INTERNATIONAL STANDARD

ISO 12569

Second edition
2012-12-01

Thermal performance of buildings and materials — Determination of specific airflow rate in buildings — Tracer gas dilution method

Performance thermique des bâtiments et des matériaux — Détermination du débit d'air spécifique dans les bâtiments — Méthode de dilution de gaz traceurs

Reference number
ISO 12569:2012(E)

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Published in Switzerland

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Foreword

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ISO 12569 was prepared by Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 1, *Test and measurement methods*.

This second edition cancels and replaces the first edition (ISO 12569:2000), which has been technically revised.

Introduction

The aim of ventilation is to maintain a proper hygienic status of the room by introducing outdoor air into a room, diluting contaminants, heat, moisture or odour generated in the room, and evacuating them. In terms of energy savings, it is also important to keep the ventilation at the required rate, in order to reduce heat loss and heat gain under air conditioning as much as possible. Measurement of airflow rates is often necessary, for example to check if the performance of a ventilation system is as intended, to assess the source strength of contaminants, to ensure that contaminants are properly eliminated, etc. The methods described here can be used to measure the ventilation rate or the specific airflow rate.

Thermal performance of buildings and materials — Determination of specific airflow rate in buildings — Tracer gas dilution method

1 Scope

This International Standard establishes an engineering standard by which to obtain the ventilation rate/specific airflow rate, using a tracer gas in a building space, which is considered to be of a single zone.

The measurement method is valid in spaces where the combined conditions concerning the uniformity of tracer gas concentration, measurement of the exhaust gas concentration, effective mixed zone and/or fluctuation of ventilation are satisfied.

This International Standard provides three measurement methods using a tracer gas: (1) concentration decay method, (2) continuous dose method, and (3) constant concentration method.

NOTE Specific measurement conditions are given in Table 1.

2 Terms and definitions

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

2.1
single zone
V
space where the ventilation rate/specific airflow rate is measured and which only exchanges air with the outside

NOTE 1 Measured in cubic metres.

NOTE 2 Conditions needed for measurement are different for each measurement method, and details are given in Clause 4.

2.2
effective mixed zone
V_{emz}
space within a single zone, excluding sealed furniture or storage space, in which tracer gas supplied to the zone is regarded as uniformly distributed

NOTE 1 Measured in cubic metres.

NOTE 2 Forced mixing of air in the zone is often needed to keep uniform tracer gas concentration.

2.3
ventilation rate
Q_v
total volume of air passing through the zone to the outdoor air per unit of time

NOTE Measured in m^3/s or m^3/h.

2.4
specific airflow rate
N
ratio of the Qv to the volume of the effective mixed zone, per second or per hour

2.5
building envelope

boundary or barrier separating the interior volume of a building from the outside environment

2.6
tracer gas

gas that can be mixed with air and measured in very small concentration in order to study airflow rate

NOTE The tracer gas volume is defined as the value of exhaust temperature converted into density. When the room air is mixed well, the room temperature approximately matches the exhaust temperature.

2.7
concentration decay method

method by which the specific airflow rate is obtained from the decaying curve of concentration observed after the end of the injection of tracer gas.

2.8
continuous dose method

method by which the ventilation rate is obtained from the concentration resulting from continuous generation or injection of the tracer gas

2.9
constant concentration method

method by which the ventilation rate is obtained from the injection rate of tracer gas dosed for constant concentration in the space

3 Measurement method and its selection

3.1 General

One of the three measurement methods concentration decay method, continuous dose method and constant concentration method, is used to measure the ventilation rate/specific airflow rate. Selection of a measurement method and data processing depends on a building structure, ventilation system and measurement instrument employed. The concentration decay method has a limited measurement time of up to several hours while the continuous dose and constant concentration methods can provide a longer measurement time up to several weeks. The guideline of selection of the method and what is measured by the method is listed in Table 1.

In order to improve the accuracy of measuring the ventilation rate/specific airflow rate, it is sometimes necessary to devise measures that approximate prerequisite conditions demanded of measurement methods. In particular, if a measurement method were used that requires uniformity of concentration in the effective mixed zone, it would be preferable to forcibly mix the internal air. In general, forced mixing of internal air has little effect on ventilation rate/specific airflow rate, but there is a risk that forced mixing affects the measured ventilation rate if natural ventilation due to temperature differences predominates and the temperature within the room is distributed significantly, or if airflow emitted from a fan for the purpose of mixing air directly impinges on the leakage areas in buildings. In such instances, a mixing system needs to be improved or it would be recommended to select a measurement method that could ensure uniformity of concentration without mixing.

