

PROGRESS AND TRENDS IN AIR INFILTRATION AND
VENTILATION RESEARCH

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THE PERFORMANCE OF THE PASSIVE PERFLUOROCARBON
METHOD

J. SATERI¹, P. JYSKE², A. MAJANEN¹, AND O. SEPPANEN¹

¹Helsinki University of Technology
02150 Espoo
Finland

²University of Helsinki
Division of Analytical Chemistry
00100 Helsinki
Finland

SYNOPSIS

The use of passive perfluorocarbon technique for air flow measurements has been developed and tested. The building and testing of the system took approximately one year. The reproducibility of the analysis was tested during the period. The results show that the relative standard deviation of the analysis for parallel samples is less than 7 % for each tracer in most of the cases. A drift of calibration was noticed, but it can be allowed for by using reference samples with known amounts of tracers.

The accuracy of the method was tested in controlled laboratory conditions. The results reveal some rather high differences from the reference, though the results are distributed evenly on both sides of the zero line. With few exceptions, the inaccuracy of the PFT-method can be estimated to be approximately ± 20 %, when PMCP or PMCH are used. For PDCH the inaccuracy is somewhat higher. Improving the calibration procedure and allowing for the drift of calibration should improve the accuracy of the method. The test in a duct flow implies that the use of the method should be limited to room flow conditions until further research has been done.

The mixing was tested in laboratory and field conditions. The results of the laboratory measurements show that the mixing was good, the relative standard deviation being generally below 10%. No stratification could be found. Field measurements were made in 50 typical Finnish homes. When the interior doors within the zone were kept open during the measurement, the concentration distribution was uniform. The standard deviations of concentration varied from 1% to approximately 25%.

The technique is best suited for studies concentrating on the health and comfort of the people living in the house. If the energy use of ventilation is studied, the use of an integrating technique should be limited to cases with little temporal variation. The technique is applicable to large field surveys of ventilation. Anyhow, the complexity of room ventilation limits the number of potential users of the method. It is important to have enough knowledge of room ventilation in order to be able to conduct the measurements properly and to interpret the results correctly.

1 INTRODUCTION

The aim of this study was to develop the use of the passive perfluorocarbon tracer gas method applicable to field measurements in a large number of homes. The use of the passive multi-tracer technique solves many of the problems normally involved in inexpensive and simple field measurements. There are, however, some important problems to be solved. The project was divided into two tasks: building and testing of the analysis system and testing of the reliability of the method.

This paper describes the applied ventilation measurement model and the research done on the testing of the method. The performance of the sources, samplers and the analysis system is discussed. The measurements made to test the accuracy of the method are described. The mixing of tracers in zones was tested with laboratory tests and field measurements in 50 homes. The results are also discussed.

2 DESCRIPTION OF THE APPLIED PFT-TECHNIQUE

2.1 The principle of the measurement

The passive perfluorocarbon air infiltration measurement technique is based on the principles presented by Dr. Dietz at Brookhaven National Laboratory¹. It is a constant emission technique with passive adsorption sampling of tracers. Each individual ventilation zone of the building is traced with separate gas. The gas emission is achieved with passive permeation sources giving a constant tracer flow. The (quasi-) equilibrium concentration is monitored with a passive adsorption tube sampler. The typical measurement period can vary from few days to several weeks. The samples are analysed in a laboratory using a gas chromatograph with an electron capture detector. The passive tracer sources and adsorption samplers were supplied by Dr. Dietz. The analysis system is a copy of the system used by Dr. Harrje at Princeton University². At the moment three different tracer gases are used.

