INDOOR AIR QUALITY:
MEASUREMENT OF CO₂

Key words: Test method, ventilation, indoor air quality, effectiveness, carbon dioxide

1 SCOPE
This method determines the overall function of the ventilation system by measuring the carbon dioxide, CO₂ generated by the occupants.
The primary intention is to measure the room air concentration, C_R with one gas analyser. However by using two or more gas analysers the effectiveness or local ventilation index can also be obtained.

2 FIELD OF APPLICATION
This method is applicable to any type of building and ventilation system.

3 REFERENCES
NT TECHN REPORT 204. Indoor Climate Problems.

4 DEFINITIONS
Outdoor air concentration, C_O [ppm]
Supply air concentration, C_S [ppm]
Exhaust air concentration, C_E [ppm]
Room air concentration, C_R [ppm]
Supply air concentration differential, ΔC_S [ppm]
ΔC_S = C_S - C_O
Exhaust air concentration differential, ΔC_E [ppm]
ΔC_E = C_E - C_O
Room air concentration differential, ΔC_R [ppm]
ΔC_R = C_R - C_S
Local ventilation index, ε_P [%]

ε_P = ΔC_E / ΔC_R * 100

Supply air temperature, T_S [K]
Room air temperature, T_R [K]
Supply air temperature differential, ΔT_S [K]
ΔT_S = T_S - T_R.

5 SAMPLING
See 6.4.

6 METHOD OF TEST
6.1 Principles
The concentration of CO₂ is measured in the ventilated space during the occupancy. Activities in the room are registered. The sampling position is located at breathing height usually in the middle of the room. Large rooms may, however, require one sampling point for each 100 m².

6.2 Apparatus
6.2.1 Base equipment
- Direct reading gas analyser
- Calibration gas
- Tubing of non adsorbing material (e.g. nylon, polyethylene or teflon)
- Stand for the measuring point.

6.3 Preparation
Room
The test is made with doors and windows closed. The number of occupants has to be constant during the test period.

Gas analyser
The gas analyser must be calibrated with calibration gas. The calibration is usually made at two points, 0 and 1000 ppm. Before measurement is started, the gas analyser must have reached its working temperature.
Determination of sampling positions

Outdoor air concentration, CO - is measured close to the intake of the ventilation system at a position where exhaust air can not cause any effect.

Supply air concentration, CS - is measured in the supply air terminal device in the room.

Exhaust air concentration, CE - is measured in the exhaust air terminal devices or in the duct from the room.

Room air concentration, CR - is measured at breathing height, 1.1 m or 1.7 m from the floor in the ventilated space. If nothing else is stated only one point is chosen at the height of 1.1 m from the floor in the middle of the room.

A sketch of the room and the sampling positions shall be made.

No measuring point for CR is located closer than 2 m in front and 1 m on each side of a person. This may cause a rearrangement of some occupants in the ventilated space as shown in Figure 1.

Simultaneous measurements

Registration of number of persons and their activities
Registration of supply-, room- and exhaust temperature
Registration of supply- and exhaust airflow

6.4 Procedure

The amount of return air into the supply air is checked initially by measuring the CO₂ concentration in the outdoor and supply air.

The supply air temperature, Ts, and the average supply air concentration, CS, are preferably measured simultaneously with the room air concentration. If this is not possible these measurements can be approximated by two measurements, measured within 10 minutes before and after the room air concentration measurements.

The measurement of room air temperature, TR, and the room air concentration, CR, is made during at least 15 minutes after the CO₂ level has reached steady state conditions. If the occupancy is interrupted before steady state conditions are achieved then samples taken during the last 15 minutes of occupancy should be used.

The exhaust air concentration, CE, is measured simultaneously with the room air measurement.

Minimum sampling interval for CR and CE is 1 measurement per minute.

6.5 Expression of results

All concentrations shall be expressed in volume parts per million, [ppm]. The supply air concentration differential is calculated as:

\[ \Delta CS = CS - CO \]

The room air concentration differential is expressed as the average of 15 minutes of measurements as:

\[ \Delta CR = CR - CS \]

where

\[ CR_i = \text{Room air concentration, reading number } i \]
\[ n = \text{Total number of concentration readings during 15 minutes} \]

The standard deviation of room air concentration is expressed as:

\[ s_R = \sqrt{\frac{\sum (CR_i - \bar{CR})^2}{(n-1)^2}} \]

The exhaust air concentration differential is expressed as the average of 15 minutes of measurements as:

\[ \Delta CE = CE - CS \]

where

\[ CE_i = \text{Exhaust air concentration, reading number } i \]
\[ n = \text{Total number of concentration readings during 15 minutes} \]

The standard deviation of room air concentration is expressed as:

\[ s_E = \sqrt{\frac{\sum (CE_i - \bar{CE})^2}{(n-1)^2}} \]

