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PFT-MEASUREMENTS IN VENTILATION DUCTS

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SYNOPSIS

The passive perfluorocarbon method (PFT-method) has been successfully applied in ventilation measurements in rooms. The method is, in principle, also applicable to air flow measurements in ventilation ducts. There are, however, several problems in applying a passive sampling technique in a duct. First, the concentration of the tracer may not be uniform through the cross-section of a duct. Second, the velocities in a duct are normally an order of magnitude higher than in a room. Third, the orientation of the sampler in respect to the flow may affect the uptake rate. This study concentrated on the solution of these three problems.

The velocity of the air in a duct had significant effect on the uptake rate of the sampler. The magnitude of the effect was in the order of an 11-16 % increase for each 1 m/s increace in nominal velocity. This indicated that the passive PFT-technique should not be used without correction for uptake rate in duct measurements. More studies are needed in order to establish this correction.

The deviations between samplers were found to be higher in a duct than in a test room. This means that the location of the samplers should be chosen carefully. A good first estimate would be the locations proposed by several standards for air velocity measurements. The orientation of the sampler had only a small effect on the uptake rate. It was found that the samplers should not be placed with their open end against the flow.

1. INTRODUCTION

The passive perfluorocarbon tracer technique introduced by Dietz[1] has been succesfully applied in residential ventilation measurements. The state-of-the-art of this technique in the Nordic countries has been described by several authors in a report published this year[2]. The reliability of the equipment used in this study has been described by Säteri[3].

In principle the method is also applicable to air flow measurements in ventilation ducts. There are, however, several problems in applying a passive sampling technique in a duct. First, the concentration of the tracer may not be uniform through the cross-section of a duct. This may be due to velocity variations within a cross-section. Second, the velocities in a duct are normally an order of magnitude higher than in a room. Increased face velocity and turbulence may have some effect on the uptake rate. Third, the orientation of the sampler in respect to the flow may affect the uptake rate. Tests are needed in order to be able to give recommendations on how to perform a PFT-measurement in a ventilation system. This study concentrated on the solution of these three problems.

2. PASSIVE TRACER GAS MEASUREMENTS IN VENTILATION DUCTS

The PFT-measurement in a ventilation system follows the well known principle of constant emission during which the equilibrium concentration is measured. The air flow is calculated by dividing the emission by the concentration. The PFT-technique measures the average concentration during the sampling time. Thus, the sampling should not be started before the end of the transient tracer step-up period.

With the passive PFT-technique, the measurement period is usually several days. One prerequisite for the use of the passive sampling technique is that the air flows are relatively constant during the measurement period. Should this not be the case, it is preferable to use pumped sampling with short-enough sampling periods.

The application of described measurement method requires that the mixing in the duct at the measuring point be uniform. The problemats are to some extent similar to those of velocity measurements in ducts. However, gravitational forces, for example, can cause the tracer flow pattern to differ from that of the air. This problem can usually be circumvented by increasing the number of sampling points. Because the number of sampling points is always limited, optimal placement of the samplers should be found. The instructions given for velocity measurements should be used to start with. Indicator smokes could also be used.

In the passive PFT-technique, the sampling is based on diffusion between ambient air and adsorbent. The uptake rate is given theoretically by Fick's law. Dietz[1] has determined the uptake rates for various perfluorocarbons and found that the concentration in the adsorbent can be assumed to be zero. So far, the measurements have usually been carried out in rooms, where the air velocities are low. There is little information available on the effects of increased velocity and turbulence on the uptake rate. It can be assumed, however, that increasing turbulence at the open end of the sampler should also increase the molecule flow between the ambient and the adsorbent. This yields a higher uptake rate if the molecules do not desorb from the adsorbent.

Dietz[1] has also reported that the sampler orientation does not affect the uptake rate. The tests were made in a small test chamber which had a unidirectional air flow. As the test set-up resembled a room more than a duct, it is necessary to check the validity of that assumption as well.

