
Indoor air —

Part 26:
Sampling strategy for carbon dioxide (CO₂)

Air intérieur —

Partie 26: Stratégie d'échantillonnage du dioxyde de carbone (CO₂)

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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 (CO₂)
- 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

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The following parts are under preparation:

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- 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

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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]

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Indoor air —

Part 26: Sampling strategy for carbon dioxide (CO₂)

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 (CO₂, 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/m³). CO₂ 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 CO₂ reacts under indoor conditions with atmospheric humidity to form carbonic acid. CO₂ is colourless, odourless and without taste, readily water soluble and chemically stable under standard conditions. The CO₂ 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, CO₂ 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 CO₂ 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 CO₂ released can be assumed (see Annex A for more detailed explanations).

Since the beginning of industrialization, the CO₂ concentration of the ambient air has been continuously rising. CO₂ measurement sites in the past were usually linked with meteorological stations and were situated in clean air regions. One of the best-known CO₂ measurement sites is on Mauna Loa in Hawaii. There, uninfluenced by any local CO₂ source, the CO₂ 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 CO₂ 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 CO₂ concentration in Cologne with approx. 400 ppm is on average about 10 % higher than in Hawaii (see Figure 1).

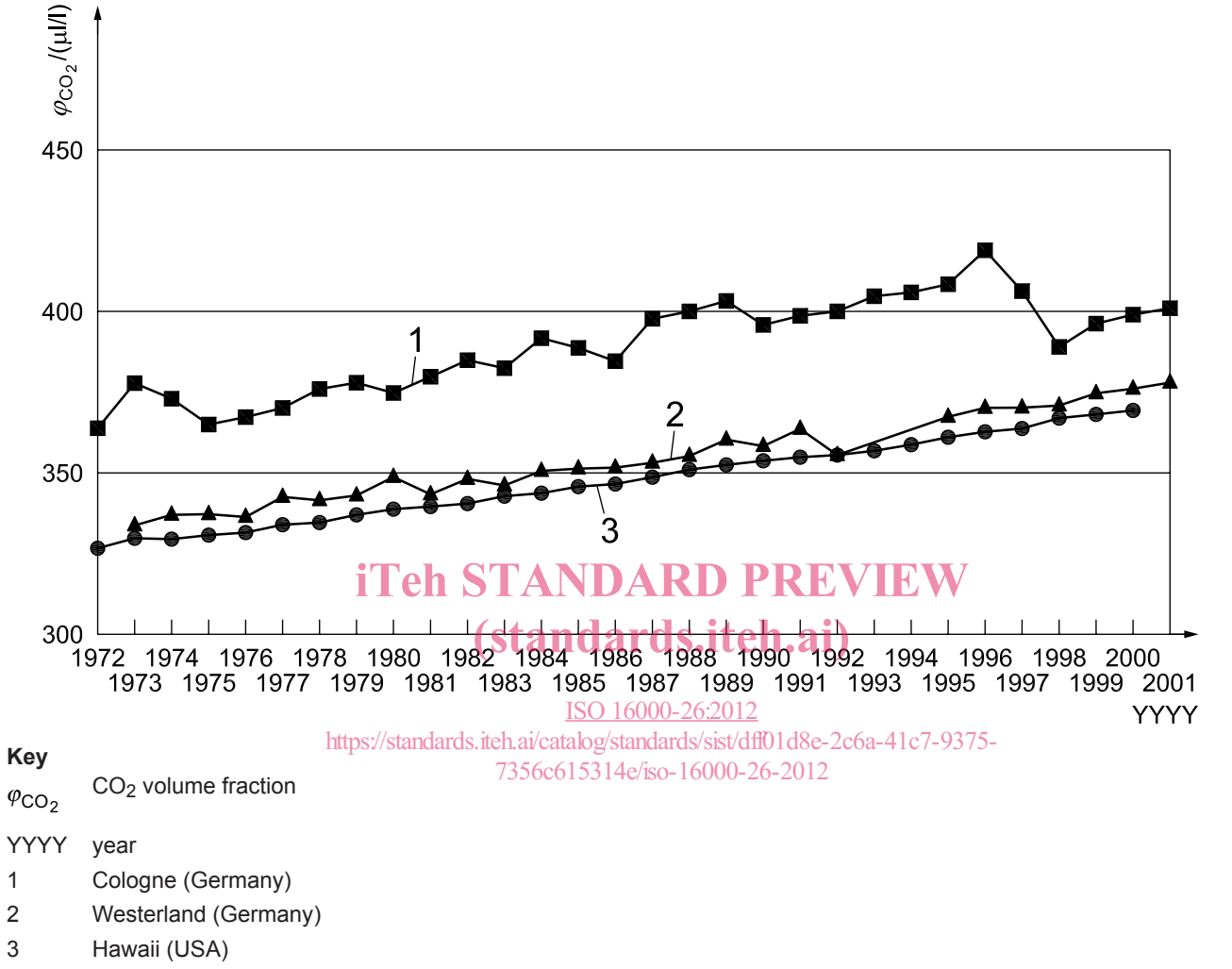


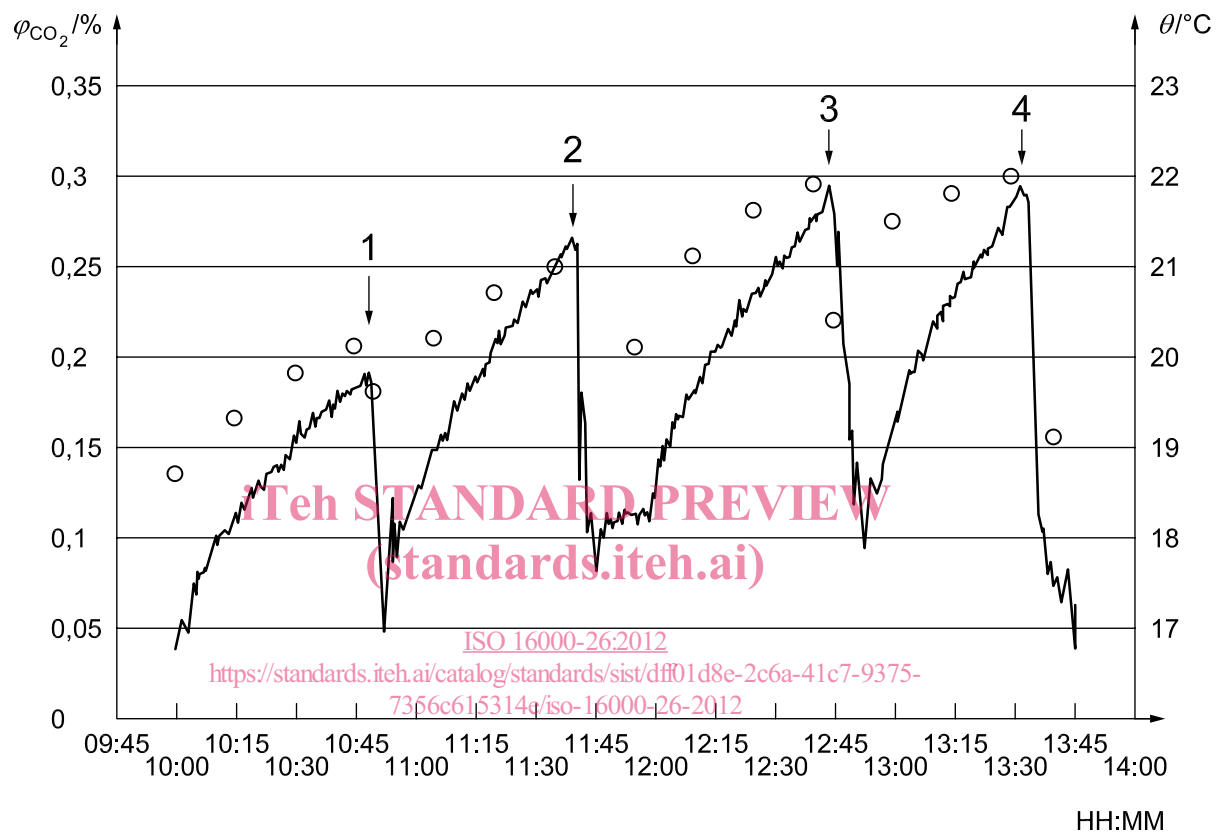
Figure 1 — Annual mean values of the CO₂ concentrations in ambient air at various locations

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 CO₂ 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 CO₂ were measured, and significant differences were found between naturally ventilated buildings (median: 750 ppm CO₂, n = 300) and air-conditioned buildings (median: 465 ppm CO₂, 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 m³, when occupied by 45 people, with closed windows and an air change rate of around 1 h⁻¹, after 1 h a CO₂ 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 CO₂ 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} CO₂ volume fraction