2.2 The ventilation measurement model

The model is based on the multi-zone models presented by Sandberg³ and Sherman⁴. A building consists of zones with uniform and instantaneous internal mixing such as that in Fig. 1. The air flows within the multi-zone system can be presented in matrix form:

$$Q = \begin{pmatrix} Q_{11} & -Q_{12} & \dots & -Q_{1N} \\ -Q_{21} & Q_{22} & \dots & -Q_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ -Q_{N1} & -Q_{N2} & \dots & Q_{NN} \end{pmatrix} \quad (1)$$

In the flow matrix Q the first index denotes the destination and the second index the origin. N is the number of zones in the system. The row sum of the flow matrix is equal to the total flow rate of outdoor air direct to zone

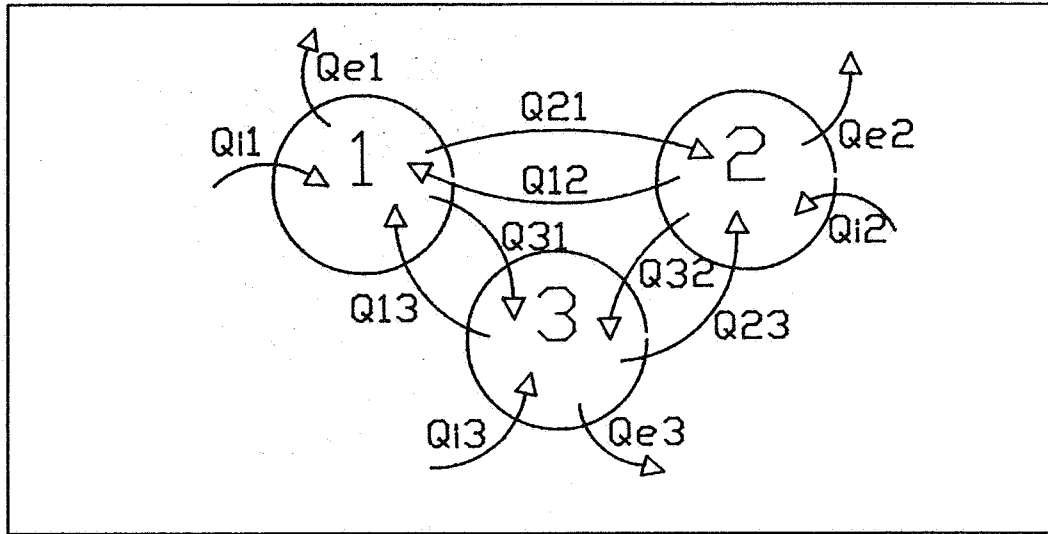


Figure 1: A multi-zone system

i and the column sum of the flow matrix indicates the total flow rate of air transferred outdoors from zone j . In the passive perfluorocarbon method a tracer gas is supplied at a constant rate to each zone. The diagonal source matrix S is composed of the emission volume rates. Constant emission and constant air flows yield a steady-state concentration of tracers in each zone. The concentration is monitored with passive adsorption samplers and a gas chromatograph. The concentration matrix C is composed analogously to the flow matrix. It can be shown³ that the steady-state flow rates in the system can be solved from a set of linear differential equations written in matrix form:

$$Q = S \times C^{-1} \quad (2)$$

This approach can be used only when measuring relatively constant air flows. With temporally varying air flows there will be a bias due to the lower efficiency of a varying air flow⁴. A quantity that better describes the performance of the ventilation system with temporally varying air flows is the age of contaminants in the exhaust, the turn-over-time. It can be shown that the turn-over-time matrix, which shall be denoted as \mathcal{T}_t , can be calculated from the following equation:

$$\mathcal{T}_t = \bar{C} \times (V^{-1} \times S)^{-1} \quad (3)$$

In Eqn. 2 the matrix \bar{C} consists of the (time-) average concentrations measured with integrating sampling. The turn-over-time is directly related to the human respiratory exposure to indoor air pollutants and can thus be used in examining the effects of ventilation on the health of the people living in the house. If the air flow rates are constant with time and there is uniform and instantaneous internal mixing in the system, the turn-over-time is equal to the nominal time-constant.

