INTERNATIONAL STANDARD

ISO 16000-23

Second edition
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Indoor air —

Part 23:
Performance test for evaluating the reduction of formaldehyde and other carbonyl compounds concentrations by sorptive building materials

Air intérieur —

Partie 23: Essai de performance pour l'évaluation de la réduction des concentrations en formaldéhyde et autres composés carbonylés par des matériaux de construction sorptifs

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 6, *Indoor air*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

This second edition cancels and replaces the first edition (ISO 16000-23:2009), which has been technically revised. The main changes compared to the previous edition are as follows.

- The target chemical compounds subject to this document have been changed from formaldehyde only to formaldehyde and other carbonyl compounds.

A list of all parts in the ISO 16000 series can be found on the ISO website.

Introduction

Sorptive building materials have been marketed in the form of sheet and board products for removing airborne pollutants via physical sorption or chemical reaction.

Harmonized test methods for evaluating sorptive effects are important for quantitative performance assessment of sorptive building materials that are used for reducing levels of indoor air contaminants.

This document specifies procedures for evaluating the performance of sorptive building materials in reducing indoor air formaldehyde and other carbonyl compounds concentrations over time.

The performance of sorptive building materials is evaluated by measuring the area-specific reduction rate and the saturation mass per area. The former directly indicates material performance with respect to formaldehyde and other carbonyl compounds concentration reduction at a point in time; the latter relates to the ability of a product to maintain such a performance. This is affected by a number of factors and the performance test in conjunction with the standardized sampling, storage of samples and preparation of test specimens has objectives to provide manufacturers, builders, and end users with comparative performance data of sorptive building materials useful for the evaluation of the impact on the indoor air quality, and to promote the development of improved products. Specific test conditions are therefore defined in this document.

This document can be applied to most sorptive building materials used indoors and to formaldehyde and other carbonyl compounds used as an indoor air contaminant. This method does not apply to materials capable of decomposing target compound(s) by catalytic reaction in the presence of ultraviolet and visible rays.

This document is based on the test chamber method as specified in ISO 16000-9.

Indoor air —

Part 23:
Performance test for evaluating the reduction of formaldehyde and other carbonyl compounds concentrations by sorptive building materials

1 Scope

This document specifies a general laboratory test method for evaluating the reduction of formaldehyde and other carbonyl compounds (aldehydes and ketones) concentrations by sorptive building materials. This method applies to boards, wallpapers, carpets, paint products, and other building materials. The sorption of those target compounds, i.e. formaldehyde and other carbonyl compounds, can be brought about by adsorption, absorption and chemisorption.

The method specified in this document employs formaldehyde and other carbonyl compound spiked supply air to determine the performance of building materials in reducing formaldehyde and other carbonyl compounds concentrations.

This document is based on the test chamber method specified in ISO 16000-9. Sampling, transport and storage of materials to be tested and preparation of test specimens are specified in ISO 16000-11. Air sampling and analytical methods for the determination of formaldehyde and other carbonyl compounds are specified in ISO 16000-3, which is part of the complete procedure.

This document applies to the determination of formaldehyde and other carbonyl compounds, such as formaldehyde, acetaldehyde, acetone, benzaldehyde, butyraldehyde, valeraldehyde, 2,5-dimethylbenzaldehyde, capronaldehyde, isovaleraldehyde, propionaldehyde, o-tolualdehyde, m-tolualdehyde, p-tolualdehyde.

2 Normative references

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

ISO 16000-3, *Indoor air — Part 3: Determination of formaldehyde and other carbonyl compounds in indoor air and test chamber air — Active sampling method*

ISO 16000-6, *Indoor air — 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*

ISO 16000-9, *Indoor air — Part 9: Determination of the emission of volatile organic compounds from building products and furnishing — Emission test chamber method*

ISO 16000-11, *Indoor air — Part 11: Determination of the emission of volatile organic compounds from building products and furnishing — Sampling, storage of samples and preparation of test specimens*

3 Terms and definitions

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

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

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at https://www.electropedia.org/

3.1
area-specific reduction rate
q_{ads}
mass of *target compound(s)* (3.14) sorbed per time unit per area at the specified *elapsed time* (3.4) from the test start

3.2
breakthrough time
t_{b}
time at which the *target compound* (3.14) concentration in the air eluting from the sample tube reaches 0,5 % of the concentration in the supplied air

3.3
degradation coefficient
ratio of the mass of *target compound(s)* (3.14) removed by the initial performance divided by the mass of the same compound(s) lost by deterioration

3.4
elapsed time
time from the start of test to the start of air sampling

Note 1 to entry: Elapsed time is expressed in hours or days.

3.5
equivalent ventilation rate per area
$q_{V,\text{ eq}}$
increased clean air ventilation rate giving the same reduction in *target compound* (3.14) concentration as the building material

3.6
guideline concentration
corresponding threshold indoor air concentration for *target compound(s)* (3.14) as specified by the WHO or an appropriate national standards body

3.7
half-lifetime
time elapsed from the start of the test until the *target compound* (3.14) concentration reduction performance decreases to one half of the initial concentration reduction performance

3.8
lifetime
t_{lt}
time period over which the product continues to reduce *target compound* (3.14) concentrations

Note 1 to entry: The lifetime is given in days or years.

Note 2 to entry: The lifetime is estimated from the *area-specific reduction rate* (3.1) and sorption capacity measured by the sample tube test.

3.9
mass transfer coefficient
k_{a}
coefficient arising from the concentration difference between the test specimen and ambient air over its surface

Note 1 to entry: Mass transfer coefficient is expressed in metres per hour (m/h).

3.10

recovery

measured mass of *target compound(s)* (3.14) in the air leaving the test chamber with no sample present conditioned over a given time period divided by the mass of target compound(s) added to the test chamber in the same time period

Note 1 to entry: The recovery is expressed as a percentage and provides information about the performance of the entire method.

