VENTILATION:
FLOW RATE, TOTAL EFFECTIVE –
BY SINGLE ZONE APPROXIMATION

Key words: Ventilation, flow rate, total effective flow rate

1. SCOPE
The purpose of this standard is to provide a description of a technique for measuring the total effective (harmonic time average) ventilation flow rate in a building using a single zone approximation.

2. FIELD OF APPLICATION
The method can be applied to occupied or empty buildings. This method should only be used in spaces in which the single zone approximation can be applied. Most single-level residential buildings or flats in apartment buildings meet this criterion. The method is suitable for buildings in which the ventilation system runs continuously, or buildings which do not have any mechanical ventilation system.

3. REFERENCES

4. DEFINITIONS
Harmonic time average: The harmonic time average of a series of values is the inverse of the time average of the inverses of the values. For example, if the air flow rate at time t is \( q_{et} \), the harmonic time average of the air flow rate \( \bar{q}_e \) is:

\[
\bar{q}_e = \frac{1}{\frac{1}{T} \int_0^T \left( \frac{1}{q_{et}(t)} \right) dt} = \frac{1}{N \sum_{t=1}^{N} \left( \frac{1}{q_{et}} \right)}
\]

Effective ventilation flow rate: Ventilation is needed to control the concentrations of contaminants in a space. Ventilation flow rate usually varies with time. The effect of a temporally varying flow rate on the concentrations is given by the effective ventilation flow rate. It is defined as the harmonic time average flow rate of outdoor air entering the measured space. The average concentration of a contaminant during the study period can be obtained by dividing the emission of the contaminant by the effective ventilation flow rate during the period.

Single zone approximation: In single zone approximation it is assumed that it is possible to obtain a single representative value of the concentration of the tracer gas leaving the space. This means that all air from the measured space is exhausted through a single exhaust outlet, or that the air in each of the exhaust outlets has the same concentration of the tracer gas. The single zone approximation is satisfied if there is uniform mixing of air and tracer gas within the measured space. Uniform mixing is, however, a special case of single zone approximation, not a prerequisite for it.

5. SAMPLING
Selection of houses to be measured (in this case irrelevant).

6. METHOD OF TEST
6.1 Principle
The total effective ventilation flow rate \( q_e \) is measured by arranging a known constant tracer emission rate \( E \) into the measured space. The flow of untraced air from outside into the measured space dilutes the tracer concentration in the space towards a quasi-equilibrium state. The time average of the concentration of the air leaving the space at each exhaust point.
If all the air entering the space is outdoor air, the total effective ventilation flow rate is determined as follows in the single zone approximation (assuming negligible background concentration):

\[
q_e = \frac{E}{\sum_{n=1}^{N} C_n} \text{ [m}^3\text{h}^{-1}] \tag{2}
\]

The concentration of the air leaving the space can, in cases of good mixing, be estimated by measuring the average concentration in the space. It should be noted that, if the air flow rate varies with time, the total effective ventilation flow rate is not the same as the average of the instantaneous flow rates during the measurement period \(q_{avg}\).

\[
q_e = \frac{1}{T} \int_0^T q_e(t) \, dt = q_{avg} \tag{3}
\]

### 6.2 Apparatus

**The tracer sources:**

The purpose of tracer sources is to create a constant emission rate of tracer into the measured space. One possible method of achieving this is to seal a flask of liquid tracer with a membrane or cap which is permeable to the tracer molecules. An example of a permeation tracer source is shown in Fig. 1a. Another possible way to achieve this is the use of a diffusion tube, which is a container equipped with a capillary tube. An example of a diffusion source is in Fig. 1b.

The amount of tracer gas emitted during the measurement period must be known within the accuracy of ±8%. One way to achieve these data is weighing the sources before and after the measurement. Weighing is not needed if the emission rate of individual sources is known within ±5% and appropriate temperature correction is made.

**The diffusive adsorption samplers:**

The purpose of the samplers is to measure the time average concentration of the tracer gas in the space. This is done by creating a tracer flow from the ambient air into the sampling material, and by trapping the tracer molecules into the sampling material. A glass or a steel tube packed with an adsorbent is generally used. The adsorbent should have a large enough surface area to maintain a practically zero concentration compared to the ambient. The net flow of tracer molecules into the adsorption material is now proportional to the tracer concentration in the air (Fick’s first law of diffusion). An example of a diffusive sampler is shown in Fig. 2.

The samplers should meet the following requirements:

* reproducibility of manufacture better than 5%,
* the equivalent air sampling rate should be independent of the tracer concentration and constant at typical concentrations, room temperatures and air velocities.
The analysis system:

The purpose of the analysis system is to measure the amount of tracer compound collected into the sampler. A suitable analysis system based on gas chromatographic separation can consist of the following components:

* a desorption unit, which can either be based on thermal desorption or liquid extraction,
* a precolumn, which is used to separate the lightweight compounds from the sample,
* a main column, which is used to separate the tracer compounds to the detector,
* a back-flush system, which is used to separate the heavy-weight compounds from the sample, and
* an electron capture detector, which measures the amounts of tracer(s) in the sample.