Table 1: The calibration of the tracer sources (22.0 °C)

Lot	PMCP			PMCH			PDCH		
	Man. Code	Emis. nl/min	std %	Man. Code	Emis. nl/min	std %	Man. Code	Emis. nl/min	std %
1	B	38.48	2.8	C	25.34	4.4	C	16.72	8.9 ^a
2	F	31.44	1.2	F	22.20	0.6	F	15.07	0.8
3 ^b	G	31.65	1.4	G	22.94	1.8	H	12.25	2.8

^aReduced to 5.0 % after excluding 4 outliers differing over 10% from the average

^bCalibration temperature 22.6 °C

3 THE PERFORMANCE OF THE INSTRUMENTS

3.1 The passive tracer sources

In the tracer source liquid perfluorocarbon tracer is sealed with a silicone rubber cap in an aluminium capsule. The gas flow is determined by the differences of the vapour pressure of the tracer over the rubber cap and the permeability of the cap material. The emission varies for two main reasons: the unreproducibility of manufacturing and the temperature of the liquid. In order to estimate the effects of these deviations the sources were calibrated individually. The sources were kept in a constant temperature for two weeks. After that the sources were weighed using a precision balance twice at a week's interval. The volume emission of each tracer was calculated from the change of mass over the weighing interval using the ideal gas law. The emissions were corrected with the purities of the liquids given by the manufacturer. Three main lots of sources were used. The results of the calibrations are presented in table 1.

The effect of temperature on the emission rate was tested by splitting the lot of 40 sources into six different calibration temperatures. The weighing procedure was as described earlier. The results of these measurements are shown in Fig.1.

The results show that there is no need to use an individual emission rate for each source—one rate for each manufacturing lot is enough. Due to the existence of outliers (as in Lot 1, PDCH) all sources should be checked at least once before use.

The effect of temperature on the emission rate correlated well with the data given by the manufacturer⁵. A change in temperature of one degree changes the emission by 3–5 %. Thus it is very important to know the source temperature during the field measurement.

3.2 The samplers and the analysis system

The sampling is based on Ficks diffusion in a glass tube. On the open end of the tube is the equilibrium concentration produced by the emission and air flows. Packed inside the tube is charcoal-like adsorbent, which has, due

