50/EC. All criteria expressed in relative units (e.g. %) shall remain the same.

The determination of the value of the performance characteristics stated in Table 1 shall be performed by a designated body during the laboratory test and field test according to the procedures described in 8.4, 8.5 and Annex A.

Table 1 — Relevant performance characteristics and criteria

No.	Performance characteristic	Symbol	Section	Lab. test	Field test	Performance criterion for CO
1	Repeatability standard deviation at zero	s_{rz}	8.4.5	x		$\leq 0,3 \mu\text{mol/mol}$
2	Repeatability standard deviation at concentration c_t (at a level of the 8-hour limit)	$s_{r,ct}$	8.4.5	x		$\leq 0,4 \mu\text{mol/mol}$
3	Lack of fit (residual from the linear regression function)		8.4.6			
3a	Largest residual from the linear regression function at concentrations higher than zero	$r_{\max}$		x		$\leq 4,0 \%$ of the measured value
3b	Residual at zero	r_z		x		$\leq 0,50 \mu\text{mol/mol}$
4	Sensitivity coefficient of sample gas pressure	b_{gp}	8.4.7	x		$\leq 0,70 \mu\text{mol/mol/kPa}$
5	Sensitivity coefficient of sample gas temperature	b_{gt}	8.4.8	x		$\leq 0,30 \mu\text{mol/mol/K}$

No.	Performance characteristic	Symbol	Section	Lab. test	Field test	Performance criterion for CO
6	Sensitivity coefficient of surrounding temperature	b_{st}	8.4.9	x		$\leq 0,30 \text{ } \mu\text{mol/mol/K}$
7	Sensitivity coefficient of electrical voltage	b_V	8.4.10	x		$\leq 0,30 \text{ } \mu\text{mol/mol/V}$
8	Interferents at zero and at concentration c_i (at a level of the 8-hour limit) ^b		8.4.11			
8a	H ₂ O with concentration 19 mmol/mol ^c	$X_{H_2O,z,ct}$	a)	x		$\leq 1,0 \text{ } \mu\text{mol/mol}$
8b	CO ₂ with concentration 500 $\mu\text{mol/mol}$	$X_{CO_2,z,ct}$		x		$\leq 0,5 \text{ } \mu\text{mol/mol}$
8c	NO with concentration 1 $\mu\text{mol/mol}$	$X_{NO,z,ct}$		x		$\leq 0,5 \text{ } \mu\text{mol/mol}$
8d	N ₂ O with concentration 50 nmol/mol	$X_{N_2O,z,ct}$		x		$\leq 0,5 \text{ } \mu\text{mol/mol}$
9	Averaging effect	E_{av}	8.4.12	x		$\leq 7,0 \text{ } \%$ of the measured value
10	Reproducibility standard deviation under field conditions	$s_{r,f}$	8.5.5		x	$\leq 5,0 \text{ } \%$ of the average of a three month period
11	Long-term drift at zero	$D_{l,z}$	8.5.4		x	$\leq 0,50 \text{ } \mu\text{mol/mol}$
12	Long-term drift at span level ^a	$D_{l,s}$	8.5.4		x	$\leq 5,0 \text{ } \%$ of maximum of certification range
13	Short-term drift at zero	$D_{s,z}$	8.4.4	x		$\leq 0,10 \text{ } \mu\text{mol/mol}$ over 12 h
14	Short-term drift at span level ^a	$D_{s,s}$	8.4.4	x		$\leq 0,60 \text{ } \mu\text{mol/mol}$ over 12 h
15	Response time (rise)	t_r	8.4.3	x		$\leq 180 \text{ s}$
16	Response time (fall)	t_f	8.4.3	x		$\leq 180 \text{ s}$
17	Difference rise time and fall time	t_d	8.4.3	x		$\leq 10 \text{ s}$
18	Difference sample/calibration port ^d	ΔX_{sc}	8.4.13	x		$\leq 1,0 \text{ } \%$
19	Period of unattended operation		8.5.6		x	3 months or less if manufacturer indicates a shorter period, but not less than 2 weeks
20	Availability of the analyser	A_a	8.5.7		x	$> 90 \text{ } \%$
^a Span level is 70-80 % of the certification range. ^b Performance criterion is set both at zero and test gas concentration level. ^c A H ₂ O-concentration of 19 mmol/mol equals 80 %RH at 20 °C and 101,3 kPa. ^d If relevant.						
NOTE $\mu\text{mol/mol} = \text{ppm}$; $\text{nmol/mol} = \text{ppb}$						