3. EXPERIMENTAL SET-UP

The measurements were made in the HVAC-laboratory during the summertime. Three different set-ups were used. In addition to these tests, two reference tests were made in one room of the test flat. The purpose of these tests was to give reference values for the uptake rate and deviation between samplers in the conditions normally used.

The first two tests were made in the experimental ventilation unit of the laboratory. These tests were made to study the mixing in a duct and the orientation of the samplers. The unit is built of commercially used components. A scheme of the unit is shown in Fig. 1a. The air coming from the unit was traced by 20 PMCP and 20 PMCH sources. The 46 samplers were placed in the D=400 mm circular duct at the distance of 9.0 m from the second 90° bend. The samplers were placed so that 1/4 of them were orientated in each direction: open end against the flow ('A'), open end up ('C'), open end away from the flow ('B') and open end down ('D'). Two different air flows were used. The durations of the tests were 7

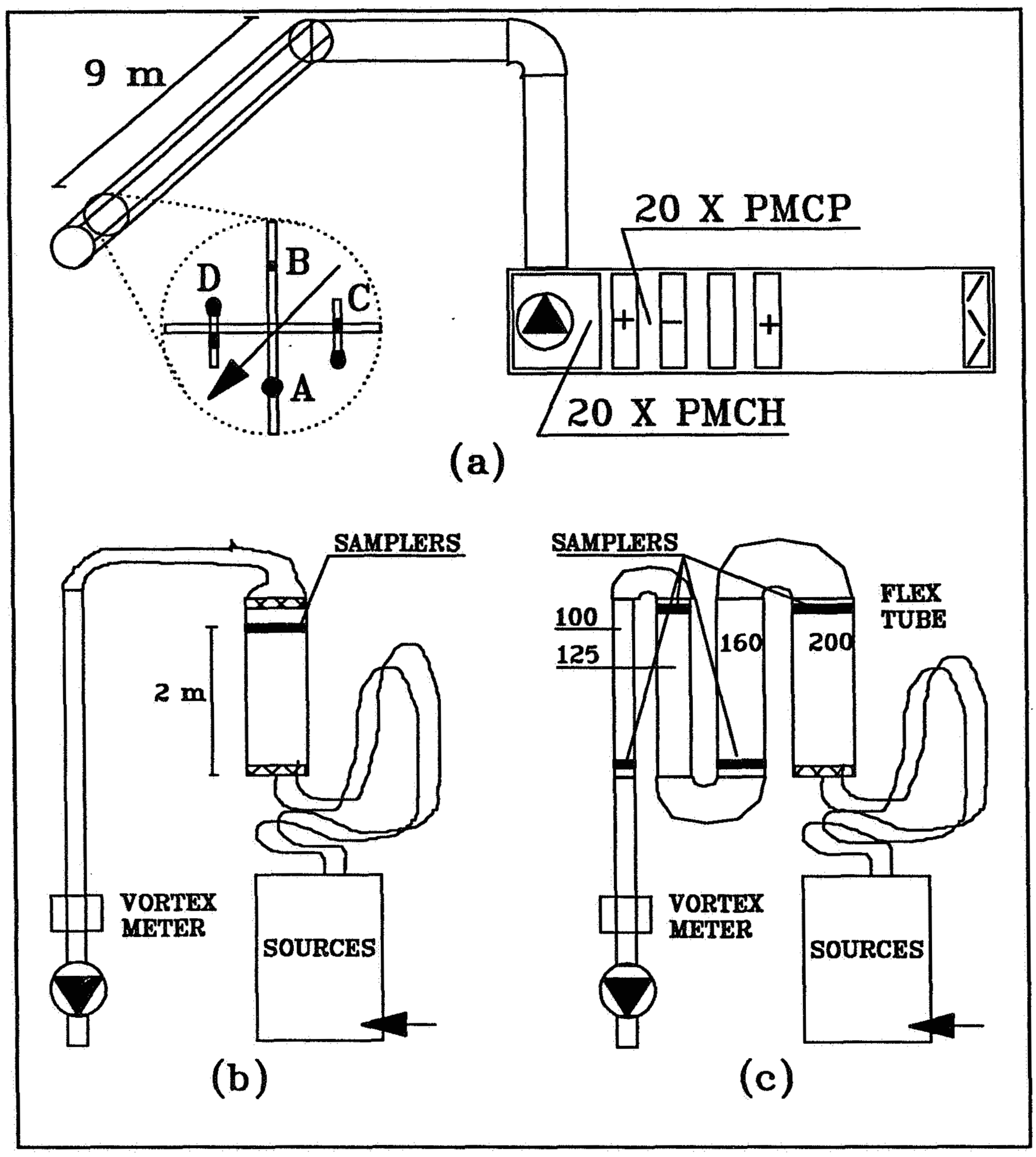

Fig. 1. a) The air-conditioning unit used in tests 1&2
b) The setup in tests 3-6.
c) The setup in testing the effect of velocity

and 11 days.

The next four tests (3 through 6) were made using the set-up in Fig. 1b. These tests were also made to study the effects of the orientation of the samplers. Now, 5 PMCP and PMCH sources and 6 PDCH sources were placed in a mixing chamber. The air was exhausted from the chamber to the measurement duct (D=200 mm) via a flexible tube (D=100 mm). There was a laminar flow stabilizer at both ends of the 200 mm duct in order to minimize the confounding effects of non-uniform mixing. In these tests, 20 samplers were placed similarly to those in tests 1 and 2. Four tests were made using different air flow rates. The durations of the tests were 7 and 10 (test 3) days.