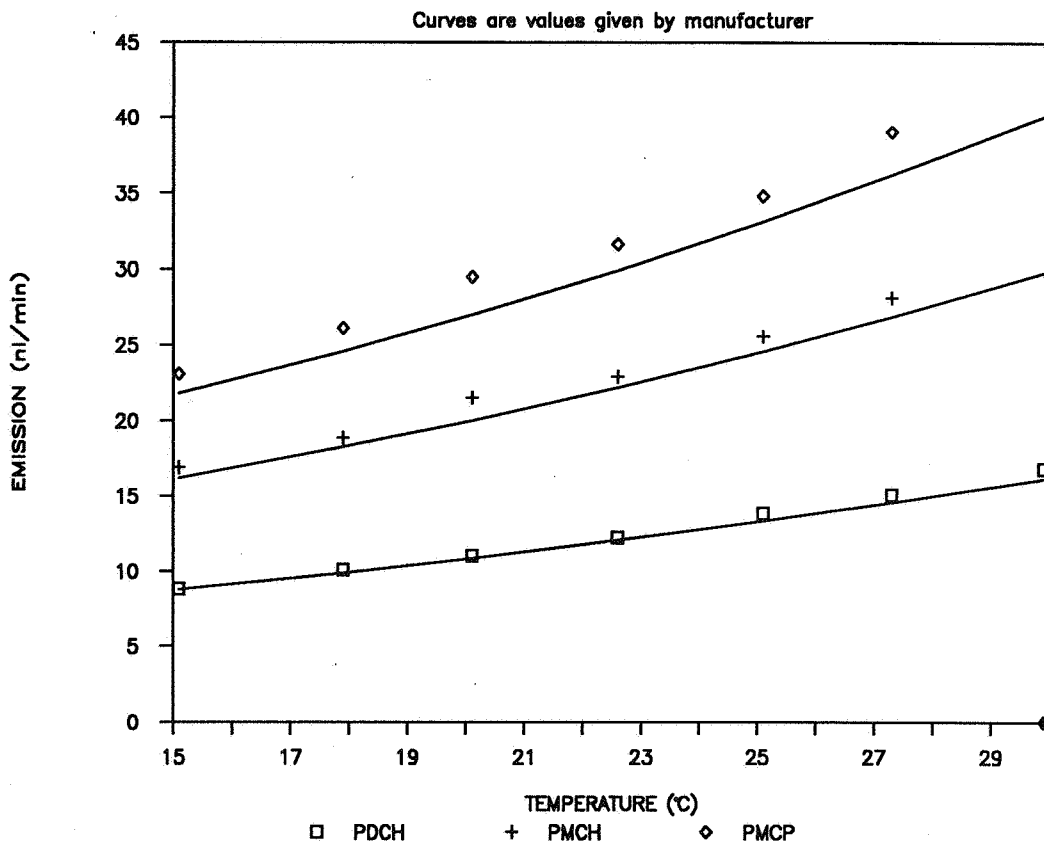


Figure 2: The effect of temperature on the emission rate

to its large surface area, practically zero concentration. The theoretically calculated sampling rates for this situation are applied in the measurements. In normal measuring conditions (sampling in a room, low concentrations) the main causes of deviations are manufacturing tolerances. In the analysis system there are several potential causes for deviation. The most important ones to overcome have been the desorption of samples in a 23-port rack, desorption from the re-concentration trap and the timing of the system. The deviations in the sampling and in the analysis were studied with several tests. The principle of the tests was to make several parallel samples and to analyse the samples with the system. Some of the samples were made in a test room or draught cabin using the permeation sources and others were made by loading the samplers with the calibration gas. The measured volumes varied from 5 to 250 pl. The results of these tests are presented in tables 2 and 3. The relative standard deviation of the samples represents the errors caused by the deviations in the sample rate and in the analysis. It is calculated from the peak height (pkhgt) or from the measured volume (vol.)—or both. The differences between these two are caused by the calibration.

The reproducibility of sampling and normal analysis (splitter on) is for PMCP 0.5–2.2 %, for PMCH 0.4–2.8 %, for PDCH:B 0.8–7.3 % and for PDCH:C 0.9–6.9 %. These results are derived from the latest tests in spring 1989. The calibration seems to give a small increase in these values, but in most of the cases the relative standard deviation is under 7 % for each tracer. In field

Table 2: The summary of the reproducibility tests (winter -89)

Date	Num. of Samp.	The Relative Standard Deviation of the Samples (%)							
		PMCP		PMCH		PDCH:B		PDCH:C	
		pkhgt	vol.	pkhgt	vol.	pkhgt	vol.	pkhgt	vol.
3.10.88	6	3.2	4.6	3.2	4.7	6.7	12.4	6.8	8.6
21.10.88	4	4.3	-	4.1	-	4.6	-	4.5	-
28.10.88	4	0.9	-	3.2	-	3.8	-	4.7	-
28.10.88	3	0.5	-	0.3	-	2.6	-	2.6	-
2.11.88	12	-	7.0	-	11.6	-	6.4	-	6.7
7.11.88	5	3.1	-	6.2	-	4.5	-	4.8	-
11.11.88	7 ^a	5.5	-	4.8	-	2.8	-	9.7	-
11.11.88	6	1.9	-	2.4	-	5.2	-	5.2	-
1.12.88	10	5.0	-	10.8	-	11.1	-	11.3	-
2.12.88	10	4.2	-	7.1	-	10.4	-	10.5	-
16.12.88	10	4.6	11.9	6.7	5.3	8.4	7.6	6.9	6.3
21.12.88	9	2.8	8.3	3.9	7.4	6.5	5.7	7.2	6.5
21.12.88	9 ^b	7.3	-	6.5	-	6.7	-	12.7	-
4. 1.89	10	5.6	-	8.6	-	12.5	-	13.9	-
6. 1.89	15	5.2	-	8.1	-	16.3	-	17.4	-

