INTERNATIONAL
STANDARD

ISO
16000-26

First edition
2012-08-01

Indoor air —

Part 26:
Sampling strategy for carbon dioxide (CO_2)

Air intérieur —

Partie 26: Stratégie d'échantillonnage du dioxyde de carbone (CO_2)

Reference number
ISO 16000-26:2012(E)

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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

ISO 16000-26 was prepared by Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 6, *Indoor air*.

ISO 16000 consists of the following parts, under the general title *Indoor air* —:

— *Part 1: General aspects of sampling strategy*

— *Part 2: Sampling strategy for formaldehyde*

— *Part 3: Determination of formaldehyde and other carbonyl compounds in indoor air and test chamber air — Active sampling method*

— *Part 4: Determination of formaldehyde — Diffusive sampling method*

— *Part 5: Sampling strategy for volatile organic compounds (VOCs)*

— *Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA® sorbent, thermal desorption and gas chromatography using MS or MS-FID*

— *Part 7: Sampling strategy for determination of airborne asbestos fibre concentrations*

— *Part 8: Determination of local mean ages of air in buildings for characterizing ventilation conditions*

— *Part 9: Determination of the emission of volatile organic compounds from building products and furnishing — Emission test chamber method*

— *Part 10: Determination of the emission of volatile organic compounds from building products and furnishing — Emission test cell method*

— *Part 11: Determination of the emission of volatile organic compounds from building products and furnishing — Sampling, storage of samples and preparation of test specimens*

— *Part 12: Sampling strategy for polychlorinated biphenyls (PCBs), polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and polycyclic aromatic hydrocarbons (PAHs)*

— *Part 13: Determination of total (gas and particle-phase) polychlorinated dioxin-like biphenyls (PCBs) and polychlorinated dibenzo-*p*-dioxins/dibenzofurans (PCDDs/PCDFs) — Collection on sorbent-backed filters*

— *Part 14: Determination of total (gas and particle-phase) polychlorinated dioxin-like biphenyls (PCBs) and polychlorinated dibenzo-*p*-dioxins/dibenzofurans (PCDDs/PCDFs) — Extraction, clean-up and analysis by high-resolution gas chromatography and mass spectrometry*

— *Part 15: Sampling strategy for nitrogen dioxide (NO2)*

— *Part 16: Detection and enumeration of moulds — Sampling by filtration*

- *Part 17: Detection and enumeration of moulds — Culture-based method*
- *Part 18: Detection and enumeration of moulds — Sampling by impaction*
- *Part 19: Sampling strategy for moulds*
- *Part 21: Detection and enumeration of moulds — Sampling from materials*
- *Part 23: Performance test for evaluating the reduction of formaldehyde concentrations by sorptive building materials*
- *Part 24: Performance test for evaluating the reduction of volatile organic compound (except formaldehyde) concentrations by sorptive building materials*
- *Part 25: Determination of the emission of semi-volatile organic compounds by building products — Micro-chamber method*
- *Part 26: Sampling strategy for carbon dioxide* (CO_2)
- *Part 28: Determination of odour emissions from building products using test chambers*
- *Part 29: Test methods for VOC detectors*
- *Part 30: Sensory testing of indoor air*
- *Part 31: Measurement of flame retardants and plasticizers based on organophosphorus compounds — Phosphoric acid ester*

The following parts are under preparation:

- *Part 27: Determination of settled fibrous dust on surfaces by SEM (scanning electron microscopy) (direct method)*
- *Part 32: Investigation of buildings for pollutants and other injurious factors — Inspections*

Introduction

In ISO 16000-1, general requirements relating to the measurement of indoor air pollutants and the important conditions to be observed before or during the sampling of individual pollutants or groups of pollutants are described.

This part of ISO 16000 describes basic aspects to be considered when working out a sampling strategy for the measurements of carbon dioxide in indoor air. It is intended to be a link between ISO 16000-1 and the analytical procedures.

This part of ISO 16000 presupposes knowledge of ISO 16000-1.

This part of ISO 16000 uses the definition for indoor environment defined in ISO 16000-1 and Reference [12] as dwellings having living rooms, bedrooms, DIY (do-it-yourself) rooms, recreation rooms and cellars, kitchens and bathrooms; workrooms or work places in buildings which are not subject to health and safety inspections with regard to air pollutants (for example, offices, sales premises); public buildings (for example hospitals, schools, kindergartens, sports halls, libraries, restaurants and bars, theatres, cinemas and other function rooms), and also cabins of vehicles and public transport.

The sampling strategy procedure described in this part of ISO 16000 is based on VDI 4300 Part 9.[11]

Indoor air —

Part 26:
Sampling strategy for carbon dioxide (CO_2)

1 Scope

This part of ISO 16000 specifies the planning of carbon dioxide indoor pollution measurements. In the case of indoor air measurements, the careful planning of sampling and the entire measurement strategy are of particular significance since the result of the measurement can have far-reaching consequences, for example, with regard to ascertaining the need for remedial action or the success of such an action.

An inappropriate measurement strategy can lead to misrepresentation of the true conditions or, worse, to erroneous results.

This part of ISO 16000 is not applicable to the measurement strategy for carbon monoxide (CO).