3.11

saturation mass per area

$\rho_{A\mathrm{a}}$

theoretical maximum mass of *target compound(s)* (3.14) that could be removed per area of the sorptive material

Note 1 to entry: Saturation mass per area is expressed in micrograms per area. It corresponds to the total mass per area of sorption at the *half-lifetime* (3.7), or is extrapolated from the *sorption capacity* (3.12) derived from the test referenced in Annex A.

3.12

sorption capacity

w_S

total mass of *target compound(s)* (3.14) sorbed at *breakthrough time* (3.2) per mass of sorbent

Note 1 to entry: Sorption capacity is expressed in micrograms per gram and is measured using the test specified in Annex A.

3.13

supply air concentration

ρ_S

mass concentration of *target compound(s)* (3.14) in the air for supply to the test chamber

3.14

target compound

formaldehyde or other carbonyl compound in indoor air

3.15

test chamber concentration

concentration of *target compound(s)* (3.14) measured at the outlet of a test chamber, derived by dividing the mass of the target compound(s) sampled at the outlet of the chamber by the volume of sampled air

3.16

total mass per area of sorption

ρ_A

integral over time of *area-specific reduction rate* (3.1) from the start of the test to the specified *elapsed time* (3.4) measured with the test chamber

Note 1 to entry: Total mass per area of sorption is expressed in micrograms per area.

3.17

air sampling period

period of time during which air is sampled from the outlet of the test chamber using sampling tubes or other devices

4 Symbols

Symbol	Meaning	Unit
A	surface area of test specimen	square metres
q_{ads}	Area-specific reduction rate	micrograms per square metre per hour
$q_{V,\mathrm{a}}$	air flow rate per area	cubic metres per square metre per hour
$q_{V,\mathrm{eq}}$	equivalent ventilation rate	cubic metres per square metre per hour
k_{a}	mass transfer coefficient determined using water vapour	metres per hour
L	product loading factor	square metres per cubic metre
m	actual mass of test specimen in sample tube	grams
n	air change rate	changes per hour
q_{c}	air flow rate of test chamber	cubic metres per hour
q_{s}	air flow rate of sample tube	litres per minute
t_{b}	breakthrough time	minutes
t_{e}	elapsed time	hours or days
t_{lt}	lifetime of the pollutant-removing performance	hours, days or years
V	air volume of test chamber	cubic metres
w_{s}	sorption capacity measured by sample tube	micrograms per gram
ρ_A	mass of sorptive material per area (surface density)	grams per square metre
$\rho_{A\mathrm{a}}$	saturation mass per area	micrograms per square metre
$\rho_{A\mathrm{c}}$	total mass per area of sorption measured by chamber test	micrograms per square metre
$\rho_{\mathrm{in},\,t}$	concentration of target compound(s) at test chamber inlet at elapsed time t	micrograms per cubic metre
$\rho_{\mathrm{out},\,t}$	test chamber concentration at elapsed time t	micrograms per cubic metre
ρ_{s}	supply air concentration in sample tube	micrograms per cubic metre

5 Principle

The performance of a building material in reducing the concentration of target compound(s), i.e. formaldehyde and other carbonyl compounds, from the indoor air is evaluated by monitoring the reduction of the concentration of these substances in the air of a test chamber containing a specimen of the test material. The test assesses both the initial performance of the material and how long that performance is maintained.

In this test method, target compound spiked air is supplied into the test chamber. The spiked air should be prepared at approximately the guideline concentration level for the target compound(s) in indoor air. Reference to the WHO or an appropriate national standards body can be made if this is clearly highlighted in the test report.

Performance is determined by monitoring the difference in the concentration of target compound(s) at the inlet and outlet of the test chamber. Testing should be carried out for the half-lifetime, i.e. until the concentration reduction performance of target compound(s) drops to one half of the performance recorded at the start of the test under constant ventilation conditions. With this test, the area-specific reduction rate, ρ_{ads}, and total mass per area of sorption, $\rho_{A\mathrm{c}}$, at the half-lifetime are determined. The value measured for $\rho_{A\mathrm{c}}$ at the half-lifetime is defined as the saturation mass per area, $\rho_{A\mathrm{a}}$.

If a test material continues to reduce target compound concentrations for longer than 28 days, the alternative methods specified in Annex A for determining $\rho_{A\mathrm{a}}$ may be applied.

The performance of sorptive building materials is mainly determined by the target compound concentration, the mass transfer coefficient of target compound(s) to the surface, and the sorption characteristics of the building materials themselves (adsorption isotherm, diffusion resistance, and so on). Therefore, the performance test method shall specify both the concentration of target compound(s) and the mass transfer coefficient associated with the sorptive building material.

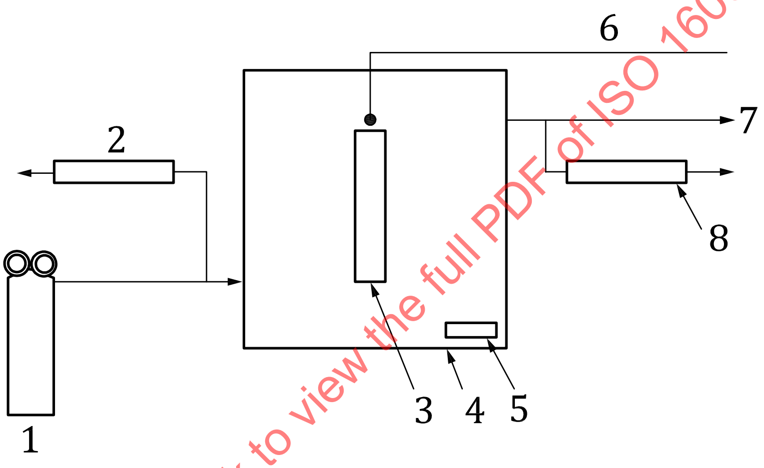
A re-emission test should be conducted following the test for evaluating the concentration reduction performance, as described in 11.3.1.