In Table 1, specifications for the various applications are described as follows:

— “Room concentration can be maintained uniform at initial stage only” means making the concentration in the effective mixed zone uniform by a method such as forced mixing when supplying a tracer gas into the zone, but allowing the concentration to be distributed in principle with the measurement.

— If it is specified that “room concentration can be maintained uniform at all times”, continuous forced mixing of air in the effective mixed zone is preferable. However, if the constant concentration method is used, and if concentration is controlled by injecting the tracer gas at several places and air is sampled at several locations, it is possible to assume that concentration is uniform without mixing.

- "Average exhaust concentration can be measured" may either mean instances in which concentration in an effective mixed zone is made uniform using mixing, or instances whereby the pressure inside a zone is kept lower than the outside when using the exhaust ventilation system, or the leakage area is extremely low so the exfiltration rate may be ignored, and exhaust pathways may be specified beforehand.
- When using measurement methods that require the "known volume of an effective mixed zone", the volume of the effective mixed zone can be estimated using room dimensions. However, when using the corresponding average inverse concentration method and average concentration method, if a sufficiently long time is taken to evaluate the ventilation rate, high accuracy for estimating the volume of an effective mixed zone is not needed.
- Measurement methods that can be applied in instances where "fluctuation in ventilation rate can be ignored", are designed on the assumption that the ventilation rate/specific airflow rate over time does not change.

Table 1 — Method, application and measured quantities

Method		**Application and measured quantities**						
		Application					**What is measured**	
		Room concentration can be maintained uniform at initial stage only	Room concentration can be maintained uniform at all times	Average exhaust concentration can be measured	Known volume of effective mixed zone	Fluctuation in ventilation rate can be ignored	Ventilation rate or specific airflow rate	Flexibility to transient ventilation rate
Concentration decay method	2-point decay method		○				Specific airflow rate	Δ
	Multi-point decay method		○			○	Specific airflow rate	
	Step-down exhaust concentration method	○		○		○	Specific airflow rate	
	Pulse method			○		○	Ventilation rate	

NOTE In addition to the measurement methods above, there is an intermittent dose method that allows the measurement the volume of an effective mixed zone and ventilation rate at the same time. For measurement of ventilation rate among the other measurements, if volume of an effective mixed zone is known, the ventilation rate can be obtained by multiplying the volume of the effective mixed zone by the specific airflow rate, and then converting to ventilation rate. The measurement methods marked with "Δ" in the "flexibility to transient ventilation rate" column can apply, in principle, to the case where changes in ventilation rate/specific airflow rate cannot be ignored, however, because the measurement is based on time-mean ventilation rate/specific airflow rate, it indicates that it does not meet the measurement of transient ventilation rate/specific airflow rate. The constant concentration methods marked with "○" indicate it meets measurement of transient ventilation rate if the dose of the tracer gas responds accurately to the transient ventilation rate with internal concentration maintained at a constant level.

Table 1 *(continued)*

Method		Application and measured quantities						
		Application					What is measured	
		Room concentration can be maintained uniform at initial stage only	Room concen-tration can be maintained uniform at all times	Average exhaust concen-tration can be measured	Known volume of effective mixed zone	Fluctuation in ventilation rate can be ignored	Ventilation rate or specific airflow rate	Flexibility to transient ventilation rate
Continuous dose method	Average of inverse concentration method		○		○		Ventilation rate	Δ
	Average concentration method		○		○	○	Ventilation rate	
	Stationary concentration method			○		○	Ventilation rate	
Constant concentration method			○				Ventilation rate	○

NOTE In addition to the measurement methods above, there is an intermittent dose method that allows the measurement the volume of an effective mixed zone and ventilation rate at the same time. For measurement of ventilation rate among the other measurements, if volume of an effective mixed zone is known, the ventilation rate can be obtained by multiplying the volume of the effective mixed zone by the specific airflow rate, and then converting to ventilation rate. The measurement methods marked with “Δ” in the “flexibility to transient ventilation rate” column can apply, in principle, to the case where changes in ventilation rate/specific airflow rate cannot be ignored, however, because the measurement is based on time-mean ventilation rate/specific airflow rate, it indicates that it does not meet the measurement of transient ventilation rate/specific airflow rate. The constant concentration methods marked with “○” indicate it meets measurement of transient ventilation rate if the dose of the tracer gas responds accurately to the transient ventilation rate with internal concentration maintained at a constant level.

