nordtest method

NT VVS 047

Approved 1985-11

Appendix 3

BUILDINGS — VENTILATING AIR: MEAN AGE OF AIR

1. SCOPE

The scope of the method is to determine the room-average age of air in a ventilated space. To obtain the room-average age of air in the room it is only necessary to carry out measurements in the extract ducts. The theoretical background of the method is described in Reference /2/.

By knowing the mean-age of the air in the room we can:

a) Determine the time it takes, on an average, to replace (exchange) the air present in the room.

b) Determine if the ventilated space is well ventilated or if there are stagnant zones. The method, however, does not reveal where the stagnant zones are located. To locate the stagnant zones it is necessary to monitor the local mean-age of the air at several points in the ventilated space. This is described in NORDTEST method NT VVS 019.

c) Determine the room-average concentration from a dynamically passive contaminant (=follows the air motions) generated at each point in the room with the same and constant release rate.

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2. FIELD OF APPLICATION

The method is applicable to systems where the bulk of the air leaves the ventilated space at well defined points. This implies, in practice, that the method is in the main applicable to spaces served by mechanical ventilation.

3. REFERENCES

The titles of the publication referred to are listed in Annex 3.

4. DEFINITIONS

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 outdoor air entering the ventilated space through the part of the building envelope enclosing the actual space. The nominal time constant but units of [s] but is usually expressed in [h].

Room-average age $\langle\tau\rangle$

The age of an air molecule at an arbitrary point and instant of time is defined 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. The room-average age of the air is equal to the mean-age of all air present in the room. It is expressed in the same units as the nominal time constant. The theoretical lower limit of the room-average age occurs for piston flow and is equal to $\tau_n/2$. When the mixing of the supplied air is complete within the space, then the room-average age is equal to τ_n. Finally, when stagnant regions occur in the room, then the room-average age is larger than the nominal time constant, τ_n.

The time it takes to replace (exchange) the air in a room is equal to twice the room-average age of the air present in the room, i.e. $2\langle\tau\rangle$.

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 main extract duct or in each individual extract duct. The concentration readings and the time of reading are used to calculate the room-average age of air in the room. When measurements are taken in several extract ducts, the volumetric flow rate of air in each duct must be known in order to calculate the room-average age of the air.

6.2 Apparatus

6.2.1 Equipment

a) 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.

b) Gas analyzer for continuous operation (e.g. infrared analyzer).

c) Tubing of non absorbing material (e.g. nylon or polyethylene) for suction and/or injection of gas.

d) Stopwatch for measuring the recorder's chart speed during the test period.

e) Propeller (mixing) fans and/or fibre-board sheets.

6.2.2 Additional equipment for simultaneous measurements in several extract ducts.

a) Manifold of valves (e.g.magnetic valves) for selection of different sampling points.

b) Pump (purging pump) that continuously sucks air from the sampling tubes when these are not connected to the analyzer. This is needed to ensure that a fresh sample is obtained each time the tube is connected to the analyzer.

6.3 Preparation of test samples

Sample points

Measuring in one duct only: A hole is made in the duct wall and the sampling tube is inserted.

Measuring in several ducts: A sample line is run through each register for extract air and inserted approximately one meter.

The ducts are examined to see if there are permanent measuring devices installed for recording the volumetric flow rate of air. Otherwise the volumetric flow rate of air should be measured by any of the methods recommended in Reference /4/.

Analyser

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 set at zero point.

Tracer gas is released into the actual room. This is best done intermittently so that too much gas is not released. The amount of gas to be discharged into the space is determinated by:

- The allowable threshold limit for the gas used. The initial concentration, C(0), must not exceed the threshold limit value.

- The sensitivity of the gas analyser.

With the propeller fans and/or the sheets as paddles, the tracer gas is mixed to an uniform concentration, C(0), 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 continuously recorded in the main extract duct or in each individual duct.

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 watervapour content in the air. Therefore a change in the humidity during the measuring period may cause an off-set error.

6.5 Expression of result

6.5.1 Measuring in one extract duct only

The room-average age is calculated from the concentration readings in the extract duct as:.

$$<\bar{\tau}> = \frac{\sum_{i=0}^{M} C_i \cdot \tau_i \cdot \Delta\tau + \frac{C_M}{\lambda_e}\left(\tau_M + \frac{1}{\lambda_e}\right)}{\sum_{i=1}^{M} C_i \cdot \Delta\tau + \frac{C_M}{\lambda_e}}$$

C_i = Concentration reading number i

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 expression above is the 0:th moment (= the area under the curve) and the numerator is the first moment (see below).

In both the numerator and the denominator above the second term is an extrapolation term that consider the tail of the curve, i.e. that part of the curve which is not recorded.