NOTE The long-term formaldehyde target compound reduction performance is represented by the saturation mass per area, ρ_{Aa}, and, if necessary, the lifetime of the pollutant-removing performance, t_{lt}, as the subsidiary index.

6 Apparatus and materials

The usual laboratory apparatus and, in particular, the following.

6.1 Test chamber, complying with the relevant specifications and requirements of ISO 16000-9 (see Figure 1). No air shall be allowed to circulate from the outlet back to the inlet.



Key

1	supply air spiked with target compound(s) (6.3)	5	device to circulate air and control air velocity
2	air sampling device (6.6)	6	temperature/humidity monitoring apparatus (6.4)
3	test specimen	7	test chamber outlet
4	test chamber (6.1)	8	air sampling device (6.6)

Figure 1 — Outline of the test chamber system

6.2 Air purifier or **cylinder of clean air**, to ensure the supply air is as clean as possible before being spiked with target compound(s), i.e. it shall not contain any contaminants at levels greater than the chamber background requirements.

6.3 Supply air spiked with target compound(s), created by applying a standard gas (whose target compound concentration is known) to the test chamber. Alternatively, use a stable source to generate air spiked with target compound(s) that can be supplied to the test chamber. The stability of the spiked target compound concentration shall be monitored.

6.4 Temperature and humidity monitoring apparatus.

Temperature shall be maintained either by installing a test chamber in a place maintained at the required temperature, or by maintaining the required temperature in the chamber. Relative humidity shall be maintained at the required humidity of the supply air. Temperature and humidity controls of the supply air are described in ISO 16000-9.

6.5 Air flow meter, installed at the inlet or the outlet of the test chamber to measure the air flow rate through the chamber.

6.6 Air sampling devices.

Use the inlet and outlet air of the test chamber for sampling. When a separate sampling port is used, sample directly from the inlet or outlet of the chamber.

If a duct or tube is used, it shall be as short as possible and kept at the same air temperature as that of the test chamber. Such a duct or tube shall be made of a material with a very low sorption capacity, e.g. polytetrafluoroethylene.

The sum of sampling air flow rates shall be smaller than the air flow rate into the chamber. Sampling devices shall comply with the specifications of ISO 16000-3. When the air is sampled from the inlet, ensure the supply air flow rate remains constant.

A multiport sampling manifold may be used to provide flexibility for duplicate air sampling. A mixing chamber between the test chamber and the manifold or between the air inlet and the test chamber can be included to permit addition and mixing of internal standard gases with the test chamber air stream.

The exhaust from the test chamber should be ducted into a fume hood, ensuring that target compound spiked air and any chemicals emitted from the test material are isolated from the laboratory environment.

6.7 High performance liquid chromatograph (HPLC), as specified in ISO 16000-3.

7 Test conditions

7.1 General

The test conditions shall comply with 7.2 and 7.3. This test shall be conducted under atmospheric pressure conditions.

An example is given in Annex C.

7.2 Test conditions to determine concentration reduction performance

7.2.1 Temperature and relative humidity

The temperature in the test chamber should be set to 23 °C ± 1 °C, and the relative humidity should be 50 % ± 5 % during the test.

For building materials with applications under other climatic conditions, alternative temperatures and air humidity conditions may be used, preferably as specified in ISO 554. State the conditions in the test report.

Initial variations can be observed in the test chamber climate after opening the test chamber door and loading a test specimen. These variations should be recorded.

NOTE Temperature and relative humidity can affect area-specific reduction rate and re-desorption from the test material.

7.2.2 Supply air quality and background concentration

The background concentration of the supply air for the test chamber and the air prior to spiking with target compound(s) shall be low enough not to interfere with the test. The total volatile organic compound (VOC) background concentration shall be lower than 20 µg/m^3. The background concentration of formaldehyde and other carbonyl compounds shall be lower than 2 µg/m^3. The purified water used for humidification shall not contain interfering VOCs that can affect the test.

7.2.3 Mass transfer coefficient

The mass transfer coefficient in terms of ambient air velocity over the surface of the test specimen inside the test chamber shall be 15 m/h ± 3 m/h (equivalent to 0,25 m/s ± 0,05 m/s) when determined using water vapour. To check the dependence of the mass transfer coefficient on material performance, take measurements under other conditions that appropriately influence the mass transfer coefficient.

NOTE 1 The mass transfer coefficient is analogous to the convective heat transfer coefficient where geometry and boundary conditions are similar. The mass transfer coefficient can be estimated with a formulation that relates the mass transfer flux (area-specific reduction rate) to a surface to the concentration differences across the boundary layer. For details concerning the mass transfer coefficient and its measurement method, see Reference [9].

NOTE 2 Reduction performance depends on the mass transfer coefficient. Mass transfer coefficient depends on the indoor concentration of the substance, air flow, and the surface area of the test specimen.

7.2.4 Air change rate

The air change rate shall be kept constant at 0,50 ± 0,03 changes per hour. The product loading factor shall comply with ISO 16000-9:2006, Annex B, or be derived from the geometry and volume of an appropriate model room.

NOTE The selection of air flow rate per area, $q_{V,\text{a}}$, affects the steady-state concentration of target compound(s) in the test chamber air.

7.2.5 Supply air concentration

The concentration of target compound(s) in the air supplied to the test chamber shall be approximately equal to the guideline concentration specified in 3.6.

Other concentrations may be applied if relevant for the purpose of the test. This shall be stated explicitly in the test report.

