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LOCAL MEAN AGE OF AIR

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1. SCOPE

The scope of the method is to determine the local mean age of air at an arbitrary point in a ventilated space. The theoretical background of the method is described in reference /2/. By knowing the mean age of the air in a point we can:

* Determine if the space surrounding the measuring point is well ventilated or not. That is whether the region is "stagnant" or not.
* Determine the concentration at the measuring point from a dynamically passive contaminant (= follows the air motions) generated at each point in the room with the same and constant release rate.

By measuring the mean age of air at several points we can follow the distribution of the ventilation air within the space.

2. FIELD OF APPLICATION

The method is primarily applicable to spaces served by mechanical ventilation.

3. REFERENCES

The titles of the publications referred to are listed in ANNEX 3.

4. DEFINITIONS

4.1 Nominal time constant, τ_n

The nominal time constant is defined as the volume of the ventilated space divided by the volumetric flow rate of out-door air entering the ventilated space through the part of the building envelope enclosing the actual space. The nominal time constant has units of [s] but is usually expressed in [h].

4.2 The local mean age. $\bar{\tau}$

The age of an air "molecule" at an arbitrary point and instant of time is defind as the time elapsed since it entered the room. The local mean age of air at an arbitrary point is the mean age of the "molecules" passing that point. It is expressed in the same units as the nominal time constant. When the mixing of the supplied air is complete within the space then the local mean age at each point is equal to the nominal time constant. At a stagnant region the local mean age is larger than the nominal time constant, τ_n.

5. SAMPLING

The sampling time-interval at each measuring point should be less than 3 minutes.

6. METHOD OF TEST

6.1 Principle

The test is accomplished by liberating tracer gas into the actual space and letting it decay without disturbing the air movements created by the ventilation system and other natural sources. The tracer gas concentration is continously recorded in the point(-s) of interest. From the concentration readings the area under the decay curve is calculated. From the initial concentration and the area under the curve the local mean age is then determinated.

6.2 Apparatus

6.2a Equipment

* Cylinder with tracer gas. A number of tracer gases and their properties are listed in reference /1/. The cylinder should be provided with a reduction valve and manometer.
* Gas analyzer for continous operation (e.g. infrared analyzer).
* Tubing of non absorbing material (e.g. nylon or polythene) for suction and/or injection of gas.
* Stop-watch for measuring the recorder´s chart speed during the test period.
* Propeller (mixing) fans and/or fibre-board sheets.

6.2b Additional equipment for simultaneous measuring in several points

* Manifold of valves (e.g. magnetic valves) for selection of different sampling points.
* Pump (purging pump) that continously sucks air from the sampling tubes when they are not connected to the analyzer. This is needed to ensure that we obtain a "fresh" sample at each time the tube is connected to the analyzer.

Analyzer

Before measuring starts the gas analyzer much have reached its working temperature which depending upon analyzer´s initial temperature, may require a few hours.

Mixing fans

As a rule of thumb for an ordinary house, two mixing fans are placed in the largest room and one mixing fan in each of the other rooms.

6.4 Procedure

* The analyzer´s pump is started up and a sample of the ambient air is taken. The analyzer is zero adjusted.
* Tracer gas is released into the actual room. This is suitable done intermittently so that too much gas is not released. The amount of gas to be discharged into the space is determinated by:
  a) The allowable threshold limit for the gas used. The initial concentration must not exceed the threshold limit value.
  b) The sensitivity of the gas analyzer.
* With the propeller fans and/or the sheets as paddles, the tracer gas is mixed to an uniform concentration, in the whole flat or in the single room in the office.
* The mixing fans are turned off and/or the "paddling" is stopped.
* The decay of the tracer gas concentration is continously recorded.

A certain minimum measuring time is needed to ensure that we are in the region of exponential decay, see ANNEX 1. when the measurements are stopped. The minimum measuring time, τ_{min}, can be estimated to:

	$\tau_n \leq 0.5$ [h]	$\tau_n > 0.5$ [h]
τ_{min} [h]	$1.2 \times \tau_n$	$1.5 \times \tau_n$

τ_n = the nominal time constant

* After the measurements have stopped the zero drift of the analyzer is controlled by taking a sample of the ambient air. Ir-analyzers are sensitive to the water-vapour content in the air. Therefore a change in the humidity during the measuring period may cause an off-set error.

6.5 Expression of results

The local mean age, $\bar{\tau}$, is calculated from the concentration readings as:

$$\bar{\tau} = \frac{\left(\sum_{i=0}^{M} C_i\right)\Delta\tau + \frac{C_M}{\lambda_e}}{C_0}$$

C_i	= Concentration reading number i
C_0	= Initial concentration (= first concentration reading)
C_M	= Last concentration reading
M	= Number of concentration readings
$\Delta\tau$	= Sampling interval
λ_e	= The slope in the exponential decay region see ANNEX 1
τ_i	= Time of reading number i
τ_M	= Total measuring time, $\tau_M = M \cdot \Delta\tau$

The denominator in the above expression is the area under the concentration curve. The second term in the denominator is an extrapolation term (residual area) which consider the "tail" of curve, see figure 1.