8.3 Design change

When the manufacturer makes design changes, the manufacturer shall notify the test laboratory and relevant body, unless the manufacturer has evidence to show that the analyser still meets the performance stated in the original analyser certificate. The following three classes of changes to type-approved analyser are defined as follows:

- Type 0: changes that have no measurable influence to the performance of the analyser;
- Type 1: changes that can have an influence on the performance of the analyser, but where subsequent tests prove that such changes do not have a significant influence;
- Type 2: changes that have a significant influence on the performance of the analyser.

A significant influence reduces the performance of the analyser compared to that recorded in the certificate for the stipulated performance characteristics. The manufacturer shall evaluate all changes to a type-approved analyser. Where Type 2 changes are identified, further evaluation shall be carried out by a test laboratory in liaison with the relevant body. It is essential that the manufacturer documents all changes and evaluations in accordance with the requirements of EN ISO 9001 and EN 15267-2 in such a way that they can be audited.

When the manufacturer makes Type 2 changes to the analyser, the test laboratory in consultation with the Competent Authority shall determine whether supplementary or complete retesting is required to maintain type approval.

8.4 Procedures for determination of the performance characteristics during the laboratory test

8.4.1 General

A designated body shall perform the determination of the performance characteristics in the laboratory as a part of the type approval test. The quality of the materials and equipment used in the described test procedures shall be in accordance with the requirements given in this standard. The tests shall be performed on at least two analysers in the laboratory test.

8.4.2 Test conditions

8.4.2.1 General

Before operating the analyser, the operating instructions of the manufacturer shall be followed particularly with regard to the set-up of equipment and the quality and quantity of the consumable products necessary.

The analyser should be allowed to warm up during the time specified by the manufacturer before undertaking any tests. If the warm-up time is not specified, a minimum of 4 h is recommended.

If auto rescaling and self-correction for drift are optional to the analyser, then these functions shall be disabled during the laboratory tests.

If an auto-rescaling function or self-correction function are not optional and considered a "normal operational condition", then the times and magnitudes of any self-correction shall be available to the test laboratory. The magnitude of the auto zero and the auto span drift corrections both have the same restrictions as laid down in the performance characteristics.

When applying test gases to the analyser, the test gas system shall be operated sufficiently long before starting the tests in order to stabilise the concentrations applied to the analyser. The analyser shall be tested with the particle filter installed.

Most analyser systems are able to give an output signal as a moving average over an adjustable period of time and some systems automatically change this integration time as a function of the frequency of the fluctuations in concentration of the detected pollutant. These options are typically used in order to smooth output data. It needs no demonstration that the set value for the averaging time or the use of an active filter will influence the result of the averaging test and response time test. During laboratory and field tests for the type approval, the settings of the

monitor shall be as the manufacturer requires. Auto zeroing and auto-scaling capabilities shall be disabled during the lab tests; during field tests the monitor shall be in the configuration as used. All settings shall be noted down in the test report.

8.4.2.2 Parameters

During the test for each individual performance characteristic, the values of the following parameters shall be stable within the specified range given in Table 2.

Table 2 — Set points and stability of test parameters

Parameter	Set points	Stability
Sample gas pressure	Manufacturer's specification (except for the sample gas pressure test, see 8.4.7)	$\pm 0,2$ kPa
Sample gas temperature	20 °C to 23 °C (except for the sample gas temperature test, see 8.4.8)	± 2 °C
Surrounding temperature	20 °C to 23 °C (except for the temperature of the surrounding air test, see 8.4.9)	± 2 °C
Electrical voltage ^a	At nominal line voltage and within manufacturer's specifications (except for the voltage dependence test, see 8.4.10)	± 1 %
Sample flow to the analyser	Manufacturer's specification	± 1 %
^a For an analyser operating on direct current the type approval test of voltage variation shall be carried out over the range of ± 10 % of the nominal voltage.		

8.4.2.3 Test gases

For the determination of the various performance characteristics, test gases traceable to (inter)nationally accepted standards shall be used unless otherwise stated in this standard. Methods for the generation of test gases are given in Table 3.