If

$$0.9 \cdot \tau_n < \frac{1}{\lambda} < 1.1 \cdot \tau_n$$

then the room-average age may, without loss of accuracy, be calculated from the slope in the exponential decay region as:

$$<\bar{\tau}> = \frac{1}{\lambda_e}$$

6.5.2 Measuring in several ducts

From the concentration readings in each duct (say duct no. d) the following quantities are first calculated (the notation is the same as under heading 6.5.1).

The 0:th moment (= the area under the curve); $\mu_d^{(o)}$:

$$\mu_d^{(o)} = \sum_{i=1}^{N} C_i \cdot \Delta\tau + \frac{C_M}{\lambda_e} \qquad \text{(ppm x h)}$$

The first moment; $\mu_d^{(1)}$:

$$\mu_d^{(1)} = \sum_{i=1}^{M} C_i \tau_i \Delta\tau + \frac{C_M}{\lambda_e} (\tau_M + \frac{1}{\lambda_e})$$

The room-average age is calculated from the 0:th and the 1:th moments and the volumetric flow rate of air in each duct as follows:

$$\langle\bar{\tau}\rangle = \frac{q_1 \cdot \mu_1^{(1)} + q_2 \cdot \mu_2^{(1)} + \ldots + q_d \cdot \mu_d^{(1)} + \ldots + q_n \cdot \mu_n^{(1)}}{q_1 \cdot \mu_1^{(o)} + q_2 \cdot \mu_2^{(o)} + \ldots + q_d \cdot \mu_d^{(o)} + \ldots + q_n \cdot \mu_n^{(o)}}$$

q_d = The volumetric flow rate of air (m^3/h) in duct no. d

n = Total number of extract ducts.

The result may be expressed in nondimensional form as an room-average air-exchange efficiency, ε_a , defined as:

$$\varepsilon_a = \frac{\tau_n}{2\langle\bar{\tau}\rangle} \times 100 \qquad (\%)$$

In Annex 2 an application is presented of the evaluation of the recorded concentrations.

6.6 Accuracy

Case a.(6.5.1) Measuring in one duct only:

The accuracy has been determinated to ± 5%.

Case b.(6.5.2) Measuring in several ducts:

In case the volumetric flow rate of air in each duct is measured with a percentual error less than 3% then the accuracy is the same as in case a, i.e. ± 5%.

In other cases, when the volumetric flow rate of air is measured with a poorer accuracy than 3%, the probable error can be estimated to be around 10%.

A systematic error will occur when, due to the occurance of leakages in the building structure, not all air leaving the ventilated space passes the measuring points. The mean-age predicted by the method will then be lower than the true value.

6.7 Test Report

The test report shall include the following information, if relevant:

a) Name and address of the testing laboratory
b) Identification number of the test report
c) Name and address of the organization 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 and address of manufacturer or supplier of the tested object
g) Name or other identification marks of the tested object
h) Description of the tested object
i) Date of supply of the tested object
j) Date of the test
k) Test method
l) Conditioning of the test specimens, environmental data during the test (temperature, pressure, RH, etc)
m) Identification of the test equipment and instruments used
n) Any deviations from the test method
o) Test results (use SI units)
p) Inaccuracy or uncertainty of the test result
q) Date and signature

Annex 1

Minimum time of measurement

Fig. 1 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.

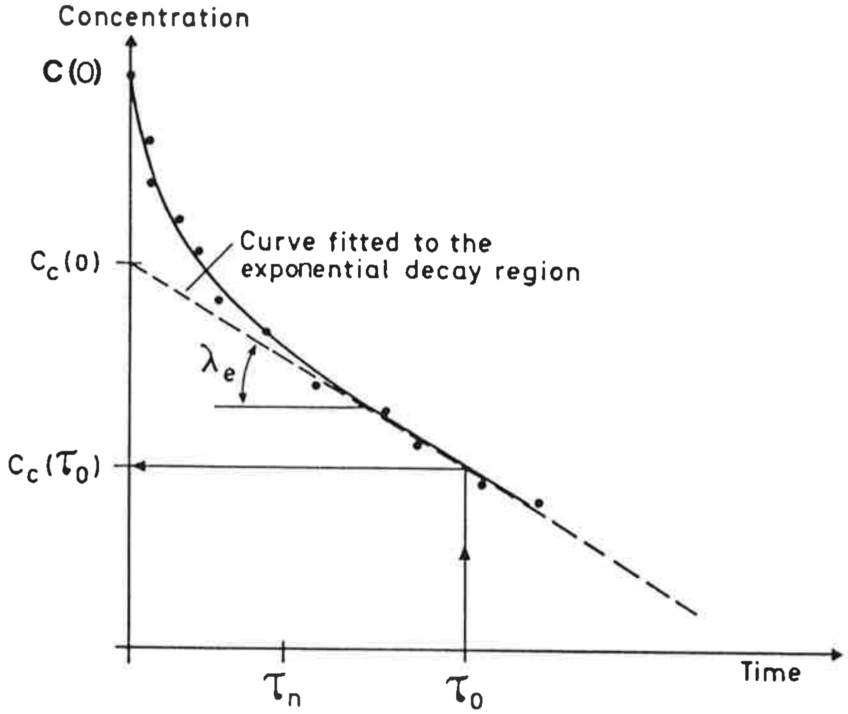

Fig. 1 Ln concentration versus time.
λ_e is the slope in the exponential decay region.