The third set-up, used to test the effect of air velocity on uptake rate, is shown in Fig. 1c. The principle of the test was to lead the air flow through four consecutive ducts of different diameters. By doing so, four different nominal (flow rate divided by duct area) velocities were achieved in one test. This way the influence of experimental errors could be minimized. The air flow was measured using a vortex meter with an inaccuracy of less than 0.5 %. The tracer sources were the same as in tests 3-6. The duct diameters and numbers of samplers were as follows: D=100 mm, 5 samplers; 125 mm, 8 samplers; 160 mm, 9 samplers; and 200 mm, 11 samplers. Half of the samplers were orientated against the flow ('A') and the rest had their open end pointing up ('C'). Two tests were made using different air flow rates. The duration of the tests was 5 days.

The reference measurements were made in one room of the test flat. The exhaust air flow from the room was measured using an orifice plate tube. The room was depressurized, and the supply air came via the supply duct, but no supply fans were used. The air velocity in the room was measured using an indoor climate analyzer. Two PFT-sources of each type were placed on a chair near the supply plenum. The samplers were placed near each other at the center of the room. Two tests with 8 and 5 samplers were made using the same air flow. The duration of the tests was 7 days.

4. RESULTS AND ANALYSIS

4.1 The mixing of tracer in a duct

The mixing of tracers in a duct was studied in tests 1 and 2. The concentrations were measured at several points on the cross-section. An relative estimate of the concentrations at various points was gained by introducing a sampling index (δ):

$$\delta = C_p / \langle C \rangle \qquad (1)$$

where C_p = concentration at a point,
$\langle C \rangle$ = average concentration of all samplers on a cross-section.