θ temperature

HH:MM time

O temperature data (right-hand ordinate)

1,2,3,4 drop in CO₂ volume fraction (left-hand ordinate) due to opening the window

Figure 2 — CO₂ 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 m³ 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 CO₂ concentration in indoor air is CO₂ 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/m²·h (Reference [21]).

For a leaf area of 1 m², 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 CO₂ 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 CO₂ 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 bellows 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 CO₂ measurement according to this part of ISO 16000.

For screening methods, see Annex C.

5 Measurement planning

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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 CO₂ 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 specified in 5.2.2 and 5.2.3 are chiefly of interest.

5.2.2 Investigating compliance with a guide value

CO₂ 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 CO₂ concentration in the air of an unused room generally does not exceed the ambient air CO₂ concentration. However, this situation is generally changed when the room is used. In rooms that are used, humans are the principle source of CO₂ 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 CO₂ 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

CO₂, 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, CO₂ 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 CO₂ concentration with time. For more detailed information, see ISO 16000-8, where the limits of the use of CO₂ as an indicator gas are also described.

When the CO₂ 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 CO₂ 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]):

$$\varepsilon_L = \frac{\varphi_{ETA} - \varphi_{SUP}}{\varphi_{IDA} - \varphi_{SUP}} \quad (1)$$

where

φ_{ETA} is the CO₂ concentration of extract air, as a percentage volume fraction;

φ_{SUP} is the CO₂ concentration of supply air, as a percentage volume fraction;

φ_{IDA} is the CO₂ 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 CO₂ 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 CO₂ 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

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]).