The average local ventilation index is calculated as

\[ \epsilon_p = \frac{\Delta CE}{\Delta CR} \times 100 \]
6.6 Inaccuracy

The inaccuracy can be divided into the following two components:
- Inaccuracy of gas analyser, \( m_G \) (at a 95% confidence level)
- Fluctuation of CO\(_2\) concentration, \( m_c \), \( m_c = 2s \)

The total inaccuracy of each measuring point, \( m \) [ppm], is then calculated as:

\[
m = \sqrt{m_G^2 + m_c^2}
\]

The total inaccuracy of each concentration differential, \( m_\Delta \) [ppm], is calculated as:

\[
m_\Delta = \sqrt{2 \cdot m_G^2 + m_C^2}
\]

The total inaccuracy of the average local ventilation index, \( \Delta \varepsilon_p \) [%] is then calculated as:

\[
\Delta \varepsilon_p = \sqrt{\left( \frac{m_{CE}}{\Delta C_e} \right)^2 + \left( \frac{m_{CR}}{\Delta C_R} \right)^2} \cdot 100
\]

The inaccuracy of the gas analyser has to be within ±150 ppm.
The fluctuation of concentration is mainly dependent on the airflow pattern in the room and will usually be within 0-10 %.

6.7 Test report

The test report shall contain the following information.

a) Name and address of the testing company
b) Identification number of the test report
c) Name and address of the organisation or the person who ordered the test
d) Purpose of the test
e) Method of sampling and other circumstances (date and person responsible for the sampling)
f) Name or identification of the tested object
g) Date of test
h) Test method
i) Condition of the test specimens, environmental data during the test (temperature, pressure, humidity, etc.)
j) Identification of the test equipment and instruments used
k) Any deviations from the test method
l) Test results (SI units)
m) Uncertainty of the test result
n) Date and signature.
EXAMPLE OF MEASUREMENT

INDOOR AIR QUALITY - CO₂ MEASUREMENT

Number of occupants: 25
Rate of exhaust airflow: 180 l/s
Dimension (b*l*h): 7*8*2.7 m
Volume: 151 m³
Supply air temperature: 18 °C
Room air temperature, 1.1 m: 21 °C
Exhaust air temperature: 22 °C
Type of activity: School during 40 minutes
Type of ventilation system: Mixed ventilation

Results:

From the measured values we calculate the mean values during the last 15 minutes:

\[
\begin{align*}
\bar{C}_O &= 350 \text{ [ppm]} \\
\bar{C}_E &= 410 \text{ [ppm]} \\
\bar{C}_{R1.1m} &= 960, s_R = 27 \text{ [ppm]} \\
\bar{C}_{R1.7m} &= 970, s_R = 27 \text{ [ppm]} \\
\bar{C}_E &= 1000, s_E = 25 \text{ [ppm]}
\end{align*}
\]

The results can also be expressed as:

\[
\begin{align*}
\Delta C_O &= 410 - 350 = 60 \text{ [ppm]} \\
\Delta C_{R1.1m} &= 960 - 410 = 550 \text{ [ppm]} \\
\Delta C_{R1.7m} &= 970 - 410 = 560 \text{ [ppm]} \\
\Delta C_E &= 1000 - 410 = 590 \text{ [ppm]}
\end{align*}
\]

The inaccuracy:

The total inaccuracy of the measuring point is then calculated as:

\[
m = \sqrt{m_G^2 + m_C^2}
\]

Gas analyser:

\[
m_G = \pm 100 \text{ [ppm]}
\]

Fluctuation of CO₂ concentration is:

\[
m_C = 2\cdot s
\]

The total inaccuracy for the room air concentration, 1.1 and 1.7 m is:

\[
m_{CR} = 2\cdot 27 = 54 \text{ [ppm]}
\]

\[
m_R = \sqrt{100^2 + 54^2} = 113 \text{ [ppm]}
\]

The total inaccuracy for the exhaust air concentration is:

\[
m_{CE} = 2\cdot 25 = 50 \text{ [ppm]}
\]

\[
m_E = \sqrt{100^2 + 50^2} = 112 \text{ [ppm]}
\]

The total inaccuracy for the 100 m air concentration differential is:

\[
m_{AR} = \sqrt{2\cdot 100^2 + 54^2} = 151 \text{ [ppm]}
\]

The total inaccuracy for the exhaust air concentration differential is:

\[
m_{AE} = \sqrt{2\cdot 100^2 + 50^2} = 150 \text{ [ppm]}
\]

The total inaccuracy of the average local ventilation index is then:

\[
\Delta \varepsilon_{p1.1m} = \sqrt{\frac{150^2}{590} + \frac{151^2}{550}} = 37 \% \text{ of measured } \varepsilon_{p1.1m}
\]