NOTE See 5.1.

2 Normative references

The following referenced documents are indispensable for the application 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.

ISO 16000-1:2004, *Indoor air — Part 1: General aspects of sampling strategy*

3 Properties, origin and occurrence of carbon dioxide

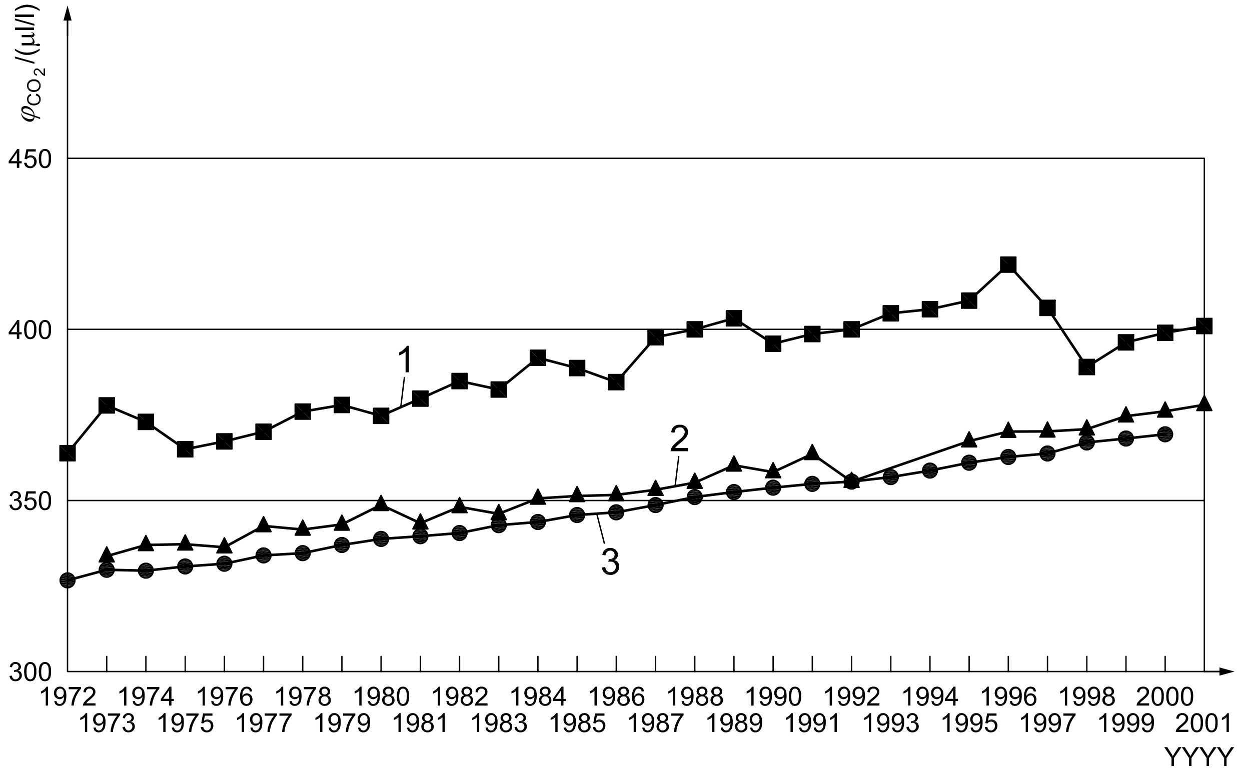
Carbon dioxide (CO_2, CAS No. 124-38-9) is a natural constituent of atmospheric air, where it is present on average at a content of a little over 0,03 % (volume fraction; equal to about 600 mg/m^3). CO_2 content measured in air is usually reported in the unit parts per million (1 ppm as a volume fraction is 1 µmol/mol), 0,03 % as volume fraction being equivalent to 300 ppm. Some CO_2 reacts under indoor conditions with atmospheric humidity to form carbonic acid. CO_2 is colourless, odourless and without taste, readily water soluble and chemically stable under standard conditions. The CO_2 molecule can absorb part of the infrared radiation reflected by the Earth’s surface as heat radiation and thus contributes to a process termed “greenhouse effect”, which causes global warming.

Carbon dioxide plays a central role in the processes of life on Earth. As a result of plant activity (from carbon dioxide and water, under the action of sunlight in the presence of chlorophyll as catalyst), organic compounds (predominantly carbohydrates) are formed, as well as the oxygen which is essential for life on Earth. More or less in reverse to this process, CO_2 is formed in the air as one of the end-products (in addition to water) of combustion of hydrocarbons. This process proceeds firstly in every type of combustion apparatus and fireplace, but secondly also plays an important role in the metabolism of living organisms. The CO_2 formed in metabolic processes is released to the ambient air.

In the case of humans, the amount released depends on the extent of physical activity. For adult persons, the orders of magnitude listed in Table A.1 of the volume of CO_2 released can be assumed (see Annex A for more detailed explanations).