7.3 Factors affecting the concentration reduction performance

7.3.1 General

To evaluate the effects of temperature, humidity and air contaminants on the target compound concentration reduction performance, modify each of the factors listed separately in 7.3.2 to 7.3.4.

7.3.2 Temperature and humidity

To evaluate the effects of temperature on concentration reduction performance, the temperature in the test chamber should be set to 18 °C ± 1 °C, 23 °C ± 1 °C and 28 °C ± 1 °C. The relative humidity in the test chamber should be set to 25 % ± 5 %, 50 % ± 5 % and 75 % ± 5 %, with the temperature in the chamber and the supply air concentration in the chamber set as specified in 3.6 and 7.2.5.

7.3.3 Concentration of target compound(s) in supply air

The target compound supply air concentration should be set to twice the guideline concentration specified in 7.2.5, and then to one half of the guideline concentration, with the constant temperature and relative humidity in the test chamber set as specified in 7.2.1 as a standard test condition.

7.3.4 Interfering gases

Various interfering gases are expected to exist in indoor environments, and their effect can be measured on the performance of test materials in target compound concentration reduction by measuring such performance while varying the concentration of each interfering gas.

8 Verification of test conditions

8.1 Monitoring of test conditions

Temperature, relative humidity and air flow rate shall be monitored and recorded continuously with instruments meeting the following accuracy specifications:

— temperature: ±0,5 °C

— relative humidity: ±3 %

— air flow rate: ±3 %

Temperature and relative humidity of air may be measured in the outlet of the chamber if the point of measurement ensures that values are identical to those inside the test chamber.

8.2 Airtightness of test chamber

Airtightness of the test chamber should be checked regularly as specified in ISO 16000-9:

— by pressure drop measurements,

— by comparison of simultaneous measurement of flow rates at the inlet and the outlet ports, or

— by tracer gas dilution measurements.

8.3 Air change rate in test chamber

The air change rate shall be regularly checked as specified in ISO 16000-9.

NOTE If the test is carried out in the outlet with an air flow meter that is not permanently installed, the back pressure introduced by the instrument can lower the flow rate through the test chamber.

8.4 Efficiency of the internal test chamber air mixing

Determine the efficiency of the air mixing as specified in ISO 16000-9.

8.5 Recovery

Recovery tests shall be performed in the test chamber by introducing supply air with the same target compound concentration as specified for the performance test and then comparing air measurement results at the outlet and inlet of the test chamber. Chamber concentrations shall be determined 72 h after starting the test and the consistency of the recovery performance during the test should be confirmed. The mean recovery shall be greater than 80 %. The value obtained by subtracting the mean recovery from 100 % indicates the adsorption capacity of the test chamber. The adsorption capacity of the test chamber itself shall be subtracted from the measured adsorption capacity. The results of the recovery test shall be reported (expected concentration versus measured concentration).

NOTE Sink effect, leakage or poor calibration can cause difficulties in meeting minimum requirements for the test.

9 Preparation of test chamber

The test chamber shall be cleaned in order to fulfil the requirements of 7.2.2. Cleaning can be done as follows.

- The inner surfaces of the test chamber are washed with a detergent.
- Two separate rinsings are performed with freshly distilled water.
- The test chamber is then dried and purged under test conditions.

The test chamber can also be cleaned by thermal desorption.

For cleaning of the test chamber, an oven may be used to volatilize any aldehyde or VOCs on the internal walls of the test chamber. Alternative methods may be used instead of an oven.

10 Preparation of test specimens

After completing test preparations, supply air spiked with the target compound(s) to the test chamber. Take a sample of the material to be tested from its package. The sample shall be a part or piece that is representative of a building material. Prepare a test specimen from the sample as specified in ISO 16000-11.

For the measurement of target compound sorption by only one surface of a test specimen, seal the cut edges and the back of the specimen with aluminium foil or other sealing material, or place two test specimens back-to-back with sealed edges.

11 Test method

11.1 Background concentration and spiked supply air

Prior to beginning a test, ventilate the test chamber for 1 day by running empty, and then measure and determine the background target compound concentration of the empty test chamber.

The background concentration shall be low enough not to affect the test.

Then start flushing the test chamber with supply air spiked with target compound(s). Allow at least five air exchanges before introducing the test specimen.

11.2 Placing the test specimen in the test chamber

Place the test specimen in the middle of the test chamber to ensure that the air can uniformly flow over the sorptive surface of the test specimen. Close the chamber. Note the time as the start of the test.

The test specimen shall be placed in test chamber as quickly as possible.

11.3 Time intervals for measurement of test chamber concentration

11.3.1 Test for target compound concentration reduction

After the start of the test, sample air from the chamber inlet and the chamber outlet in accordance with 11.4 at predefined elapsed times.

Measure the quantity of target compound(s) removed from the test chamber air per area of the test specimen exposed to the test chamber air under the conditions specified in 7.2.

Check the total air flow through the test chamber and ensure that there is no air leakage from it. Then, ensure that the outlet air flow rate during air sampling is equal to the inlet air flow rate minus the sum of the sampling air flow rates. The remaining outlet air flow rate shall be at least 20 % of the total sampling air flow rates. Air samples shall be taken 24 h ± 2 h, 72 h ± 6 h, 168 h ± 14 h, 14 days ± 1 day, and 28 days ± 2 days after the start of the test. Additional air samples may be collected. Duplicate sampling should be conducted.

The stability of the spiked target compound concentration at the air inlet shall be monitored.

Other time intervals may be selected according to the purpose of the test. If data on long-term performance of the testing material are required, further test samples may be collected at even longer times from test start; i.e. >28 days. When the reduction performance decreases to one half of the initial value, terminate the test.