Table 3 — Methods for preparation of test gases

Method	Description	Traceability/ standard to be used
Cylinder	Gas cylinder of CO gas mixture in (synthetic) air	EN ISO 6142 EN ISO 6143
Dynamic dilution	Dynamic dilution of carbon monoxide-air mixtures	EN ISO 6145-6 or EN ISO 6145-7
Static dilution	Preparation by means of injecting known amounts of CO into a known volume of air	EN ISO 6144

The maximum permitted expanded uncertainty (95 % confidence) in the concentration of span gases and zero gas used for laboratory tests shall be 3 %.

Possible contamination of zero and span gas shall not significantly influence the results of the laboratory tests. Therefore, the span gases and zero gas shall meet the specifications given in Tables 4a to 4c.

Table 4a — Specification for purity of span gas

Pollutant	Concentration
CO ₂	≤ 4 µmol/mol
NO	≤ 1 nmol/mol
N ₂ O	≤ 0,5 nmol/mol
Water	≤ 150 µmol/mol

Table 4b — Specification for purity of zero gas for interferents testing

Pollutant	Concentration
CO ₂	≤ 4 µmol/mol
NO	≤ 1 nmol/mol
N ₂ O	≤ 0,5 nmol/mol
Water	≤ 150 µmol/mol
CO	≤ 0,1 µmol/mol

Table 4c — Specification for purity of zero gas for other tests

Pollutant	Concentration
CO ₂	≤ 400 µmol/mol
NO	≤ 1 nmol/mol
N ₂ O	≤ 0,5 nmol/mol
Water	≤ 150 µmol/mol
CO	≤ 0,1 µmol/mol

It is advisable to perform the field tests with the same set of cylinders and zero air generators, exclusively reserved for the tests. The stability of both the zero air and the span gas should be guaranteed over a period longer than the test period.

8.4.3 Response time

8.4.3.1 General requirements

The response time of the analyser shall be determined at the nominal sample flow rate specified by the manufacturer.

The sample flow rate shall be kept constant within the requirements as given in 8.4.2 (± 1 %) during the test.

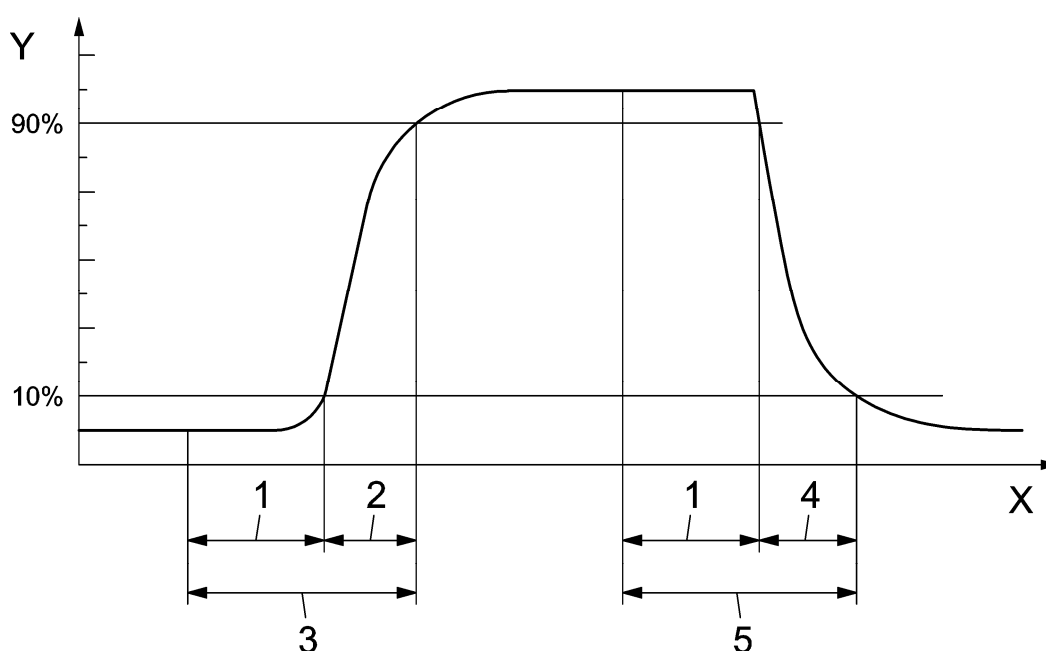
8.4.3.2 Test procedure

The determination of the response time shall be carried out by applying to the analyser a step function in the concentration from less than 20 % to about 80 % of the maximum of the certification range of carbon monoxide and vice versa (see Figure 1).