Since the beginning of industrialization, the CO_2 concentration of the ambient air has been continuously rising. CO_2 measurement sites in the past were usually linked with meteorological stations and were situated in clean air regions. One of the best-known CO_2 measurement sites is on Mauna Loa in Hawaii. There, uninfluenced by any local CO_2 source, the CO_2 concentration increased, for example, from 316,0 ppm in 1959 to 369,4 ppm in

2000 (Reference [13]). This is an increase of 53,4 ppm or 4,1 ‰ per year. Since CO_2 is a climatically relevant substance (greenhouse effect), the increase is being observed with great concern. In the vicinity of emissions sources, e.g. metropolitan areas with heavy vehicle traffic and domestic fires or industrial combustion plants, significantly higher concentrations can also occur. Thus the CO_2 concentration in Cologne with approx. 400 ppm is on average about 10 % higher than in Hawaii (see Figure 1).



Key

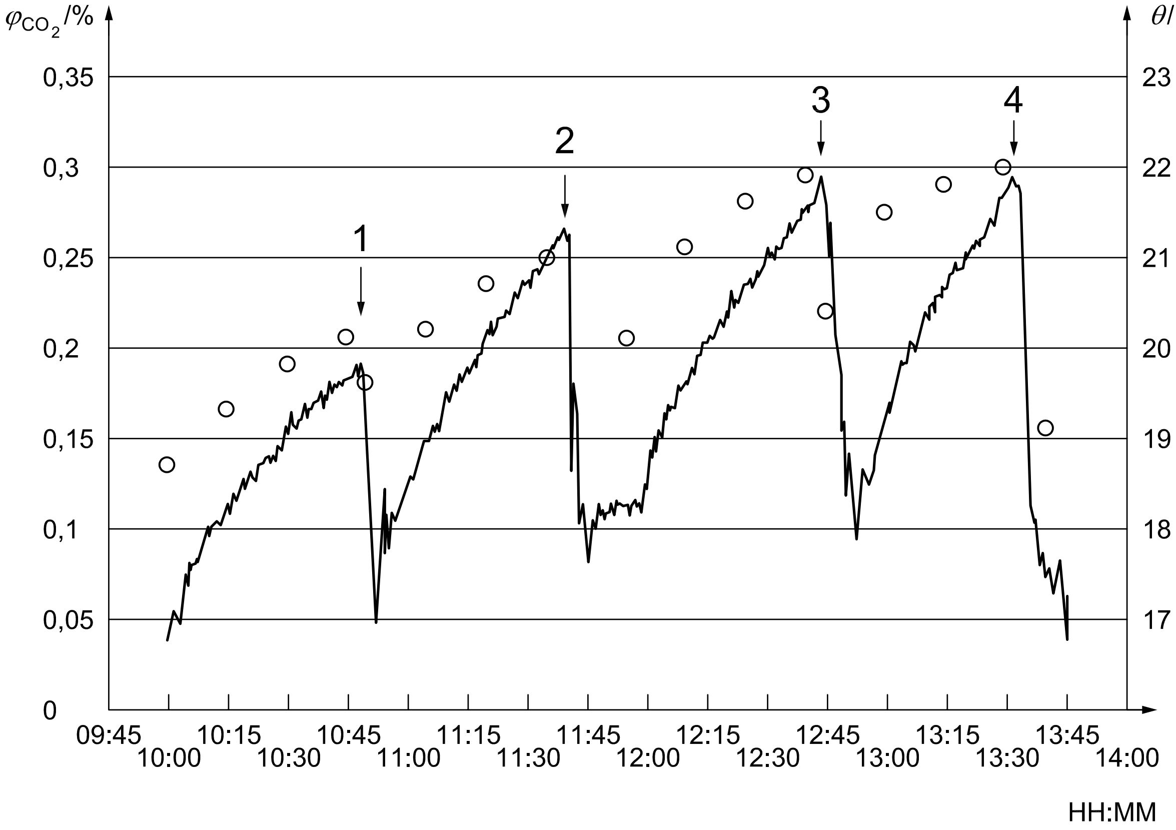
φ_{CO_2}	CO_2 volume fraction
YYYY	year
1	Cologne (Germany)
2	Westerland (Germany)
3	Hawaii (USA)

Figure 1 — Annual mean values of the CO_2 concentrations in ambient air at various locations

Such levels of ambient air concentrations do not have any disadvantageous direct effect on human health. Objectively measurable effects are not observed until about 5 000 ppm to 10 000 ppm. These effects consist of an increase in respiration frequency, changes in the blood pH and a reduction in physical capability. At concentrations greater than 15 000 ppm, breathing becomes more difficult, and concentrations above 30 000 ppm can cause headaches and dizziness. Above 60 000 ppm to 80 000 ppm, unconsciousness and death may be expected (Reference [14]).