A subsequent test of re-emission should be conducted by supplying clean air to the test chamber. It is preferable to undertake re-emission tests routinely as part of the target compound concentration reduction performance test. Air samples should be taken 24 h (and other times if required) after the start of the re-emission test. In cases where significant sorption of target compound(s) to test chamber surfaces occurs, the relative contribution of the sample and the chamber walls to the total emission shall be assessed. This may be achieved by conducting appropriate control tests without material samples.

If VOCs and other organic compounds of interest are emitted from the material sample, measure their emission rates as described in ISO 16000-3, ISO 16000-6 and ISO 16000-9.

11.3.2 Test for long-term reduction performance

Determine the half-lifetime and then measure the total mass per area of sorption, $\rho_{A\mathrm{c}}$, of formaldehyde and other carbonyl compounds and the elapsed time, t_e. The value after 24 h shall be used for initial concentration.

An example is given in Annex D.

11.3.3 Factors affecting the reduction performance

The effect of each environmental factor may be measured by varying the value of only one factor at a time against those conditions used for the measurement of the reduction performance in 11.3.1. The measuring conditions shall be as specified in 7.2.

11.4 Air sampling

A tube filled with 2,4-dinitrophenylhydrazine (DNPH) as specified in ISO 16000-3 shall be used for air sampling for the determination of formaldehyde and other carbonyl compounds concentration.

12 Determination of target compound(s)

Elute the DNPH derivative of formaldehyde and other carbonyl compounds from the DNPH tube and analyse as specified in ISO 16000-3.

13 Expression of results

13.1 Calculation of area-specific reduction rate

Calculate the area-specific reduction rate per time unit per area at the elapsed time t_e, $\rho_{\mathrm{ads},t\mathrm{e}}$, using Formula (1):

$$\rho_{\mathrm{ads},t_e} = \frac{(\rho_{\mathrm{in},t_\mathrm{e}} - \rho_{\mathrm{out},t_\mathrm{e}})q_\mathrm{c}}{A} \qquad (1)$$

where

$\rho_{\text{in},\,te}$	is the concentration of target compound(s) at test chamber inlet at elapsed time, t_{e};
$\rho_{\text{out},\,te}$	is the test chamber concentration at elapsed time, t_{e};
q_{c}	is the air flow rate of test chamber;
A	is the surface area of test specimen.

When the adsorption capacity of the test chamber itself cannot be disregarded, subtract the area-specific reduction rate of the test chamber when measured with no test specimen from the measured area-specific reduction rate.

13.2 Calculation of equivalent ventilation rate per area

Assuming that the concentration falls due to an increasing clean air flow rate, calculate the equivalent ventilation rate per area at the elapsed time t_{e}, $q_{V,\,\text{eq}}$ using Formula (2):

$$q_{V,\text{eq}} = \frac{\left(\dfrac{\rho_{\text{in},t_e}}{\rho_{\text{out},t_e}} - 1\right) q_{\text{c}}}{A} \tag{2}$$

13.3 Calculation of total mass per area of sorption and saturation mass per area

Calculate the total mass per area of sorption, $\rho_{A\text{c}}$, at the half-lifetime, applying Formula (3):

$$\rho_{A\text{c}} = \int_{0}^{t_e} \left(\rho_{\text{ads},t}\right) \text{d}t \tag{3}$$

where

ρ_{ads}	is the area-specific reduction rate;
t_{e}	is the elapsed time.

The saturation mass per area, $\rho_{A\text{a}}$, is given by the identity:

$\rho_{A\text{a}} \equiv \rho_{A\text{c}}$

14 Test report

The test report shall include at least the following information:

a) test laboratory:

   1) name and address of the test laboratory,

   2) name of the responsible person;

b) sample description:

   1) type of building material (and brand name, if appropriate),

   2) sample selection process (e.g. random),

   3) product history (date of production, batch number, date of arrival at the test laboratory, date and time of unpacking, date and time of preparation of test specimen, etc.);

c) test results:

   1) area-specific reduction rate of target compound(s), total mass per area of sorption, equivalent ventilation rate per area at the half-life time and other specified elapsed time,

   2) saturation mass and reduction performance in the presence of interfering gases,

   3) details of the method used, with a reference to this document, i.e. ISO 16000-23:2018;

d) test conditions:

   1) test chamber conditions [temperature, relative humidity, air change rate, mass transfer coefficient, concentration of supply air spiked with target compound(s)],

   2) surface area of the test specimen and loading factor,

   3) whether the test specimen was sealed (and how) or not,

   4) information on air sampling (sampling tube used, volume of air sampled, air sampling period from the test start, number of air samplings, etc.),

   5) test conditions for long-term performance test (temperature, target compound spiked supply air concentration);

e) devices: information on the equipment and procedure (test chamber, sealing material or sealing box, target compound spiking technique, air purifier, temperature and humidity controls, air flow meter, air sampling devices, analytical instrument, etc.);

f) quality control/quality assurance (details are as specified in Annex B):

   1) background concentration of formaldehyde and other carbonyl compounds and VOCs,

   2) recovery data of target compound(s),

   3) number of measurements,

   4) result of each analysis of air sampled, if duplicate sampling was undertaken,

   5) accuracy of temperature, relative humidity and air change rate,

   6) quality assurance report;

g) additional details for test materials such as paints, coatings, or plastering materials:

   1) number of test specimens,

   2) mass per area,

   3) thickness,

   4) other observations that can influence the test results (drying conditions, storage, preservation, moisture content, surface treatment),

   5) mass per area, in grams per square metre,

   6) area,

   7) method used.

Annex A
(normative)

Sample tube test for long-term reduction performance

A.1 Principle

A.1.1 General

If a test material has a reduction performance greater than 28 days, meaning that a chamber test would take too long, a sample tube test for determining $\rho_{A\mathrm{a}}$ may be applied, based on the physical sorption, chemisorption and decomposition reaction. This sample tube test is helpful for estimating the long-term reduction performance as an alternative to using the test chamber.