3.2 Concentration decay method

3.2.1 General

At the start of measurement, the tracer gas is supplied in the zone to be measured, and ventilation rate/specific airflow rate is evaluated based on the concentration decay data obtained. In case of the forced mixing for uniform distribution or if the average exhaust concentration can be measured, the measurement point can be limited to one. The amount of tracer gas needed is very small for one measurement, and it is not required to accurately measure the amount of injected gas except for the pulse method.

The basic equation that can be commonly applied to the methods is as follows:

$$\frac{dV_{\mathrm{gas}}(t)}{dt} = -C_{\mathrm{E}}(t)Qv(t) \quad (\mathrm{m^3/h\ or\ m^3/s}) \tag{1}$$

where

t	is time, hours or seconds;
$V_{\text{gas}}(\text{t})$	is total volume of tracer gas in a zone at time “t” (= $\iiint_V c\left(x,t\right)dV$) (m^3);
x	is location in a zone;
$C(x, t)$	is concentration at “t”, “x” in a zone (m^3/m^3);
$Qv(t)$	is ventilation rate at “t” (m^3/h);
$C_{\text{E}}(t)$	is average exhaust concentration at “t” (m^3/m^3).

NOTE Formula (1) assumes that indoor-outdoor air density difference, mostly resulting from temperature difference can be neglected.

3.2.2 2-point decay method

With the concentration in an effective mixed zone continuously made uniform, the time-mean air charge rate is calculated from the measurement start point to the end point. It is not necessary for the specific airflow rate to be constant during measuring.

The following equation is established from the above conditions.

$$V_{\text{gas}}(t) = V_{\text{emz}} \cdot C(t)$$

$$C_{\text{E}}(t) = C(t) \tag{2}$$

where

$C(t)$	is concentration in an effective mixed zone (uniform distribution) at t (m^3/m^3);
V_{emz}	is volume of an effective mixed zone (no time changes are assumed) $[= \iiint_V c\left(x,t\right)dV \,/\, c_{\text{E}}\left(t\right)]$ (m^3).

Formula (1) and Formula (2) provide Formula (3) to give Formula (4).

$$\int_{t1}^{t2} \frac{dC}{C\left(t\right)} = -\int_{t1}^{t2} \frac{Q\left(t\right)}{V_{\text{emz}}} dt \tag{3}$$

$$\overline{N} = \frac{1}{t2 - t1} \log_e \frac{C\left(t_1\right)}{C\left(t_2\right)} \tag{4}$$

where

t	is time (t_1: Measurement start point, t_2: Measurement end point) (h);
$\overline{N}$	is time-mean specific airflow rate $\left(= \frac{1}{t2 - t1} \int_{t1}^{t2} \frac{Q\left(t\right)}{V_{\text{emz}}} dt\right)$ (1/h).

Based on the measured concentration data of two different time points, the time-mean specific airflow rate is calculated for that period. During the measurement period the concentration in the effective mixed zone must be uniformly maintained. It is necessary for the accurate measuring of specific airflow rate that the difference in concentration between the measurement start point and end point be sufficiently greater than the concentration measurement error.

3.2.3 Multipoint decay method

Specific airflow rate is calculated when the concentration distribution in an effective mixed zone is maintained uniform and the ventilation rate does not fluctuate over time.

Formula (5) is obtained when the ventilation rate in Formula (3) is made constant and the equation is transformed.

$$\log_\mathrm{e} C(t) = \log_\mathrm{e} C(t_1) - N(t - t_1) \tag{5}$$

where N is specific airflow rate (h).

Specific airflow rate is calculated by applying the measured data of concentration using the least square method to a straight line shown in Formula (5). The precondition that specific airflow rate does not fluctuate over time is confirmed when $\log_\mathrm{e} C(t)$ is plotted against t and there is a linear relationship. Lack of a linear relationship indicates that ventilation rate is not constant, so the specific airflow rate obtained using this method is not the time-mean specific airflow rate. In this instance the 2-point decay method should be applied.