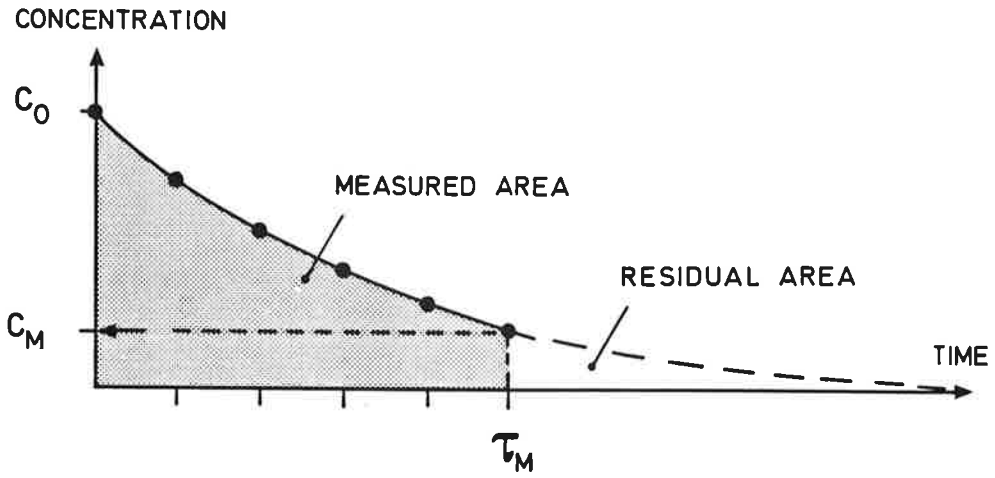

Figure 1. Measured and residual area

6.6 Accuracy

The accuracy has been determinated to ± 5%.

MINIMUM TIME OF MEASUREMENT

Figure 2 shows a typical picture of the tracer gas concentrations as a function of time on a linear/logarithmic plot. At the beginning we have a region with a non-exponential decay, but after a certain period of time the gas concentration is decaying exponentially, i.e. the curve is a straight line.

The measurements may be stopped when the concentration is decaying exponentially. The conditions on the magnitude of the minimum time of measurement given under the heading 6.4 are founded on experience and will normally quarantee that we are in the "region of exponential decay" when the measurements are stopped.

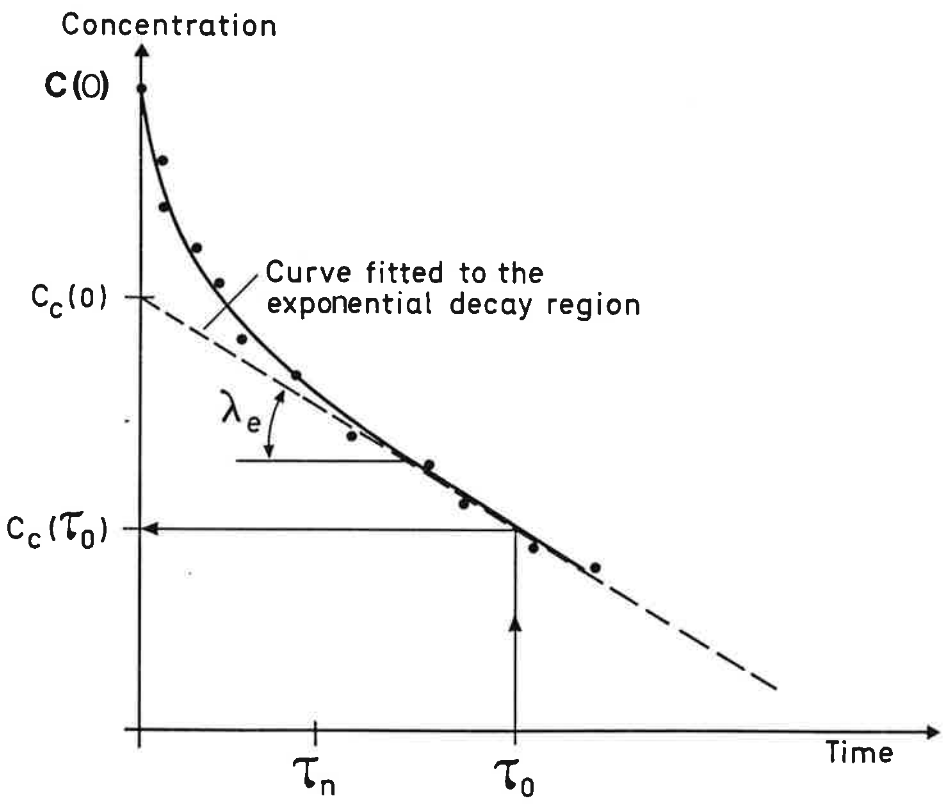

Figure 2. Ln concentration versus time. λ_e is the slope in the exponential decay region.

By a least-square fit a straight line is fitted to the straight part of the decay curve.