The sample tube test for long-term target compound concentration reduction performance is one method to estimate the sorption capacity, w_S.

NOTE In many cases, the value of $\rho_{A\mathrm{a}}$ estimated by the chamber test is less than the value of $\rho_{A\mathrm{a}}$ estimated by the sample tube test.

A.1.2 Target compound reduction by physical sorption

The saturation mass per area, $\rho_{A\mathrm{a}}$, shall be calculated from the sorption capacity, w_S, which is measured by passing air containing target compound(s) through a glass sample tube filled with a small mass of finely ground (2 mm diameter or less) test specimen at breakthrough time.

A.1.3 Target compound reduction by chemisorption and/or decomposition reaction

The saturation mass per area, $\rho_{A\mathrm{a}}$, shall be calculated from the sorption capacity, w_S, which shall be measured as specified in A.1.2.

Chemisorption and/or decomposition can be calculated when the chemical reaction scheme is widely known.

The composition of the chemical substance shall be known in this case, because the molar concentration of the sorption agent employed is used in the calculation. Therefore, this method is not applicable to natural materials with unknown composition.

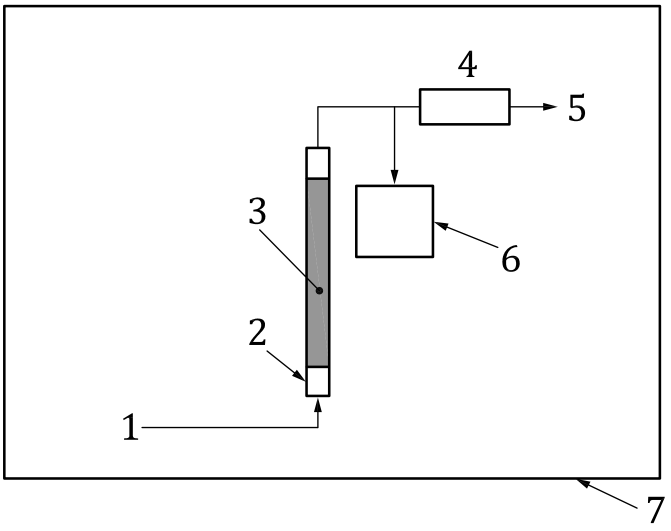
Any calculation of long-term reduction performance should be confirmed by experimental data (testing).

Alternatively, an evaluation by calculation of chemical reaction between sorption agent and target compound(s) may be performed.

A.2 Apparatus and materials

The usual laboratory equipment and, in particular, the following.

See Figure A.1 for a typical setup.



Key

1	inlet air	5	outlet air
2	sample tube	6	target compound detector
3	ground test specimen	7	climate chamber
4	air flow meter		

Figure A.1 — Example of apparatus to evaluate concentration reduction performance

A.2.1 Sample tube which fits the testing system and can accommodate the test specimen. The sample tube is installed so that its length is vertical.

A.2.2 Supply air spiked with target compound(s), complying with 6.4.

A.2.3 Temperature monitoring apparatus, complying with 6.5.

A.2.4 Air flow meter, installed before the sample tube or behind the air sampling pump for measuring target compound air flow. Other devices may be used if they have equal or better performance.

A.2.5 Target compound detector, installed at the outlet of the sample tube. It should be able to detect target compound(s) at 0,5 % of the challenge concentration in the supply air. For example, thermal conductivity detectors or mass spectrometry may be used. Target compound detectors may be applied only after calibration of their response. A DNPH tube may also be installed at the outlet of the sample tube to collect air samples at appropriate time intervals.

A.2.6 Climate chamber, in which the sample tube shall be contained. The climate chamber shall be a chamber controlled to the required temperature ± 2,0 °C.

A.3 Test conditions

A.3.1 Supply air concentration

The concentration of the supply air spiked with target compound(s) in the sample tube should be approximately equal to the guideline concentration.

If that cannot be done, perform this determination at relatively high target compound concentrations of the order of 10 times the guideline value.

A.3.2 Temperature and relative humidity

The supply air should be dry.

The temperature should be set to 18 °C ± 1 °C, 23 °C ± 1 °C and 28 °C ± 1 °C.

The humidity tends to affect the result. The humidity of the supply air shall be controlled at 50 % ± 5 % during the test and recorded if the test is not conducted with dry air.

Performance in reducing target compound concentration by physical sorption depends on temperature. Therefore, measurement at three temperatures as specified in 7.3.2 is recommended.

A.4 Test method

A.4.1 Sampling and pretreatment of test specimen

Grind the test specimen to form fragments that can be fitted in the sample tube, while maintaining secondary structure. Fine particles should be removed prior to the test. The test specimen shall be vacuum-dried.

The secondary structure which works effectively to absorb target compound(s) is maintained as long as the particle radius is approximately 10 times that of the pore.

When dry air is supplied to the sample tube, the test specimen may be vacuum-dried after grinding for homogeneity and reproducibility. In this case, absolute dryness may be assumed to be fundamental. If moist (humid) air is used for this test, the specimen may be controlled at equilibrium condition at the target humidity level.

This procedure shall not be applied to material of inhomogeneous structure.

A.4.2 Preparation of sample tubes

Weigh the ground test specimen and put it into sample tube. Use glass wool to hold the test specimen in position in the sample tube.

When the tube diameter is large, a perforated support should be installed into the inlet side in order to support the sample, to enhance diffusion of the gas. If a perforated support is not installed, non-uniform diffusion is observed in the sample tube.

A.4.3 Monitoring the target compound concentration of the supply air

Prior to connecting the sample tube to the system, connect an air sampling tube or detector, and determine the target compound concentration of the spiked supply air as specified.