The advantage of a sampling index is being able to compare various measurements and tracer gases. It is

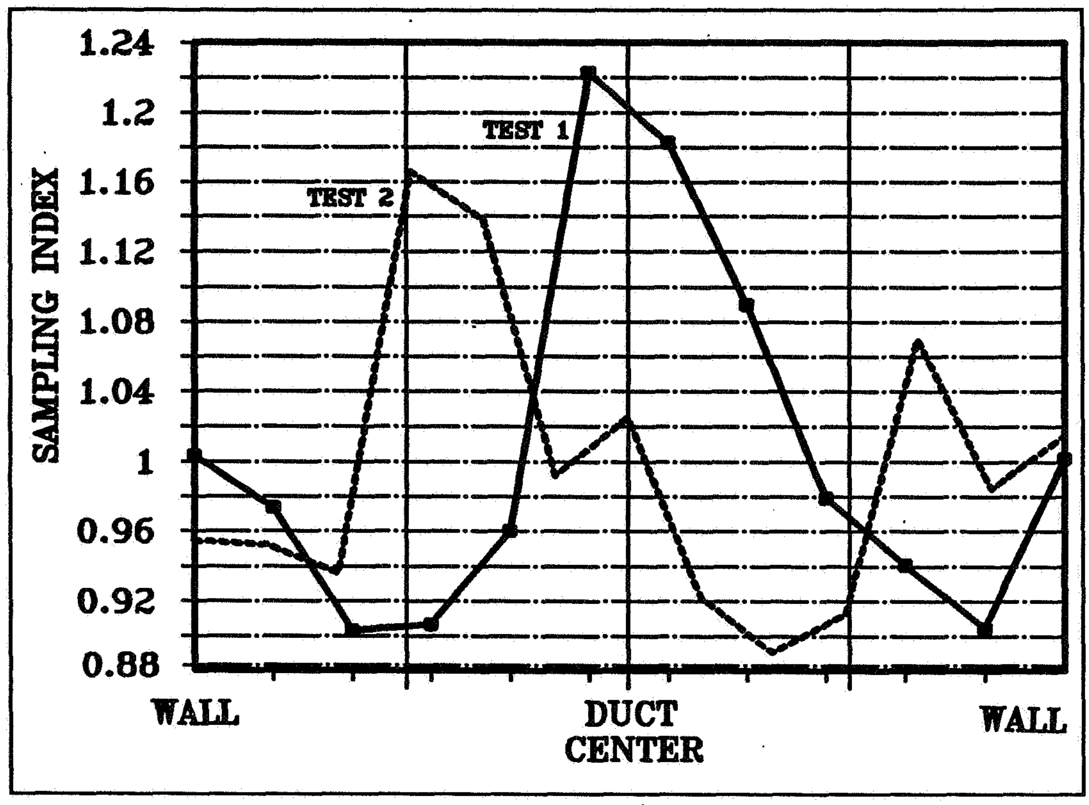

Fig. 2. Sampling indices in tests 1 and 2.

used both in mixing studies as well as orientation studies. Another measure of the mixing on a cross-section is, of course, the relative standard deviation (RSD) of the measured concentrations at various similarly orientated samplers.

The results of tests 1 through 6 are presented in Fig. 2 and tables 1 and 2. From Fig. 2 it can be seen that *on*

Table 1: The relative standard deviations of concentrations measured from similarly orientated samplers.

	A			B			C			D		
test	pmcp	pmch	pdch	pmcp	pmch	pdch	pmcp	pmch	pdch	pmcp	pmch	pdch
1	10.6	8.2	--	20.8	13.1	--	15.3	17.8	--	11.6	12.9	--
2	12.9	9.0	--	8.6	10.4	--	19.1	18.9	--	33.6	18.8	--
3	3.4	4.2	2.8	10.2	17.2	35.2	3.4	5.6	3.3	28.0	21.2	43.5
4	9.7	4.2	10.3	3.7	4.2	6.9	13.8	3.0	10.2	6.5	10.3	13.6
5	13.3	4.2	7.6	3.7	6.2	7.0	4.9	8.7	10.5	10.0	13.1	14.0
6	3.2	4.1	5.1	4.2	4.2	4.3	9.8	6.6	12.0	17.7	47.4	20.2

average the deviation of the measured concentration was within the range of -10 % to +20 % from the average concentration for the whole cross-section. The relative standard deviations (table 1) of similarly orientated samplers varied in tests 1 and 2 between 8.6 % - 33.6 % (PMCP) and 8.2 % - 18.9 % (PMCH). This also includes the deviation due to the orientation of the samplers as well as the uncertainties of the sampling and analysis.