The analysis system should meet the following requirements:

* reproducibility better than 5 %,
* accuracy of calibration better than 5 %
* the eventual drift of the analysis should be taken into account by e.g. using reference samples at regular intervals.

The analysis laboratory should have accomplished a verified quality assurance programme.

6.3 Preparation of test samples

Either reusable or discard-after-use samplers can be used. Reusable samplers must be regenerated before the measurement in order to remove all possible contaminants. Unused samplers of the discard-after-use-type should be prepared in the laboratory before they are taken into the field.

The sources and samplers should be stored apart from each other, preferably in separate buildings or draught cabins, so that the risk of sampler contamination is minimized. During short transportation, the sources and samplers should be kept in separate containers. Unexposed control tubes should be used in order to reveal unintentional contamination during storage and transportation.

6.4 Procedure

The deployment of sources:

The principle in the deployment of tracer sources is to mark all the air in the space before it leaves the space. The following main principles should be used:

* one source is placed in each room with direct inflow of outdoor air. This usually means excluding closed rooms with an exhaust only,
* sources should be placed according to the assumed rates of direct outdoor air flow into each room. In the field, the floor area is usually the only a priori estimate of the air flow rate, e.g. a room with twice the area of the smallest room should have twice the amount of tracer sources,
* the sources should be placed near (0.5 - 1.0 m) outside walls or air supply devices but away from warm or cold surfaces and direct solar radiation.

The deployment of samplers:

The samplers should be placed so that the air they sample is representative of the air leaving the measured space. If there is a limited number of exhausts, the best way to achieve this is to place the samplers near the exhausts, but not in the ducts. With an unknown number of exhausts, e.g. in natural ventilation, the samplers should be placed in the middle of the room(s). The following principles should be used:

* one sampler at each exhaust point with a minimum of three samplers per measurement,
* the samplers should be placed near the exhausts or, if they are not known, or the number of exhausts is less than three, near the centre of the occupied space,
* the distance between a sampler and a source should be at least 1 m.

6.5 Expression of results

The concentration of the air leaving the object is calculated by taking the average of the concentrations measured near the exhausts. If the exhausts are not known, the concentration of the air leaving the object is estimated by calculating the average of all concentrations measured in the space. The total effective ventilation flow rate is calculated using Equation 2. This flow rate is the primary result of the measurement. However, sometimes it is more useful to express the results proportional to the volume of the measured space (V). The average turnover time (τt) which is the characteristic time for a contaminant to approach steady state, is calculated as follows:

\[
\tau_t = \frac{3600 \cdot V}{q_e} = \left[ \frac{m^3}{m^3/h} = h \right]
\]

The effective specific air flow rate (ne) is calculated as follows:

\[
n_e = \frac{q_e}{3600 \cdot V} \left[ \frac{m^3/h}{m} - \frac{1}{h} \right]
\]

6.6 Accuracy

The estimate of the total inaccuracy (s) is calculated as follows:

\[
s = \sqrt{s^2_{sour} + s^2_{samp} + s^2_{mix} + s^2_{anal}}
\]
where

\[ s_{\text{sour}} \] is inaccuracy of sources (max 0.08)
\[ s_{\text{sampl}} \] inaccuracy of sampling mass flow rate (max. 0.05)
\[ s_{\text{mix}} \] relative standard deviation of the concentration (max. 0.20)
\[ s_{\text{anal}} \] inaccuracy of analysis (reproducibility + drift + uncertainty of calibration gas) (max. 0.08)

The inaccuracies \( s_{\text{sour}}, s_{\text{sampl}}, \) and \( s_{\text{anal}} \) must be based on documented tests carried out before the measurements by the manufacturer of the instruments and the provider of analysis services. The inaccuracy of the mixing \( s_{\text{mix}} \) is assessed after the measurement by taking the relative standard deviation of the measured concentrations.

The maximum allowable estimate of error is 0.24 when the given maximum values are used. An estimate of error higher than this usually indicates false application of the single zone approximation. In these cases, the concentrations at each measurement point should be studied carefully in order to assess the actual pattern of ventilation flows in the measured space. In certain limited cases it may be possible to improve the accuracy of the measurement by taking only selected concentration measurements into account. However, this requires good knowledge of the ventilation phenomenon in the space. In most of the cases with too high an estimate of error, the only way reliable results can be obtained is to repeat the measurements using a better approximation of the air flows within the space.

6.7 Test report

The test report shall contain:

**During the field measurement:**

a) address
b) house type
c) type of ventilation system
d) sketch of the measurement set-up
e) area and room height and volume
f) codes of sources and samplers used
g) start and end times
h) indoor temperature
i) outdoor temperature

**After the analysis of the results**

j) total effective ventilation flow rate
k) effective specific air flow rate
l) error estimates

**Other data:**

m) the name and address of the analysis laboratory.