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 $C_c(T_o)$ 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 concentrations. The slope, λ_e, is used to calculate the "extrapolation" terms that consider the tail of the decay curve.

Annex 2

Example

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	τ_i (min)	C_i (ppm)	$C_i \cdot \tau_i$ (ppm·min)
0	0	654	0
1	2.5	491	1228
2	5.0	393	1965
3	7.5	326	2445
4	10.0	271	2710
5	12.5	234	2925
6	15.0	207	3105
7	17.5	188	3290
8	20.0	165	3300
9	22.5	147	3308
10	25.0	137	3425
11	27.5	127	3492
12	30.0	122	3660
13	32.5	106	3445
14	35.0	103	3605
15	37.5	95	3563
16	40.0	09	3600
17	42.5	85	3612
18	45.0	83	3735
19	47.5	78	3705
20	50.0	74	3700
21	52.5	69	3623
22	55.0	64	3520

ΣC_i = 4 309 $\Sigma C_i \cdot \tau_i$ = 70 961

$$\Sigma C_i \Delta\tau = 4309 \times \frac{2.5}{60} = 180 \text{ (ppm x h)}$$

$$\Sigma C_i \cdot \tau_i \cdot \Delta\tau = \frac{70\ 961}{60} \times \frac{2.5}{60} = 49 \text{ (ppm x h}^2\text{)}$$

In the figure below are plotted the concentration readings versus time, see Fig. 2.

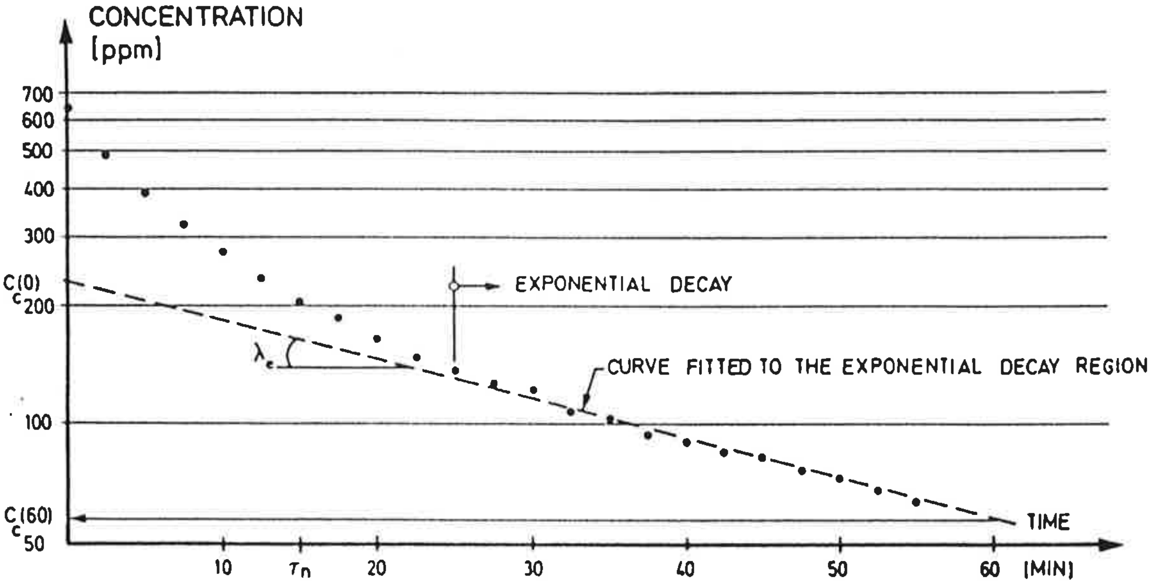

Fig. 2.

From the figure above 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 for the 0:th moment becomes:

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

and for the first moment the extrapolation term becomes:

$$\frac{C_M}{\lambda_e} \cdot (\tau_M + \frac{1}{\lambda_e}) = 47 \times (\frac{55}{60} + \frac{1}{1.36}) = 47 \times 1.65 = 77.6 \qquad \text{(ppm x h)}$$

Room-average age: $\langle\bar{\tau}\rangle = \frac{49 + 77.6}{180 + 47} = \frac{126.6}{227} = 0.56 \qquad \text{(h)}$

Room-average air-change efficiency:

$$\langle\varepsilon_a\rangle = \frac{0.25}{2 \cdot 0.56} \times 100 = 23$$

Annex 3

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