In the reference measurements made in the test flat the relative standard deviations were as follows: test 1; PMCP 9.9 %, PMCH 11.6 % (8 samplers) and test 2; PMCP 9.0 %, PMCH 7.9 % (5 samplers). Another comparison can be made with the relative standard deviations in tests 3 through 6 in which laminar flow stabilizers were used in order to stabilize the flow.

4.2 The effect of sampler orientation

The effect of sampler orientation on the measured concentration was studied in tests 1 through 6. The results are presented in table 2. In table 2, a value of less than unity indicates a lower measured concentration than the average concentration for the whole cross-section (all samplers included), and vice versa for values greater than unity. Theoretically, all tracers should give similar values, but measurement inaccuracies cause some variation in the results. There are not, however, any systematic variations between the three different tracers used. So, the value calculated for each orientation is the average of all used tracers. In tests 1 and 2 the relative standard deviations were higher than in tests 3-6. This may confound the analysis of the effect of orientation. As no systematic

Table 2: The sampling indices of tests 1 through 6.

	A			B			C			D		
test	pmcp	pcmh	pdch	pmcp	pcmh	pdch	pmcp	pcmh	pdch	pmcp	pcmh	pdch
1	0.89	0.87	--	1.15	1.12	--	0.99	1.02	--	0.97	0.99	--
2	0.88	0.88	--	1.05	1.12	--	1.08	1.10	--	0.98	0.90	--
3	0.92	0.85	0.87	1.00	1.10	1.13	0.94	0.88	0.89	1.13	1.17	1.11
4	1.00	1.00	0.98	0.96	0.96	0.99	1.09	1.06	1.01	0.95	0.98	1.02
5	1.02	0.94	0.91	0.99	1.03	1.03	0.99	0.99	0.98	1.00	1.04	1.07
6	0.88	0.93	0.86	0.92	0.97	0.90	1.25	1.33	1.19	0.95	0.77	1.06
avg1	0.93	0.91	0.90	1.01	1.05	1.01	1.06	1.06	1.02	1.00	0.98	1.06
rsd	0.06	0.05	0.05	0.07	0.07	0.08	0.10	0.14	0.11	0.06	0.12	0.03
avg2	0.92			1.03			1.05			1.01		