In indoor air, owing to exchange of air due to ventilation, the same concentrations as in ambient air are to be expected. However, this only applies if there are no sinks or sources in the room. A sink is, for example, alkaline masonry. The most important source in the room is normally humans. The concentrations occurring depend on the number of people in a room and on the ventilation intensity. For instance, in the case of 10 different measurements in a closed bedroom overnight containing two people, maximum CO_2 concentrations of between 1 200 ppm and 4 300 ppm have been determined (Reference [15]). With closed windows and a half-open door, the maximum concentration was only 1 700 ppm. In the air of offices, at 630 measurement points, 350 ppm to 2 350 ppm (median: 555 ppm) of CO_2 were measured, and significant differences were found between naturally ventilated buildings (median: 750 ppm CO_2, $n = 300$) and air-conditioned buildings (median: 465 ppm CO_2, $n = 330$) (Reference [16]). Concentrations of 400 ppm to 800 ppm have also been measured in office air (Reference [17]). In a classroom having an interior volume of just 200 m^3, when occupied by 45 people, with closed windows and an air change rate of around 1 h^{-1}, after 1 h a CO_2 concentration of about 3 000 ppm resulted (Reference [18]). From such findings, there resulted the recommendation to ensure sufficient ventilation.

In Annex A, the calculation of the ventilation requirements of a room is described. Whereas CO_2 is removed continuously from indoor air in the case of mechanical ventilation, its removal is best achieved in rooms with natural ventilation by rapid air change by opening as many windows as possible at regular intervals (see Figure 2). This applies in particular to most school rooms (Reference [19]).



Key

φ_{CO_2}	CO_2 volume fraction
θ	temperature
HH:MM	time
O	temperature data (right-hand ordinate)
1,2,3,4	drop in CO_2 volume fraction (left-hand ordinate) due to opening the window

Figure 2 — CO_2 measurement in a school with 5 min rapid air change by opening door and window in the breaks after a 45 min lesson. The room volume was 155 m^3 and during the lesson there were 28 people in the room (Reference [19])

In certain cases, sources other than humans can also play an important part. Moreover, combustion processes frequently take place indoors. The carbon dioxide formed in this way passes, together with other combustion products, into the indoor air. Most sources of combustion gases indoors are visible, e.g. tobacco smoke, open flames of cooking and heating appliances or burning candles. The emission formation caused by them can therefore be predicted and the emissions can be removed as a precaution by ventilation measures. An invisible source is, for example, a leaking chimney, but this situation rarely occurs.

Of subsidiary importance for the CO_2 concentration in indoor air is CO_2 emission by plants. During darkness, plants also release small amounts of carbon dioxide. From literature data, it is possible to estimate the carbon dioxide release per leaf area and hour by plants in the dark at approximately ~400 ml/m^2·h (Reference [21]).

For a leaf area of 1 m^2, this roughly corresponds to 1 % of the amount of carbon dioxide released by an adult per hour. This small amount, in addition, stands in comparison to the consumption of carbon dioxide by the photosynthesis processes proceeding in the plant in light.

4 Measurement technique

A number of methods exist for measuring carbon dioxide in indoor air. The most widespread measurement principle is, as for ambient air studies, non-dispersive infrared spectrometry (NDIR) (References [22][23]). In addition, photoacoustic spectroscopy (PAS) is also used. This is a method which converts the excitation energy absorbed in the infrared region into an acoustic signal (Reference [24]). The CO_2 is measured using a narrow-band IR filter at 2 270 cm^{-1}. Both methods require a compensation for cross-effects, in particular water vapour, during the calibration.

The measuring instruments operating according to NDIR or PAS methods enable reliable and continuous CO_2 determination in the concentration range from about 1 ppm to 5 000 ppm.

For a first survey of the situation in a room, sampling tubes can also be used. Short-time sampling tubes in which the air is drawn through the sampling tube using a bellow pump give a measured value within a few minutes, whereas in the case of direct-indicating diffusion sampling tubes, some hours are required for the measurement. The sampling tubes used for the concentration of interest indoors are to cover a range of 100 ppm to 3 000 ppm, see Reference [25].

Carbon dioxide sensors are used in indoor air technology to control ventilation and air-conditioning equipment (VAC equipment). In addition to selective sensors which operate by a two-channel infrared absorption principle, electrochemical sensors and semiconductor gas sensors are also used for monitoring indoor air quality. These sensors are not designed for CO_2 measurement according to this part of ISO 16000.

For screening methods, see Annex C.

5 Measurement planning

5.1 General

In Clause 3, it has already been stated that carbon dioxide, in addition to its unavoidable presence as a natural constituent of atmospheric air, passes into indoor air not only via humans themselves, but also as a product of combustion processes using open flames. Since this does not concern continuous constant sources, meaning therefore that constant CO_2 concentrations in indoor air are not to be expected, the correct measurement strategy is of great importance.

If it is also intended to measure carbon monoxide (CO), this part of ISO 16000 is not suitable for CO measurement planning. CO is an odourless, colourless and very toxic gas that can cause sudden illness and death. It occurs in an incomplete combustion process and can pollute indoor air due to a defective chimney or due to a fireplace that draws air badly. CO can be measured with automated measurement devices or direct-reading detector tubes which are commercially available (measurement range about 2 ppm to 60 ppm) (see also Annex C).

5.2 Measurement objective and boundary conditions

5.2.1 General

Before indoor air measurements are carried out, the purpose of the measurement shall be clearly defined. In the case of determination of carbon dioxide, the objectives specifed in 5.2.2 and 5.2.3 are chiefly of interest.