The slope, λ_e, of the straight line is obtained from two arbitrary chosen "concentrations" $C_c(0)$ and $C_c(\tau_o)$ on the line:

$$\lambda_e = \frac{1}{\tau_o} \ln \frac{C_c(0)}{C_c(\tau_o)}$$

where τ_o is the time interval between the selected concentrations.

The slope, λ_e, is used to calculate the "extrapolation" term that consider the tail of the decay curve.

ANNEX 2

EXAMPEL

A room with one extract duct.

Nominal time constant: τ_n = 0.25 (h) = 15 min.

Sampling interval: $\Delta\tau$ = 2.5 min.

Measuring time: τ_m = 55 min.

Monitored concentrations are given in the table below:

Reading No	C_i [ppm]
0	654
1	491
2	393
3	326
4	271
5	234
6	207
7	188
8	165
9	147
10	137
11	127
12	122
13	106
14	103
15	95
16	90
17	85
18	83
19	78
20	74
21	69
22	64

$\Sigma C_i = 4309$

In figure 3 are plotted the concentration readings versus time.

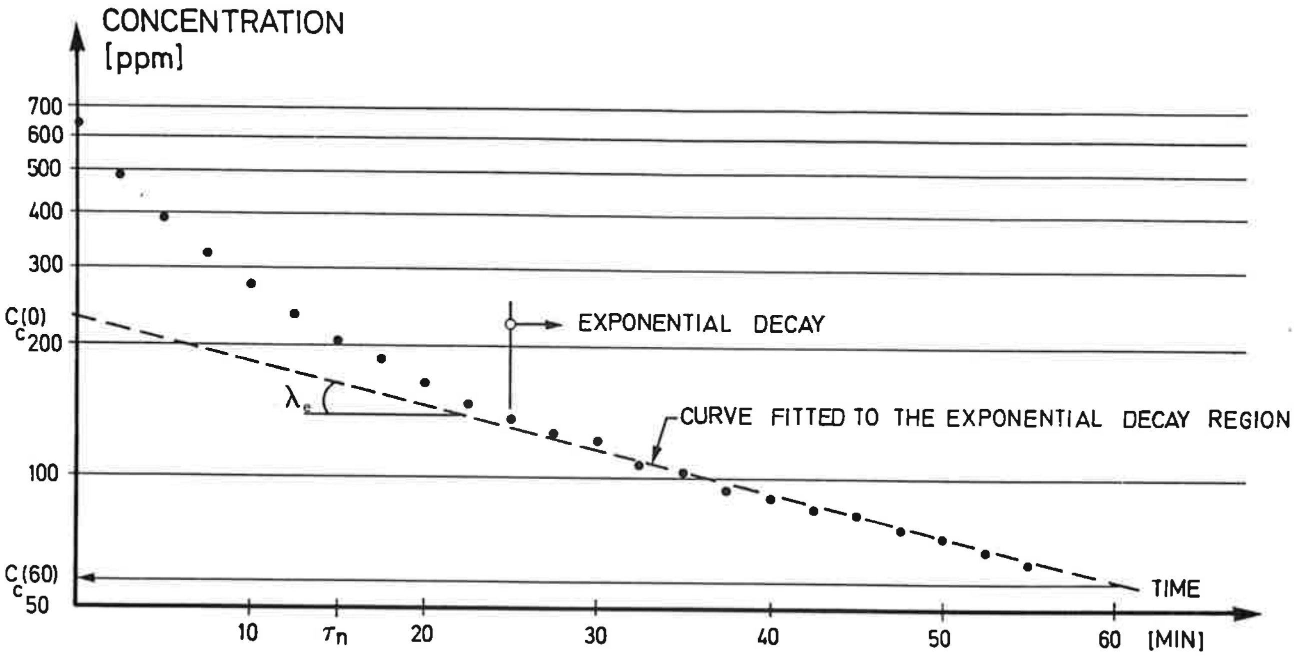

Figure 3. Ln concentrations versus time.

From the table below we obtain:

$$\left(\sum_{i=0}^{22} C_i\right)\Delta\tau = 4\ 309 \times \frac{2.5}{60} = 180 \text{ (ppm x h)}$$

From figure 3 we obtain the final slope, λ_e, of the decay curve.

$$\lambda_e = \frac{1}{\tau_o} \ln \frac{C_c(0)}{C_c(\tau_o)} = \frac{1}{1} \ln \frac{230}{59} = 1.36 \ (\frac{1}{h})$$

The "extrapolation" term becomes:

$$\frac{C_M}{\tau_e} = \frac{64}{1.36} = 47 \quad \text{(ppm x h)}$$

and finally the mean age of the air becomes:

$$\bar{\tau} = \frac{180 + 47}{654} \simeq 0.35 \quad [h]$$

ANNEX 3

REFERENCES

/1/ Kronvall, J., Airtightness measurements and measurement methods. D8:1980. Swedish Council for Building Research, Stockholm Sweden.

/2/ Sandberg, M. & Sjöberg, M., The Use of Moments for Assessing Air Quality in Ventilated Rooms. Building and Environment, Vol. 18, 1983.