NOTE Usually zero gas and span gas are used for this test.

The change from zero gas to span gas and vice versa needs to be made almost instantaneously, with the use of a suitable valve. The valve outlet shall be mounted direct to the inlet of the analyser, and both zero gas and span gas shall have the same amount of gas in excess, which is vented by the use of a tee. The gas flows of both zero gas and span gas shall be chosen in such a way that the dead time in the valve and tee can be neglected compared to the lag time of the analyser system. The step change is made by switching the valve from zero gas to span gas. This event needs to be timed and is the start ($t = 0$) of the (rise) lag time according to Figure 1. When the reading over 5 min is constant to within ± 2 % of the test gas (span) concentration, the span gas can be changed to zero

gas again; this event is the start ($t = 0$) of the (fall) lag time. When the reading over 5 min is stable to within $0,30 \mu\text{mol/mol}$ of the zero gas concentration the whole cycle as shown in Figure 1 is complete.



Key

- Y analyser response
- X time
- 1 lag time
- 2 rise time
- 3 response time (rise)
- 4 fall time
- 5 response time (fall)

Figure 1 — Diagram illustrating the response time

The elapsed time (response time) between the start of the step change and reaching 90 % of the analyser final stable reading of the applied concentration shall be measured. The whole cycle shall be repeated four times. The average of the four response times (rise) and the average of the four response times (fall) shall be calculated.

The difference in response times shall be calculated according to:

$$t_d = \bar{t}_r - \bar{t}_f \quad (1)$$

where

t_d is the difference between response time (rise) and response time (fall), in s;

$\bar{t}_r$ is the response time (rise) (average of the four response times - rise), in s;

$\bar{t}_f$ is the response time (fall) (average of the four response times - fall), in s.

t_d , $\bar{t}_r$ and $\bar{t}_f$ shall comply with the performance criteria in Table 1.

8.4.4 Short-term drift

After the required stabilisation period (8.4.2.1), the analyser shall be adjusted at zero and span level (around 70 % to 80 % of the maximum of the certification range of carbon monoxide). Wait the time equivalent to one independent reading and then record 20 individual measurements, first at zero and then at span concentration. From these 20 measurements, the average is calculated for zero and span level.

The analyser shall be kept running under the laboratory conditions (8.4.2.2) while analysing ambient air. After a period of 12 hours zero gas, and subsequently span gas, is fed to the analyser. Wait the time equivalent to one independent reading and then record 20 individual measurements, first at zero and then at span concentration. The averages for zero and span level shall be calculated.

NOTE Compliance with this test shows that drift is not the dominant factor in any of the test results.

The short-term drift at zero and span level shall be calculated as follows:

$$D_{s,z} = (C_{z,2} - C_{z,1}) \quad (2)$$

where

$D_{s,z}$ is the 12-hour drift at zero, in $\mu\text{mol/mol}$;

$C_{z,1}$ is the average concentration of the measurements at zero at the beginning of the drift period, in $\mu\text{mol/mol}$;

$C_{z,2}$ is the average concentration of the measurements at zero at the end of the drift period, in $\mu\text{mol/mol}$.

$D_{s,z}$ shall comply with the performance criterion in Table 1.

$$D_{s,s} = (C_{s,2} - C_{s,1}) - D_{s,z} \quad (3)$$

where

$D_{s,s}$ is the 12-hour drift at span, in $\mu\text{mol/mol}$;

$C_{s,1}$ is the average concentration of the measurements at span level at the beginning of the drift period, in $\mu\text{mol/mol}$;

$C_{s,2}$ is the average concentration of the measurements at span level at the end of the drift period, in $\mu\text{mol/mol}$.

$D_{s,s}$ shall comply with the performance criterion in Table 1.

8.4.5 Repeatability standard deviation

After waiting the time equivalent of one independent reading, 20 individual measurements both at zero concentration and at a test concentration (c_t) similar to the 8-hour limit value shall be performed.