^aNo Splitter^bPeak Area Measured with Integrator

Table 3: The summary of the reproducibility tests (spring -89)

Date	Num. of Samp.	The Relative Standard Deviation of the Samples (%)							
		PMCP		PMCH		PDCH:B		PDCH:C	
		pkhgt	vol.	pkhgt	vol.	pkhgt	vol.	pkhgt	vol.
12.4.89	5	2.2	6.5	2.8	4.0	7.3	2.4	6.9	2.8
13.4.89	5	1.3	4.2	1.5	2.8	3.9	1.6	3.9	1.5
14.4.89	5	1.1	3.4	1.1	2.0	3.3	1.2	3.5	1.5
17.4.89	5	0.5	1.6	0.9	2.2	4.7	2.1	4.8	2.5
3.5.89	5	1.6	6.5	0.4	1.1	5.2	2.5	3.9	2.1
21.4.89	5 ^a	6.0	-	3.9	-	1.1	-	1.2	-
24.4.89	5 ^a	1.6	-	1.0	-	0.4	-	0.5	-
25.4.89	5 ^a	3.6	-	2.7	-	0.8	-	0.9	-
26.4.89	5 ^a	9.3	-	6.1	-	1.6	-	1.6	-
27.4.89	5 ^a	3.2	-	2.2	-	1.1	-	1.1	-
3.5.89	5 ^a	4.2	-	2.8	-	1.7	-	1.6	-
5.5.89	10	1.7	-	0.6	-	1.0	-	0.9	-
5.5.89	10	1.9	-	0.8	-	1.1	-	0.9	-
8.5.89	10	1.0	-	0.5	-	0.8	-	0.9	-