A.4.4 Test for the target compound breakthrough time

Connect the sample tube to the system, start the target compound spiked air flow. Continue the target compound spiked air flow until the outlet air contains 0,5 % of supply air concentration, and then determine the sorption capacity, w_s, (saturated target compound mass per mass of sorbent) at that concentration. Consider this time as the breakthrough time, t_b.

NOTE 1 At low concentrations of target compound(s) in supply air, it can take a long time for the gas to break through the tube and for saturation to occur. To avoid long testing times, measuring at high target compound concentration can be done. However, measurement under concentrations greatly in excess of 1 000 µg/m^3 decreases the reliability of the regression curve that shows the results of measurements at multiple concentrations.

NOTE 2 The sorption isotherm is given by the same procedure as specified in this subclause using a different target compound concentration at the test temperature. The sorption capacity at the guideline value of 100 µg/m^3 can then be estimated by using the regression curve.

If the mass of compound comprising the test specimen and details of the chemical reaction with target compound(s) are known, the concentration reduction performance can be calculated. Results by experimental data (testing) should always be substantiated.

NOTE 3 Concentration dependency can be determined by a few tests where the load masses are different. The activation energy can be determined by an Arrhenius plot through a few test results at different temperatures. A half-lifetime (the time at which performance has decreased to one half of initial performance) can be found from the reaction velocity constant that is obtained from the concentration transition along with the time taken.

A.4.5 Expression of results

A.4.5.1 Calculation of sorption capacity

Calculate the target compound sorption capacity, w_s, of the test specimen using Formula (A.1):

$$w_\mathrm{s} = \frac{\rho_\mathrm{s} q_\mathrm{s} t_\mathrm{b}}{1\ 000m} \tag{A.1}$$

where

ρ_s is the target compound concentration in the supply air;

q_s is the air flow rate;

t_b is the breakthrough time;

m is the mass of test specimen in the sample tube.

A.4.5.2 Calculation of saturation mass per area

Calculate the saturation mass per area, $\rho_{A\mathrm{a}}$, using Formula (A.2):

$$\rho_{A\mathrm{a}} = w_\mathrm{s} \rho_A \tag{A.2}$$

Annex B
(normative)

System for quality assurance and quality control

B.1 General

Chamber testing for evaluating the concentration reduction performance of formaldehyde and other carbonyl compounds by sorptive building materials shall be conducted within the framework of a quality assurance project plan (QAPP). The QAPP shall contain a project description, data quality objectives and acceptance criteria, quality assurance and quality control (QA/QC) approaches and activities, and QA/QC audits. In particlular, air sampling and analytical methods to determine formaldehyde and other carbonyl compounds are specified in ISO 16000-3, and sampling, transport and storage of materials to be tested and preparation of test specimens are specified in ISO 16000-11. The QA/QC procedures shall be conducted in accordance with the requirement of ISO 16000-3 and ISO 16000-11.

B.2 Project description

A brief description shall include what materials are to be tested, how the testing is to be conducted, and who is responsible for various project activities. The project experimental design shall contain the necessary information for this portion of the QAPP.

B.3 Data quality objectives and acceptance criteria

This section of the QAPP defines the precision, accuracy, and completeness desired for each parameter being measured.

B.4 QA/QC approaches and activities

See Reference [9].

The types of QA/QC activities that can be specified in the QAPP include the establishment of a system of records or notebooks to ensure proper operation of equipment and recording of data, such as:

a) sample log to record receipt, storage, and disposal of materials;

b) HPLC standards preparation log to document preparation of all organic compound substances;

c) permeation tube log to record mass loss data for all permeation tubes;

d) calibration logs to contain environmental systems calibration data;

e) instrument maintenance logs to document maintenance and repairs of all equipment;

f) materials testing logs in which to record all pertinent information for each test, including sample details, sample identification (ID) number and HPLC run ID number;

g) DNPH tube cleanup and solvent extraction log and QC validation of DNPH tubes;

h) separate electronic log to document location and content of electronically stored data;

i) manuals governing operation of all equipment used by the project.

QC activities are carried out by project staff in a routine, consistent manner to provide necessary feedback in operation of all measurement systems. Such activities can include:

1) routine maintenance and calibration of systems;
2) daily recording of HPLC calibration accuracy and precision (i.e. control charting);
3) timely monitoring of the percentage recovery of the internal standard that was added to all samples;
4) collection and analysis of duplicate samples;
5) QC checking of organic collection sorbent tubes;
6) periodic analysis of audit gases supplied by an independent source.

B.5 QA/QC audits

Finally, the QA/QC programme shall include periodic audits by QA personnel to evaluate compliance with QAPP protocols.

Annex C
(informative)

Example measurements of construction materials

C.1 General

This annex comprehends example measurements of construction materials with sorptive effects. Some of the experimental conditions in this example, e.g. the chamber size and the duration of measurement, do not match the conditions defined in this document. However, this example is informative and can be useful for the understanding of a series of experiment procedures.