From these measurements, the repeatability standard deviation (s_r) at zero concentration and at concentration c_t (8-hour limit value) shall be calculated according to:

$$s_r = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} \quad (4)$$

where

s_r is the repeatability standard deviation, in $\mu\text{mol/mol}$;

- x_i is the i th measurement, in $\mu\text{mol/mol}$;
- $\bar{x}$ is the average of the 20 measurements, in $\mu\text{mol/mol}$;
- n is the number of measurements, $n = 20$.

The repeatability standard deviation shall be calculated separately for both series of measurements (zero gas and concentration c_t).

s_r shall comply with the performance criterion in Table 1, both at zero and at the test concentration c_t (8-hour limit value).

The repeatability standard deviation at zero is used in combination with the slope of the calibration function determined in 8.4.6 to calculate the detection limit of the analyser as [3]:

$$l_{\text{det}} = 3,3 \cdot \frac{s_{r,z}}{B} \quad (5)$$

where

- l_{det} is the detection limit of the analyser, in nmol/mol ;
- $s_{r,z}$ is the repeatability standard deviation at zero, in nmol/mol ;
- B is the slope of the calibration function determined according to Annex A using the data from 8.4.6.

8.4.6 Lack of fit of linearity of the calibration function

The lack of fit of linearity of the calibration function of the analyser shall be tested over the range of 0 % to 95 % of the maximum of the certification range of carbon monoxide, using at least six concentrations (including the zero point). The analyser shall be adjusted at a concentration of about 80 % of the maximum of the certification range. At each concentration (including zero) at least five individual measurements shall be performed.

The concentrations shall be applied in the following sequence: 80 %, 40 %, 0 %, 60 %, 20 % and 95 %. After each change in concentration, at least four response times shall be taken into account before the next measurement is performed.

The uncertainty in the dilution ratios for the applied concentrations shall be less than 1,5 % with respect to each other.

NOTE The design of the test (number of concentrations and number of repetitions) is such that the deviation from a linear function can be determined with sufficient accuracy. The test is also sufficiently robust to detect the case of non-linearity in the range from zero to some concentration at the lower end of the range as well as non-linearity from that lower end of the range to the higher end of the range.

Calculation of the linear regression function and residuals shall be performed according to Annex A. All the (relative) residuals from the linear regression function shall fulfil the criteria as stated in Table 1.

The largest value of the relative residuals is reported as r_{max} and shall be taken into account in demonstrating compliance with type approval requirement 1. The value of the relative residual value at the level of the 8-hour limit value shall be taken in the calculation of type approval requirements 2 and 4.

8.4.7 Sensitivity coefficient to sample gas pressure

Measurements are taken at a concentration of about 70 % to 80 % of the maximum of the certification range of carbon monoxide at an absolute pressure of about $(80 \pm 0,2)$ kPa and at an absolute pressure of about $(110 \pm 0,2)$ kPa. At each pressure after waiting the time equivalent to one independent reading three individual measurements are recorded. From these three measurements, the averages at each pressure are calculated.

Measurements at different pressures shall be separated by at least four response times.

The sample gas pressure influence is calculated by:

$$b_{gp} = \left| \frac{(C_{P2} - C_{P1})}{(P_2 - P_1)} \right| \quad (6)$$

where

- b_{gp} is the sample gas pressure sensitivity coefficient, in $\mu\text{mol/mol/kPa}$;
- C_{P1} is the average concentration of the measurements at sampling gas pressure P_1 , in $\mu\text{mol/mol}$;
- C_{P2} is the average concentration of the measurements at sampling gas pressure P_2 , in $\mu\text{mol/mol}$;
- P_1 is the minimum sampling gas pressure, in kPa;
- P_2 is the maximum sampling gas pressure, in kPa.

b_{gp} shall comply with the performance criterion in Table 1.

8.4.8 Sensitivity coefficient to sample gas temperature

Measurements shall be performed at sample gas temperatures of $T_{G,1} = 0\text{ }^{\circ}\text{C}$ and $T_{G,2} = 30\text{ }^{\circ}\text{C}$. A concentration around 70 % to 80 % of the maximum of the certification range of carbon monoxide shall be applied. Wait the time equivalent to one independent and record three individual measurements at each temperature. The sample gas temperature, measured at the inlet of the analyser, shall be held constant for at least 30 min.