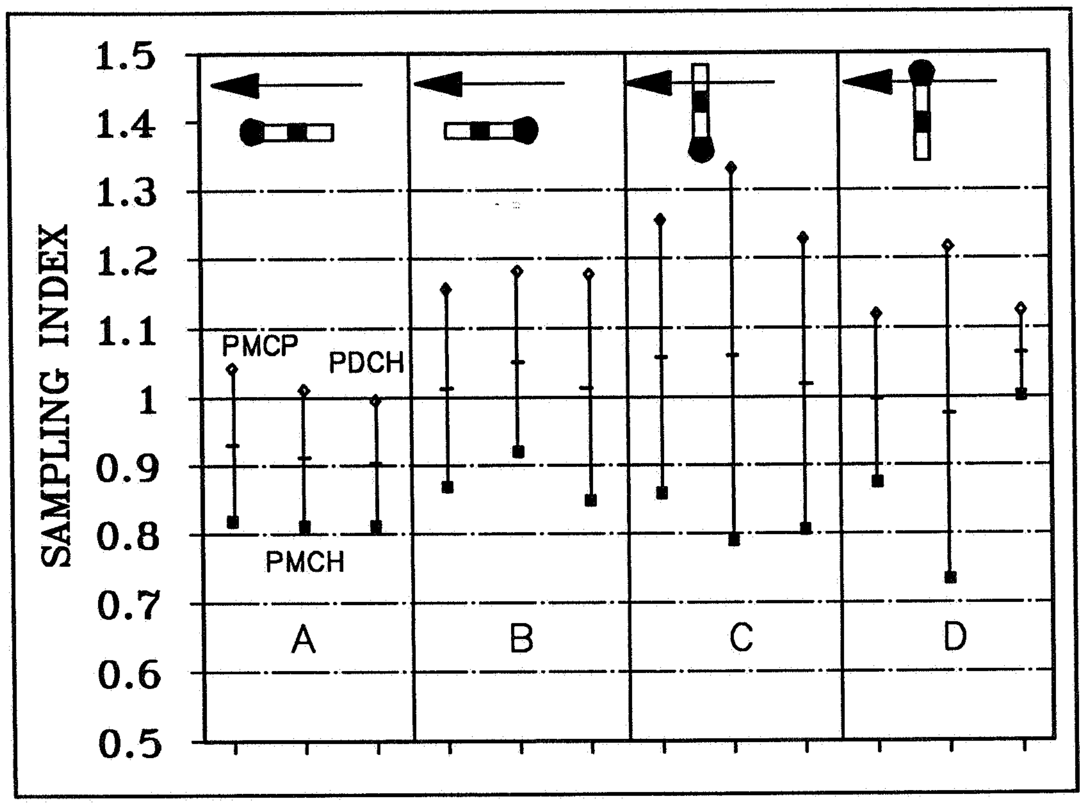

Fig. 3: The 95 % confidence intervals of sampler orientation tests 1 through 6.

difference between tests 1&2 and 3-6 was found, the analysis is based on average values for all six tests.

The sampling index (δ) for samplers orientated against the flow (A) was 0.92. For samplers orientated with their open end up (C), δ=1.05. For samplers orientated with their open end pointing away from the flow (B), δ=1.03. The sampling index for samplers orientated with their open end down (D) was 0.92. The standard deviations of these values varied between 0.03 and 0.14. In cases B, C and D the 95 % confidence intervals included unity (Fig. 3.). This means that the orientation of the sampler did not in these cases have a significant effect on the uptake rate. However, it seems that a sampler should not be placed with its open end directly against the flow (case A).

4.3 The effect of air velocity on uptake rate

The calculated uptake rates are presented in table 3. The plot in Fig. 4 shows the relative increase in the uptake rate compared with the uptake rate measured simultaneously in a room. All samplers (duct and room)

Table 3: The measured uptake rates in the test room and tests A and B. The relative rate is the ratio duct and room rates.

test #	vel. (m/s)	uptake rate (mL/d) pmcp	pmch	pdch	relative rate pmcp	pmch	pdch
room	0.05	186	249	197	1	1	1
A	0.64	219	285	239	1.18	1.14	1.21
A	0.99	230	304	256	1.24	1.22	1.30
A	1.63	225	317	273	1.21	1.27	1.39
A	2.55	245	343	300	1.32	1.37	1.53
B	1.27	266	314	281	1.43	1.26	1.43
B	1.99	241	297	281	1.30	1.19	1.43
B	3.26	275	341	324	1.48	1.37	1.64
B	5.09	305	392	372	1.64	1.57	1.89

were analysed in a random order so that any drift in the analysis would not confound the results. The average air velocities measured in the room were approximately 0.05 m/s. The uptake rates at this velocity were used as references to the rates measured in the duct. Any inaccuracies in the calibration of the analysis system