C.2 Testing conditions

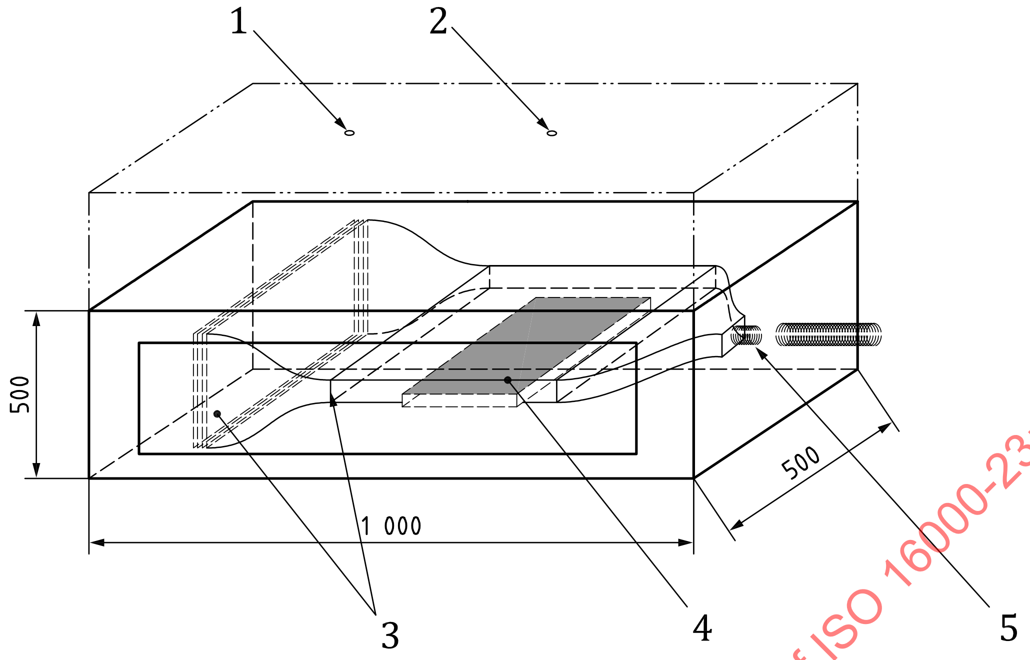
Testing conditions were set up as shown in Table C.1. The materials tested are shown in Table C.2. A boundary-layer-type small test chamber was used for the measurements, of which Figure C.1 shows an outline. This experiment was carried out with the quotient of the air flow rate to the surface area of the test specimen set to 0,23 and also 1,33.

Table C.1 — Testing conditions

Inner test chamber volume	0,6 m × 0,6 m × 0,06 m	
Outer test chamber volume	1,0 m × 0,8 m × 0,5 m	
Surface area of test specimen	0,15 m^2	
Loading factor	0,38 m^2/m^3	
Temperature	23 °C ± 1 °C	28 °C ± 1 °C
Relative humidity	50 ± 5 % RH	50 ± 5 % RH
Air change rate	0,5 /h	0,5 /h, 0,09 /h
Air flow rate/surface area of test specimen: q/A	1,33	0,23, 1,33
Inner test chamber average air velocity	0,1 m/s	0,1 m/s
Mass transfer coefficient determined using water vapour	15,5 m/h	15,5 m/h

Table C.2 — Testing materials

Symbols	**Building materials**
HGB	Formaldehyde-reducing gypsum board
RW	Formaldehyde-reducing rock wool acoustic board



Key

1	inlet
2	outlet
3	mesh
4	test material
5	fan

Figure C.1 — Test chamber

C.3 Assembly procedure

Before the test, the boundary-layer-type small test chamber was dismantled, the test chamber and its fittings (screws, etc.) were washed, and a bake-out was performed using a large oven at 260 °C.

After cooling, the boundary-layer-type small test chamber was assembled in a thermostatic oven, the system was run for about an hour, and after confirming the temperature and humidity had stabilized, the specimen was introduced to the boundary-layer-type small test chamber. After ventilating the room until it was considered that the test chamber had reached a stable temperature, supply air containing formaldehyde was passed through and when the concentration was considered to be steady, sampling was performed.

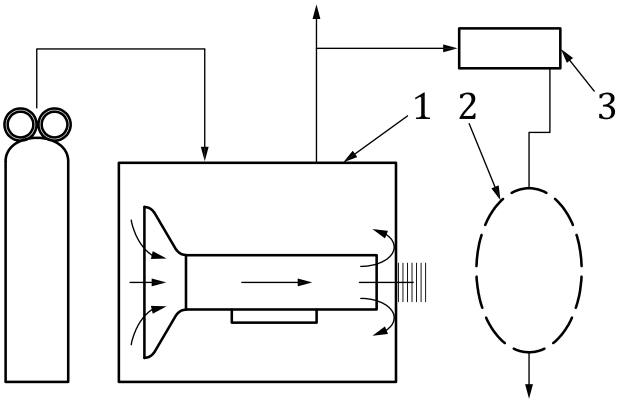
C.4 Sampling procedure and analytical conditions

Figure C.2 shows the series of flows for chemical sampling centred on the boundary-layer-type small test chamber. Air containing formaldehyde was supplied to the small outer chamber at a ventilation frequency of 0,5 times per hour. Polytetrafluoroethylene tubing was used for all pipes.

The specimen was set up in the test chamber, and after the concentration of formaldehyde in the test chamber stabilized, collection pipes were connected, and the necessary mass was drawn in with an external pump. Table C.3 shows the sampling conditions for formaldehyde.

However, these conditions change depending on the specimen and the objective of the test. To maintain the accuracy of the data, the collection mass is increased for measurements of specimens expected to adsorb a large mass.

Table C.4 shows the analytical conditions for formaldehyde.



Key

1 test chamber
2 pump
3 adsorbent

Figure C.2 — Measurement system

Table C.3 — Sampling conditions

Sampler	Waters Sep-Pak® DNPH-Silica Cartridge (short type)[a]
Air flow rate	0,5 l/min
Sampling volume	15 l

[a] Waters Sep-Pak® is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

Table C.4 — Analytical conditions (HPLC)

HPLC	Agilent HP1100® series[a]
Column	ZORBAX XDB-C18® [a]
Mobile phase	water + acetonitrile = 40 + 60
Oven temperature	40 °C
Injection volume	10 µl
Detector	UV 360 nm

[a] Agilent HP1100® series are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of these products.

C.5 Measurement

Table C.5 and Figure C.3 show the results of the test. For a supplied formaldehyde concentration of approximately 100 µg/m^3, the decrease in concentration in the small chamber indicates an ability to decrease the formaldehyde concentration. The ability of test specimen RW to reduce the formaldehyde concentration was small compared to that of test specimen HGB.