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MEAN AGE OF ROOM AIR $<\bar{\tau}>$ FOR IDEAL AND NON-IDEAL FLOW PATTERNS

Dr Sture Holmberg
National Institute of Occupational Health
Ventilation Division
S - 171 84 Solna, Sweden

ABSTRACT

In order to obtain good estimate of the air change efficiency in a ventilated room, the mean age of the room air should be found with the highest possible accuracy. For the two idealized flow patterns, plug flow (displaced flow) and complete mixing, there are analytical expressions for the mean age of room air. With actual non-ideal flow, the mean age of the air can be estimated as an average time by using the internal age distribution function of the room air, I(t). The expression for I(t) varies with the tracer gas method chosen. The article gives the most common expressions for I(t) when analyzing tracer gas concentration step and impulse responses. Difficulties when dealing with complicated flow patterns and slowly decaying tracer gas curves are discussed. Stagnant flow zones in the room may give errors in the estimated age of the air and thus errors in the air change efficiency. The report gives examples.

KEYWORDS: External residence time, Internal age, Mean age of air, Air change efficiency

INTRODUCTION

During the 1980s, several new terms and concepts have been formulated for describing and assessing different types of ventilation and ventilation systems. One such concept is the mean age of the room air. This report studies the age of room air, both for ideal flow cases and for the non-ideal cases which occur in practice. The report describes a method for qualitatively describing the air flow through a room; it is also designed to

- disseminate information and increase understanding of the ideas behind formulae and concepts
- provide a broader information basis for those who need to be able to measure air quality and determine the functioning of ventilation systems in houses and work places, and
- discuss limitations and areas of use, bearing in mind the many and specific requirements imposed by ventilation.

$$\bar{t} < \tau_n \tag{7}$$

This is explained by the fact that certain parts of the room volume hardly participate at all in the air flow, or that they have such a low molecular turnover that they can be regarded as stagnant zones.

The stagnant volume fractions V_{st} of the total room volume V can be calculated according to

$$V_{st} = q \cdot (\tau_n - \bar{t}) \tag{8}$$

where q is the total flow rate used.
In the case of cross-flow or by-pass the air exchange can be delayed. In these cases, see Figure 1, the mean air residence time in the room is given by

$$\bar{t} > \tau_n \tag{9}$$

This is because the air exchange in a large fraction of the room volume takes place at a very slow rate, while a small fraction is renewed rapidly. Here, as in the previous case, the mean air residence time is determined experimentally with the help of expression (5).

When determining the age experimentally, trace elements are added to the air and their concentration c(t) is followed continuously in the outgoing air. The trace element concentration and mean trace element age in the room are important parameters for assessing the ventilation quality. The c(t) curve can be recalculated to give the mean air age in the room. Different methods are described below.

With concentration decay, the mean age of the air $\langle\bar{\tau}\rangle$ is calculated using an expression of the same type as that used in Equation (5). However, in this case there is not an impulse change but a step change. The following expression is obtained for the mean age of air in the room determined experimentally from concentration decay, compare Equations (3) and (5)

$$\langle\bar{\tau}\rangle = \int_0^{co} t \cdot I(t)\,dt \tag{10}$$

where

$$I(t) = \frac{c(t)}{\int_0^{\infty} c(t)\, dt} \quad \textit{(internal age distribution, concentration decay)} \tag{11}$$

The most usual method when the mean age of the air is being determined in this way is to first create an even trace element concentration in the whole room with the help of mixing fans. At t = 0 the ventilation system begins to blow in fresh air (free of tracer gas) into the system. The age distribution I(t) of the internal "trace element air" that exists in the system then follows the trace element concentration c(t) of the outgoing air according to Equation (11).

With <u>concentration growth</u> the internal volume is free of trace elements at t=0. Thus the age distribution I(t) of the internal volume follows the complementary curve to c(t) according to

$$I(t) = \frac{1-\frac{c(t)}{c(\infty)}}{\int_0^{\infty}(1-\frac{c(t)}{c(\infty)})dt} \quad \textit{(internal age distribution, concentration growth)} \tag{12}$$

The mean age of the air in the room with concentration growth is obtained by inserting the expression for I(t) in (12) into Equation (10).