3.2.4 Step-down exhaust concentration method

The specific airflow rate is calculated when the average exhaust concentration is measurable, the distribution of the concentration in an effective mixed zone at the measurement start point is uniform, and the ventilation rate does not fluctuate over time. It can also be applied when the concentration is distributed after the start of measuring. Simultaneous measurement with the mean age of air distribution is possible.

When time is integrated up to ∞ by making constant the ventilation rate in Formula (1), Formula (6) is obtained

$$\int_{t_1}^{\infty} dV_\mathrm{gas}(t) = Qv\int_{t_1}^{\infty} C_\mathrm{E}(t)\,dt \tag{6}$$

If the concentration in an effective mixed zone is made uniform at the measurement start point, the result is

$$V_\mathrm{gas}(t_1) = V_\mathrm{emz} \cdot C(t_1)$$

and after sufficient time has elapsed the result is

$$V_\mathrm{gas}(\infty) = 0$$

which provides Formula (7).

$$N = \frac{C(t_1)}{\int_{t_1}^{\infty} C_\mathrm{E}(t)\,dt} \tag{7}$$

That is, the reciprocal value to the mean local age of air in the exhaust outlet becomes the specific airflow rate in the room. In the event of multiple exhaust outlets, the average exhaust concentration weighted depending on the exhaust airflow rate at each exhaust outlet is used.

NOTE Refer to Annex F if the difference between the exhaust temperature and room temperature cannot be ignored.

3.2.5 Pulse method

The ventilation rate is calculated when the average exhaust concentration is measurable and the ventilation rate does not fluctuate over time. The tracer gas volume supplied at the measurement start point needs to be accurately evaluated, but the concentration distribution in a zone does not need to be uniform.

In this instance, in Formula (6), $V_{gas}(t_1)$ is already known, and after sufficient time has elapsed, the result is

$$V_{gas}(\infty) = 0$$

which provides Formula (8).

$$Qv = \frac{V_{gas}(t_1)}{\int_{t_1}^{\infty} C_E(t)\,dt} \tag{8}$$

where $V_{gas}(t)$ is tracer gas volume (= supplied tracer gas volume) retained in the room at the measurement start time t_1 (m^3).

NOTE For the tracer gas volume, a value of exhaust temperature converted into density is used.

3.3 Continuous dose method

3.3.1 General

With the tracer gas being supplied continuously in the zone, the ventilation rate is measured by the amount of the dosage and concentration measurement data. If a measurement method that requires uniformly distributed concentration throughout the effective mixed zone with the tracer gas supplied is used, it normally requires multiple concentration monitoring points to verify the uniform distribution of the concentration. The amount of the tracer gas supplied increases as the measurement time extends, however, the method can be applied to measurement that extends for a long time. The passive measurement that uses carbon dioxide generated by exhalation of residents as the tracer gas, is also one of the continuous concentration methods.

The basic equation that can be commonly applied to the methods is as follows:

$$\frac{dV_{gas}(t)}{dt} = m(t) - C_E(t)Qv(t) \tag{9}$$

where $m(t)$ is dosage of tracer gas at “t” (m^3/h).

3.3.2 Average inverse concentration method

The time-mean specific airflow rate is calculated from the start to the end of measuring, where the concentration distribution in an effective mixed zone is maintained uniform. It is not necessary for the ventilation rate to be constant during measuring, but the instantaneous concentration during measurement, the instantaneous dosage of tracer gas, and the volume of the effective mixed zone are required.

The following equation is established based on the assumed conditions.

$$\begin{aligned} V_{gas}(t) &= V_{emz} \cdot C(t) \\ C_E(t) &= C(t) \end{aligned} \tag{10}$$

where

$C(t)$ is concentration in an effective mixed zone (uniform distribution) at t (m^3/m^3);

V_{emz} is volume of an effective mixed zone (m^3).

Formula (9) and Formula (10) provide Formula (11), which gives Formula (12).

$$V_{emz} \int_{t_1}^{t_2} \frac{dC}{C(t)} = \int_{t_1}^{t_2} \frac{m(t)}{C(t)} dt - \int_{t_1}^{t_2} Qv(t)\,dt \tag{11}$$

$$\overline{Qv} = \overline{\left[\frac{m}{C}\right]} + \frac{V_{\text{emz}}}{t_2 - t_1}\log_e\frac{C\left(t_1\right)}{C\left(t_2\right)} \tag{12}$$

where

t is time (t_1: Measurement start point, t_2: Measurement end point) (h);

$\overline{Qv}$ is time-mean specific airflow rate $\left(= \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} Qv\left(t\right)dt\right)$ (m^3/h);

$\overline{\left[\frac{m}{C}\right]} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2}\frac{m\left(t\right)}{C\left(t\right)}dt$ (m^3/h).