5.2.2 Investigating compliance with a guide value

CO_2 is frequently used as a general indicator of indoor air pollution of human origin. Particularly in rooms to be ventilated naturally which are regularly occupied by a relatively large number of people, e.g. in school rooms or auditoria, this value can sometimes be considerably exceeded without the required ventilation. Regulations for this purpose, as well as specifications for the design of ventilation and air conditioning systems, are given in DIN 1946-4,[5] DIN 1946-6,[6] and References [20][29][30].

The CO_2 concentration in the air of an unused room generally does not exceed the ambient air CO_2 concentration. However, this situation is generally changed when the room is used. In rooms that are used, humans are the principle source of CO_2 emissions, if none of the further sources described in Clause 3 are present. Investigating the guide value is therefore only meaningful under customary conditions of use and with the usual number of occupants. The room, before measurements are started, should be vigorously ventilated for some minutes, preferably by cross-venting. If appropriate, other sources and their emission characteristics need to be taken into account.

If particular complaints from users of the room are made under conditions that could be associated with the CO_2 concentration, to clarify the situation, perform measurements under the same conditions.

When a study is being made of rooms which are ventilated using VAC equipment, the equipment shall be operated during the measurements under the conditions customary for the room.

5.2.3 Investigating the ventilation situation in a room

CO_2, because of its inert character and its ease of analysis, can also be used to determine the air exchange in a room. For this, in the absence of the users of the room, CO_2 is additionally introduced into the room air to achieve a concentration which is significantly above the natural concentration in the air. This concentration should not exceed 20 000 ppm.[1] The air change rate can be calculated from measurement of the decrease in CO_2 concentration with time. For more detailed information, see ISO 16000-8, where the limits of the use of CO_2 as an indicator gas are also described.

When the CO_2 concentration of a room is being reported, it is assumed that the air in the room is uniformly mixed and is thus of the same quality at all points, that is to say also has the same CO_2 concentration. However, this need not necessarily be the case, particularly in the case of mechanically ventilated rooms. Especially in very large rooms, e.g. in auditoria, open-plan offices or angular rooms, depending on the position of the orifices for supply air and extract air or else on the type of mounting of installations, “dead zones” can be formed in which the air exchange is reduced.

For a mechanically ventilated room, the ventilation effectiveness ε_L is defined according to Formula (1) (see EN 13779[3]):

$$\varepsilon_L = \frac{\varphi_{ETA} - \varphi_{SUP}}{\varphi_{IDA} - \varphi_{SUP}} \tag{1}$$

where

φ_{ETA}	is the CO_2 concentration of extract air, as a percentage volume fraction;
φ_{SUP}	is the CO_2 concentration of supply air, as a percentage volume fraction;
φ_{IDA}	is the CO_2 concentration of indoor air, as a percentage volume fraction.

The ventilation effectiveness has the value 1 when the concentrations in the extract air and in the indoor air at the point in question are identical. The homogeneity of the air distribution in a room can be investigated using CO_2 concentration measurements following each other closely in time at differing points in the room.

5.3 When to measure

The start of measurement will be determined by the measurement objective (see 5.2).

If an investigation is to be made as to whether hygienically safe conditions with respect to CO_2 concentration prevail in a room (see 5.2.2), the concentration is continuously recorded over a certain time during the intended use (occupancy by people) of the room, e.g. over the time of the customary period of use. The measurement is

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[1] This concentration is four times the AGW value (maximum workplace atmosphere limit value) of 5 000 ppm and is permissible four times for a period each of 15 min distributed over a working shift (TRGS 900[7] and Reference [20]).

started after the room has been vigorously ventilated, so that the resultant starting point is the CO_2 concentration of the ambient air. Dependent on the level of a constant air change with time, the concentration is established at a constant level more or less rapidly. If the air change is altered by opening windows or doors, this becomes noticeable by an immediately indicated fall in concentration (see Figure 2). In mechanically ventilated rooms, a base measurement of the unoccupied room is carried out about 1 h after starting up the VAC equipment and then in the presence of the users of the room, as in the case of a room with free ventilation. In both cases, to determine the contribution of the ambient air to the CO_2 concentration in the room, the CO_2 concentration of the ambient air should be determined at the site, closely connected in time to the indoor air measurements, but at least on the same day. If the ventilation situation in a room is to be evaluated (see 5.2.3), the CO_2 concentration is likewise recorded continuously. In the case of air change measurements, this recording starts about 15 min to 30 min after injection of the additional CO_2 into the room air which is homogeneously distributed in the room during this time using a table fan (see ISO 16000-8). If the ventilation effectiveness is to be determined in a mechanically ventilated room, with the room occupied, the CO_2 concentration is measured at various points in the room about 2 h after starting up the VAC plant.

If the emission characteristics of a source are to be recorded or if an unknown source of combustion exhaust gases is suspected in a room, the CO_2 concentration is continuously recorded over a longer period. The exact time period can be determined in advance only with difficulty in any case, it shall be chosen so that the time point of the activity of the potential source falls within the measurement period. Thus, it may be very difficult to trace a leaking chimney in a domestic residence outside the heating period.