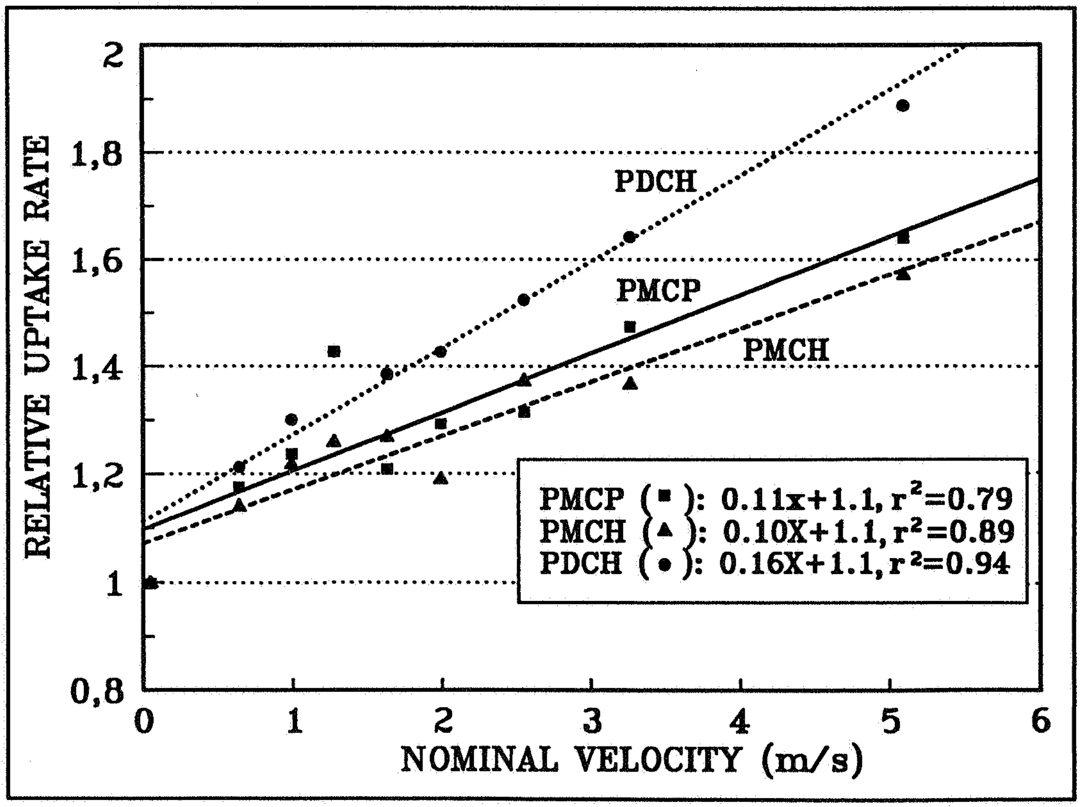

Fig. 4. Uptake rate vs. nominal air velocity in the duct.

and tracer source rates were thus taken into account.

As Fig. 4 reveals, the nominal velocity of air in a duct has a significant effect on the uptake rate. The magnitude of the effect is in the order of an 11% (PMCP), 10 % (PDCH), and 16 % (PDCH) increase for each 1 m/s increase in nominal velocity. This means that passive PFT-sampling should not be used without correction in duct measurements. This effect should be studied more to establish the dependence of uptake rate on velocity and turbulence, which was not measured in this study. Once this correlation has been found, it is possible to iterate the actual uptake and air flow rates from a passive PFT-measurement in a ventilation system. Another possibility could perhaps be the development of shielding techniques, so that the flow field at the end of the tube would be more independent of the flow itself.

5. CONCLUSIONS

The velocity of the air in a duct has a significant effect on the uptake rate of the sampler. The magnitude of the effect is in the order of an 11-16 % increase for each 1 m/s increace in nominal velocity. This indicated that the passive PFT-technique should not be used without correction for uptake rate in duct measurements. More studies are needed in order to establish this correction.

The deviations between samplers were found to be higher in a duct than in a test room. This means that the location of the samplers should be chosen carefully. A good first estimate would be the locations proposed by several standards for air velocity measurements. The orientation of the sampler had only a small effect on the uptake rate. It was found that the samplers should not be placed with their open end against the flow.

The experiences gained from this study yield a conclusion that active (pumped) sampling techniques are preferable to passive techniques in the measurement of air flows in a ventilation system. With active sampling, it is also possible to allow for diurnal operating sequencies of the ventilation systems.

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