The influence of sample gas temperature is calculated from:

$$b_{gt} = \left| \frac{(C_{GT,2} - C_{GT,1})}{(T_{G,2} - T_{G,1})} \right| \quad (7)$$

where

- b_{gt} is the sample gas temperature sensitivity coefficient, in $\mu\text{mol/mol/K}$;
- $C_{GT,1}$ is the average concentration of the measurements at sample gas temperature $T_{G,1}$, in $\mu\text{mol/mol}$;
- $C_{GT,2}$ is the average concentration of the measurements at sample gas temperature $T_{G,2}$, in $\mu\text{mol/mol}$;
- $T_{G,1}$ is the minimum sample gas temperature, in $^{\circ}\text{C}$;
- $T_{G,2}$ is the maximum sample gas temperature, in $^{\circ}\text{C}$.

b_{gt} shall comply with the performance criterion in Table 1.

8.4.9 Sensitivity coefficient to the surrounding temperature

The sensitivity of the analyser readings to the surrounding temperature shall be determined by performing measurements at the following temperatures (within the specifications of the manufacturer):

- a) at the minimum temperature $T_{S,1} = 0\text{ }^{\circ}\text{C}$;
- b) at the temperature $T_{S,0}$: see Table 2;

c) at the maximum temperature $T_{S,2} = 30\text{ }^{\circ}\text{C}$.

For these tests a climate chamber is necessary.

A concentration around 70 % to 80 % of the maximum of the certification range of carbon monoxide shall be applied. At each temperature setting after waiting the time equivalent to one independent measurement, three individual measurements at zero and at span shall be recorded.

At each temperature setting, the criteria for warm-up or stabilisation time are to be met according to 8.4.2.1.

At the first temperature ($T_{S,0}$), the analyser shall be adjusted at zero and at span level (70 % to 80 % of the maximum of the certification range). Then three individual measurements are recorded after waiting the time equivalent to one independent reading at $T_{S,0}$, at $T_{S,1}$ and again at $T_{S,0}$. This procedure shall be repeated at the temperature sequence of $T_{S,0}$, $T_{S,2}$, and at $T_{S,0}$.

In order to exclude any possible drift due to factors other than temperature, the measurements at $T_{S,0}$ are averaged, which is taken into account in the following formula for calculation of the sensitivity coefficient for temperature dependence:

$$b_{st} = \left| \frac{x_T - \frac{x_1 + x_2}{2}}{T_S - \overline{T_{S,0}}} \right| \quad (8)$$

where

b_{st} is the surrounding temperature sensitivity coefficient at zero or span and at $T_{S,1}$ or $T_{S,2}$, in $\mu\text{mol/mol/K}$;

x_T is the average of the measurements at $T_{S,1}$ or $T_{S,2}$, in $\mu\text{mol/mol}$;

x_1 is the first average of the measurements at $T_{S,0}$, in nmol/mol ;

x_2 is the second average of the measurements at $T_{S,0}$, in nmol/mol ;

T_S is the extreme surrounding air temperature at which the test is performed, in $^{\circ}\text{C}$;

$\overline{T_{S,0}}$ is the average of the surrounding air temperatures at set point (see Table 2), in $^{\circ}\text{C}$;

$T_{S,1}$ is the minimum surrounding temperature, in $^{\circ}\text{C}$;

$T_{S,2}$ is the maximum surrounding temperature, in $^{\circ}\text{C}$.

For reporting the surrounding temperature dependence the higher value is taken of the two calculations of the temperature dependence at $T_{S,1}$ and $T_{S,2}$.

b_{st} shall comply with the performance criterion in Table 1.

8.4.10 Sensitivity coefficient to electrical voltage

The sensitivity coefficient of electrical voltage shall be determined at both ends of the specified voltage range, V_1 and V_2 at zero concentration and at a concentration around 70 % to 80 % of the maximum of the certification range of carbon monoxide. After waiting the time equivalent to one independent measurement, three individual measurements at each voltage and concentration level shall be recorded.

The voltage dependence is calculated from:

$$b_v = \left| \frac{(C_{V_2} - C_{V_1})}{(V_2 - V_1)} \right| \quad (9)$$