5.4 Measurement location

For rooms of a surface area of up to 50 m^2, it is generally sufficient to have one sampling point per room that should be at a height of 1,5 m and should be at a distance of at least 1 m to 2 m from the walls. For larger rooms, more sampling sites should be provided to ensure that any concentration gradients are determined. This is necessary particularly when investigating ventilation effectiveness. To avoid a direct effect on the measurement result by air respired by people in the vicinity (and in exhaled air about 40 000 ppm CO_2 have been measured), care shall be taken to ensure a sufficiently large separation from the measurement instrument. This also applies to the sampler during the running measurement (distance of sampler from people 1,5 m to 2 m).

In the search for an unrecognized source of combustion exhaust gases in the room, the position of the intake probe of the measurement instrument shall be changed after in each case 5 min to 10 min, in order to be able to find the site of the highest concentration and thus to obtain an indication of the localization of the source.

When measurements are made in mechanically ventilated rooms, it is necessary to have a measurement at the point at which the supply air passes into the room to be able to recognize any prior pollution. Such prior pollution can be due to a recirculation air fraction in the supply air, or due to pollutants of the fresh air, for example due to vicinity of power stations or due to high occurrence of traffic. The level of CO_2 concentration in fresh air can be determined by ambient air measurements.

5.5 Measurement period

Except for the screening measurement using sampling tubes (see Clause 4), the CO_2 concentration is recorded continuously using an automatic instrument. This makes it possible to follow the change of CO_2 concentration with time, to obtain indications for recommendations of the optimum ventilation behaviour. In addition, depending on the question, mean concentrations can also be taken from the mean course of the curve over time periods of interest.

5.6 Measurement uncertainty and presentation of result

In the context of measurement planning, it is necessary to establish in what way the measurement uncertainty is to be described and which performance characteristics are to be used to describe the results in the measurement report. Measurement uncertainties inevitably occur. They are caused by the limited extent of the measurements and by uncertainties in sampling and analytical determination. The representativeness of a single measurement is affected by concentration changes in time and space.

The measurement report also covers, in addition to a reference to the measurement method used, a description of the performance characteristics valid at the time point of carrying out the measurement, especially the limit of detection and limit of determination.2)

Measurement results are usually reported in parts per million (see Clause 3).

In the measurement results, numerical data are usually reported so that the last decimal place (significant figure) at the same time reflects the order of magnitude of the measurement uncertainty.

5.7 Quality assurance

Depending on the objective, preparation of the room before beginning measurements, the measurement time, the sampling period, the frequency and location of measurement, and, if this is meaningful for the problem under investigation, the measurement point(s) in the room shall be specified. During measurement, the specified boundary conditions shall be met and recorded accurately, especially the ventilation state and possible presence of CO_2-emitting sources indoors, including any users of the room. Such a protocol should be established during the appropriate measurement planning. Adopt the general recommendations concerning information to be recorded during indoor air measurement given in ISO 16000-1:2004, Annex D.

The quality demands of the client shall be defined in the measurement strategy. As further quality assurance measures, before a contract is awarded to a measuring institute, at least the following questions should be clarified.

- Does the measuring laboratory have a documented quality assurance system (e.g. according to ISO/IEC 17025[1]) or if not does the laboratory at least participate in interlaboratory tests?
- Are collocated measurements necessary?
- How are the uncertainties defined (e.g. according to ISO/IEC Guide 98-3[2])?
- What calibration procedures are used, how often, and how extensively?

5.8 Test report

The report shall contain at least following information:

a) purpose of the measurements;

b) description of the sampling location;

c) time and date of the sampling:

d) sampling conditions (temperature, relative humidity);

e) reference to this part of ISO 16000;

f) full description of the sampling procedure;

g) full description of the analytical procedure;

h) detection limit of the analytical method;

i) uncertainty of the reported results.

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2) The limit of determination is the smallest value of the parameter which can be differentiated from the limit of detection at a (agreed) certainty of 95 % (see VDI 2449 Part 1[8] and VDI 2449 Part 2[9]).

Annex A
(informative)

Calculation of the ventilation requirement

CO_2 is formed in metabolic processes and is released via respiratory air. The CO_2 content in the exhaled mixture depends on the oxygen consumption and is, for an adult in a state of rest, approximately 13 l/h to 14 l/h (Reference [26]). For adults and various states of effort, the orders of magnitude for $q_{V,\mathrm{CO_2}}$ specified in Table A.1 can be assumed.

Table A.1 — CO_2 output of an adult for various physical activities (source: VDI 4300 Part 7[10])

Activity	$q_{V,\mathrm{CO_2}}$ l/h
Seated activity	15–20
Light work	20–40
Moderately heavy work	40–70
Heavy work	70–110

At a known air change rate and room use, it is possible to estimate the CO_2 level by calculation. This can be used as the yardstick for determining the ventilation requirements. For a background loading $\varphi_{\mathrm{CO_2(ambient)}}$, this gives the following relationship for CO_2 level in individual indoor air, $\varphi_{\mathrm{CO_2}}(t)$, expressed as a percentage volume fraction, as a function of time:

$$\varphi_{\mathrm{CO_2}}(t) = \varphi_{\mathrm{CO_2(ambient)}} + \frac{N q_{V,\mathrm{CO_2}}}{10\ nV}\left[1-\exp(-nt)\right] \qquad (A.1)$$

where

$\varphi_{\mathrm{CO_2(ambient)}}$	is the CO_2 ambient air concentration, as a percentage volume fraction;
N	is the number of persons;
n	is the air change rate, in h^{-1};
V	is the room volume, in m^3;
$q_{V,\mathrm{CO_2}}$	is the specific emission rate CO_2, in l/h;
t	is the time, in h.