$\overline{(m/C)}$ is in general different to $(\overline{m}/\overline{C})$. When the tracer gas dose during measuring is constant and is m, $\overline{(m/C)}$ is replaced by $m\overline{(1/C)}$. When there is sufficient measuring time, the effect of the second term on the right side in Formula (12) is diminished, so in such circumstance this method may be applied also to instances where sufficient accuracy is not obtained for estimation of the volume of the effective mixed zone. Immediately after the start of tracer gas dosing, the concentration is generally small, which tends to have a strong effect of delaying the response to the concentration measurement system including the sampling system, and causing errors in the measured concentration value, so at this point data must not be used for calculating the ventilation rate.

3.3.3 Average concentration method

The ventilation rate that does not fluctuate over time when the concentration distribution in an effective mixed zone has been made constantly uniform is calculated. When there is sufficient measuring time, calculation is possible using only the time-mean tracer gas dose and time-mean concentration during the measuring.

Once Formula (10) is supposed for Formula (9), integration in the measuring time provides Formula (13).

$$\int_{t_1}^{t_2} C\left(t\right)Q\left(t\right)dt = \int_{t_1}^{t_2} m\left(t\right)dt - V_{\text{emz}}\int_{t_1}^{t_2} dC \tag{13}$$

If $Q_v(t) = Q_v$ without the ventilation rate changing over time, Formula (14) is obtained.

$$Q = \frac{\overline{m}}{\overline{C}} - \frac{V_{\text{emz}}}{t_2 - t_1}\left[\frac{C\left(t_2\right) - C\left(t_1\right)}{\overline{C}}\right] \tag{14}$$

where

$\overline{m} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} m\left(t\right)dt$ (m^3/h);

$$\bar{C} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} C(t)\,dt \quad (\mathrm{m}^3/\mathrm{m}^3).$$

When there is sufficient measuring time, the effect of the second term in Formula (14) is relatively minor and can be ignored. However, in the event that the ventilation rate changes over time, if the mean value theorem in Formula (13) were applied, Formula (15) would be obtained.

$$Qv(\xi) = \frac{\bar{m}}{\bar{C}} - \frac{V_{\mathrm{emz}}}{t_2 - t_1}\left[\frac{C(t_2) - C(t_1)}{\bar{C}}\right], \quad t_1 \le \xi \le t_2 \tag{15}$$

The ventilation rate obtained in Formula (15) provides the ventilation rate at a time during measuring, but it does not end up as the time-mean ventilation rate. The ventilation rate obtained from Formula (15) is suitable in cases where the purpose is to simulate generation of the contaminating substance in the room using tracer gas dosing, and estimate the time-mean concentration to which the inhabitant is exposed. Therefore, when it is possible to measure the instantaneous concentration and instantaneous dosage of tracer gas for the purpose of measuring the mean ventilation rate, the inverse concentration method should be used.

3.3.4 Stationary concentration method

The ventilation rate is calculated when the ventilation rate does not fluctuate over time, under conditions in which the average exhaust concentration is measurable. It can also be applied when concentration in a zone is distributed.

Formula (16) is obtained when a stationary state is reached and there are no temporal changes in Formula (9).

$$Qv = \frac{m}{C_{\mathrm{E}}} \tag{16}$$

where

m is tracer gas dose (m^3/h);

C_{E} is average exhaust concentration (m^3/m^3);

That is, the ventilation rate is obtained by dividing the constant concentration by the tracer gas dose.

3.4 Constant concentration method

In order to make the concentration in an effective zone regularly constant at targeted value, the tracer gas dose should be controlled and the ventilation rate evaluated from the dosage of tracer gas. Even when the internal air is not uniformly mixed, by establishing multiple tracer gas dose points and measuring points, it is possible to make the concentration distribution uniform. Special equipment is necessary to control the tracer gas dose.

The basic equation to be applied is as follows (background concentration has been set at 0 for ease of understanding).

$$0 = \frac{dV_{\mathrm{gas}}(t)}{dt} = m(t) - C_{\mathrm{target}}Q(t) \tag{17}$$

where