With <u>pulsed injection</u>, it becomes more difficult to visualize the mathematical form which will be adopted by the I(t) curve. Consequently it is necessary to derive the expression, and the initial reasoning used here is taken from Danckwerts (1953). Here as before, for the <u>theoretical</u> case the following applies

$$<\bar{\tau}> = \int_0^{\infty} t \cdot I(t)\, dt \tag{13}$$

Further, we have

$$\int_0^{\infty} I(t)\, dt \equiv \frac{q}{V}\int_0^{\infty}[1-F(t)]\, dt = 1 \tag{14}$$

where F(t) is the external cumulative residence time distribution. This gives the following expression for Equation (13)

$$<\bar{\tau}> = \int_0^\infty t \cdot I(t)\,dt = \frac{q}{V}\int_0^\infty t[1-F(t)]\,dt \tag{15}$$

After partial integration, Equation (15) gives

$$<\bar{\tau}> = \frac{q}{2V}\int_0^1 t^2\,dF(t) \tag{16}$$

which in turn can be re-written as

$$<\bar{\tau}> = \frac{q}{2V}\int_0^\infty t^2 E(t)\,dt \tag{17}$$

since (see Danckwerts (1953))

$$E(t)\,dt = dF(t) \tag{18}$$

The external residence time distribution E(t) has been defined in Equation (6). In the non-ideal experimental case, q/V (17) is replaced by $1/\bar{t}$, compare Equations (3) and (5).

Finally, for the mean age of air in the room with <u>experimental</u> determination and pulsed injection we obtain

$$<\bar{\tau}> = \frac{1}{2\bar{t}}\int_0^\infty t^2 \cdot E(t)\,dt = \frac{1}{2}\,\frac{\int_0^\infty t^2 \cdot c(t)\,dt}{\int_0^\infty t \cdot c(t)\,dt} \tag{19}$$

The re-formulation in Equation (19) is done by substituting expression (5) for $\bar{t}$ and expression (6) for E(t).

The expressions for mean age of air in the room which are given in Equations (10), (11), (12) and (19) have been re-formulated and collected in Table 1.

Table 1. Expressions for the mean age of air $\langle\bar{\tau}\rangle$ in the room with experimental determination. The integration limit co is the cutoff point, which in the normal case is 2 - 4 τ_{n}. c(t) denotes the trace element concentration in the exhaust inlet.

Method	Mean age of air in the room $\langle\bar{\tau}\rangle$
Concentration decay	$\langle\bar{\tau}\rangle = \dfrac{\int_{0}^{co} t\cdot c(t)\,dt}{\int_{0}^{co} c(t)\,dt} \qquad (20)$
Concentration growth	$\langle\bar{\tau}\rangle = \dfrac{\int_{0}^{co} t(1-\frac{c(t)}{c(\infty)})\,dt}{\int_{0}^{co} (1-\frac{c(t)}{c(\infty)})\,dt} \qquad (21)$
Pulsed injection	$\langle\bar{\tau}\rangle = \dfrac{1}{2}\cdot\dfrac{\int_{0}^{co} t^{2}\cdot c(t)\,dt}{\int_{0}^{co} t\cdot c(t)\,dt} \qquad (22)$

DISCUSSION

In the introductory chapters there is a division into ideal and non-ideal flow. The ideal flow does not occur in practical applications; it is intended to be used as a comparison with what can be achieved in practice. These references are needed, both for direct comparisons of air flow patterns in the room and for the interpretation and discussions of concentration determinations in general. In this connection it may be mentioned that the recent debate as to whether we should use displacement or mixing ventilation is chiefly concerned with which of the two ideal flow profiles (plug flow or complete mixing) we should strive towards.

SUMMARY

This report introduces the reader to a qualitative model for estimating the air-flow pattern in a ventilated room. A detailed background is given to the important definition of the mean age of air. An efficient pattern of air flow through the room will have several advantages. The amount of air supplied and the energy required for heating can be minimized. The whole room will have a better air quality. One of the positive results is the increased possibility of achieving fixed goals in terms of hygiene, energy and thermal comfort.

REFERENCES

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