Table A.2 — CO_2 concentrations after 45 min and 90 min, calculated from Formula A.1 for $\varphi_{CO_2(\text{ambient})} = 0{,}03$ % volume fraction, $V = 146$ m^3 and $n = 0{,}26$ h^{-1}

N	q_{V,CO_2} l/h	φ_{CO_2} % volume fraction after 45 min	after 90 min	$t \to \infty$
28	15	0,23	0,39	1,14
28	20	0,29	0,51	1,51
28	25	0,36	0,63	1,87
25	15	0,20	0,35	1,02
25	20	0,26	0,46	1,35
25	25	0,32	0,56	1,68
20	15	0,17	0,29	0,82
20	20	0,22	0,37	1,08
20	25	0,26	0,46	1,35

NOTE For symbols, see the variable definitions of Formula (A.1).

From Formula (A.1), the air change rate required to meet a defined CO_2 concentration can be calculated. In this calculation, the equilibrium concentration, $\varphi_{CO_2,(t\to\infty)}$, is usually used as a starting point. From this there results the simplified Formula (A.2):

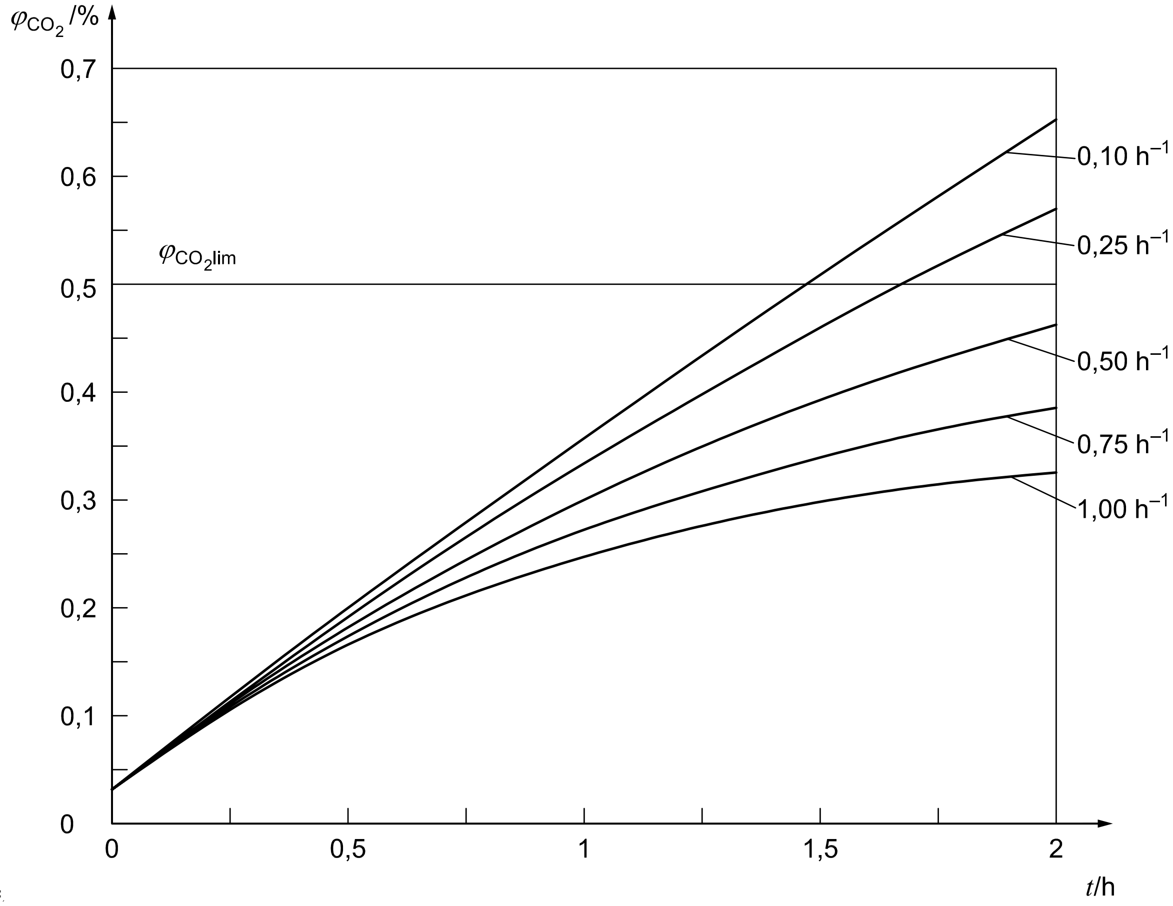
$$n = \frac{N q_{V,CO_2}}{10V\left[\varphi_{CO_2,(t\to\infty)} - \varphi_{CO_2(\text{ambient})}\right]} \tag{A.2}$$

See the variable definitions to Formula (A.1) for the remaining symbols.

EXAMPLE A school room of 146 m^3 in volume is to be used to give lessons to 20 to 28 pupils.

For $\varphi_{CO_2(\text{ambient})} = 0{,}03$ % volume fraction, $V = 146$ m^3 and the measured air change rate $n = 0{,}26$ h^{-1}, the CO_2 concentrations compiled in Table A.2 may be calculated for various numbers of persons N, times t and emission rates q_{V,CO_2}.

Figure A.1 shows the time course of CO_2 level as a function of air change rate. In order not to exceed a level of 0,15 % volume fraction as equilibrium level, for the room in question at $\varphi_{CO_2(\text{ambient})} = 0{,}03$ % volume fraction, $N = 25$ and $q_{V,CO_2} = 20$ l/h, for example, an air change rate of $n = 2{,}85$ h^{-1} would be necessary.



Key

φ_{CO_2} CO$_2$ volume fraction

t time

$\varphi_{CO_2,lim}$ AGW value (Arbeitsplatzgrenzwert; maximum workplace atmosphere limit value, 5 000 ppm, TGRS 900[7])

Figure A.1 — Time course of CO$_2$ concentration calculated from Formula (A.1) for $\varphi_{CO_2(ambient)}$ = 0,03 % volume fraction, V = 146 m^3, N = 25 and q_{V,CO_2} = 20 l/h at a number of air change rates (indicated in reciprocal hours)

Annex B
(informative)

Regulations

In the middle of the 19th century, Max von Pettenkofer suggested that the CO_2 concentration in indoor air be restricted to 0,1 % volume fraction, equivalent to 1 000 ppm (Reference [27]). At this value, which is now known as the Pettenkofer number, the indoor air pollution due to human exhalation (“bioeffluents”) is said to be limited to an extent safe for health. The value has been used for decades as a criterion of good air quality indoors and for calculating the design of room conditioning systems for ventilating indoor areas. For this purpose, the so-called ventilation standard, DIN 1946-2,[4][3] specified a value of 0,15 % volume fraction (1 500 ppm). Meanwhile EN 13779[3] classifies indoor air quality according to the increase of CO_2 level relative to ambient air, based on an ambient air level of approx. 350 ppm to 400 ppm according to Clause 3 (see Table B.1).

Table B.1 — General classification of indoor air quality and CO_2 concentration indoors

Description	**Increase of CO_2 concentration relative to ambient air CO_2 concentration** ppm	
	Common range	**Standard value** (see Reference [3])
Special indoor air quality	≤400	350
High indoor air quality	400–600	500
Medium indoor air quality	600–1 000	800
Low indoor air quality	>1 000	1 200

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[3] Superseded by EN 13779.[3]

Annex C
(informative)

Examples of screening tests and of continuously registering measuring devices for CO_2 and CO

C.1 General

Screening test methods are of the type which can quickly provide an indication of the air pollution present without using expensive analysis techniques. The result can inform a decision on the extent of further required measurements. When using screening tests the basic demands of the measuring strategy have to be considered in any case.

If it is also intended to measure CO in polluted indoor air, CO can also be measured via direct reading detector tubes.

C.2 Direct reading detector tubes for CO_2

Direct reading detector tubes measure CO_2 in the range 100 ppm to 3 000 ppm. Typical commercially available devices rely on changes in colouration of adsorbing powders from the CO_2 in air (Reference [25]). Sufficient colour change should occur at the guideline value.

To carry out the measurement, a volume of 1 l air is drawn with the bellow pump through the detector tube. When CO_2 is present, a colour change from white to blue–violet will occur. The length of the colour change is a measure of the concentration, which can be read from the scale on the tube.

Direct reading diffusion tubes measure CO_2 in the range 65 ppm to 20 000 ppm. The measuring time depends on the CO_2 level and is between 1 h and 8 h. When CO_2 is present, a colour change from blue to white will occur. The length of the colour change is a measure of the exposure which can be read from the scale on the tube. To determine the concentration, the reading has to be divided by the measuring period.

If the reading is less than 400 ppm to 500 ppm on the scale, no further measurements are required.

C.3 Direct reading detector tubes for CO

Direct reading detector tubes measure CO in the range of 2 ppm to 60 ppm. Typical commercially available devices rely on changes in colouration of adsorbing powders from the CO in air (Reference [26]). Sufficient colour change should occur at the guideline value.

To carry out the measurement, a volume of 1 l air is drawn with the bellow pump through the detector tube. When CO is present, a colour change from white to green–brown occurs. The length of the colour change is a measure of the concentration, which can be read from the scale on the tube.

If there is no colour change or the reading is less than 2 ppm on the scale, no further measurements are required.

C.4 Determination of CO and CO_2 with continuously registering measuring devices

Continuously registering measuring devices for CO and/or CO_2, which are used, for example, for the personal monitoring in working areas, can also be used for indoor air measurements (Reference [28]), when the measuring range meets the concentrations according to this part of ISO 16000. Such devices are equipped with an electrochemical sensor for CO and an infrared sensor for CO_2. The measured data are saved by a data logger, which can be read out after the measurement to get information about the concentration gradient.

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ICS 13.040.20

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