^aNo Splitter

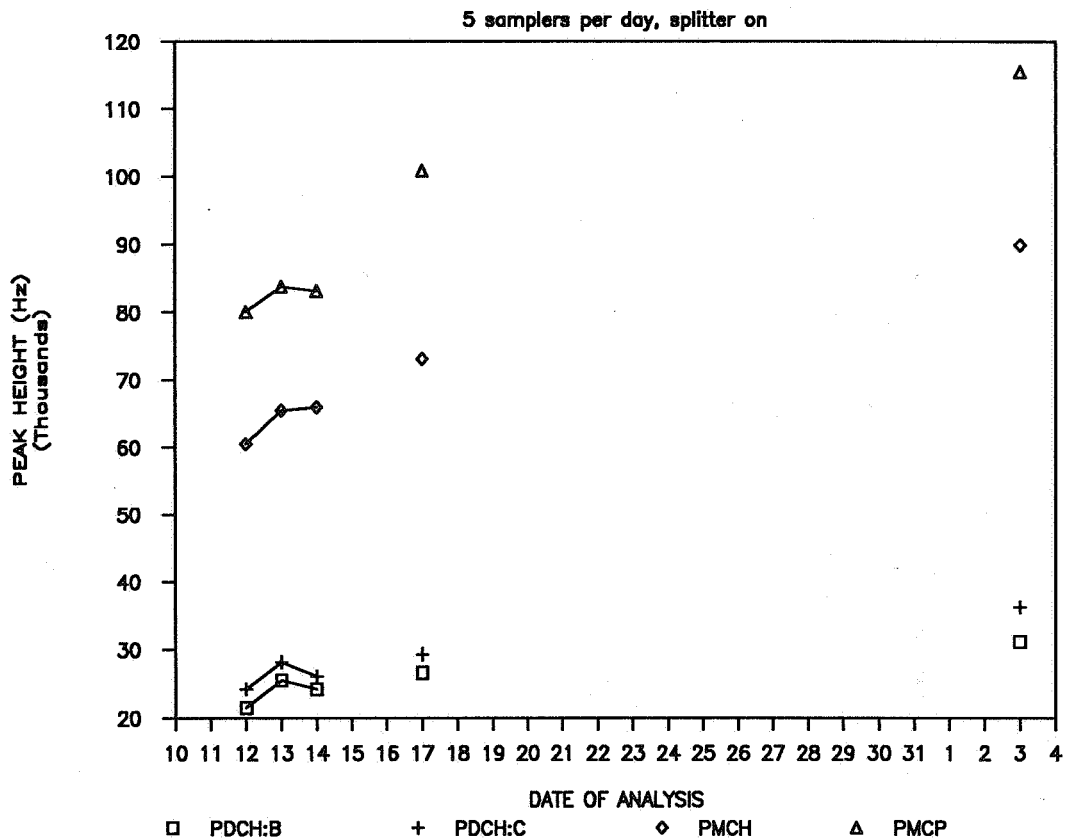


Figure 3: The drift of the analysis system

measurements the effect of poor tracer mixing within a zone must be added to this deviation.

The analysis system is calibrated done by loading samplers with known amounts of calibration gas and analysing the samples. The calibration curve is composed of measured peak heights plotted versus the amounts of loaded gas. A fourth degree polynomial is fitted to this curve. The main problem in the calibration was to determine the concentration of the calibration gas delivered with the system. This was done in the following manner. The permeation sources were used to create equilibrium concentration in a small flask. The flask was kept in a constant temperature. Pure nitrogen was released through a glass heat-exchanger to the flask. The dilution was led to a sample loop in the gas chromatograph. The contents of the loop were flushed with carrier gas to the samplers. Five samplers on five different levels were made. The samplers were analysed without using the splitter. The concentration on the calibration gas cylinder was determined by comparing the gas with this calibration.

The drift of the calibration was studied by making parallel samplers which were analysed on different dates. The analysis was done normally. An example of the results is shown in figure 3. It can be seen that there is a positive drift. The drift seems to be a function of time or the number of analysed samples.

The temperature of the carrier gas can also have an effect on the drift. The effect of this drift can be allowed for by using reference samplers with known amounts of tracers in each run.

4 THE ACCURACY OF THE PFT-METHOD

4.1 The test procedures

The accuracy of the applied PFT-technique was studied in controlled laboratory conditions. Several tests were made during the research project. The principle of the test was always the same: the PFT-method was compared to (in most cases continuous) air flow measurement. The air flows were kept as constant as possible and internal mixing fans were used in all tests except test set IV. Individual tests were arranged as follows:

- I The tests were carried out in September 1986 in test chamber 2. The air flows and temperatures during the test were recorded using a data-logger. The air flow rates were checked with the tracer gas decay method before and after the tests. The samplers were analysed by Brookhaven National Laboratory.
- II The tests were carried out in September 1987 in test chamber 1. The air flows were set before the measurements and the situation was checked regularly. The air flows were measured after the test set with the tracer gas decay method. The temperatures were measured using a recorder. This test set consists of one situation with five different measurement periods.
- III The tests were made in December 1987 in test chamber 1. The air flows and temperatures were measured as in test set II. Different tests had different combinations of tracer sources and concentration levels.
- IV This set was carried out in February 1989 in a test apartment with two rooms and a hall between the rooms. The temperatures and air flows were recorded using a data-logger. The air flow measurement was made with an orifice tube and precision manometer. The first test was a single zone case with the samplers in one place in the middle of the hall. The other tests were two zone cases with samplers placed at 23 points in the apartment. The air flows are calculated from the third tracer emitted in both zones.
- V The purpose of this test was to study the method in measuring air flows in a duct. The sources were placed in a mixing chamber from which the air was exhausted to the duct. The samplers were placed perpendicular to the flow on two sides of an orifice plate. The caps on one end of the sampler caused the samplers to tilt approximately four degrees. The air flow was measured with a vortex meter and recorded with a data-logger. The test took place in February 1989.

Table 4: The summary of the accuracy tests

Set	Test	Num. of Samp.	Reference Air Flow		Measured Air Flow					
			l/s	std%	PMCP		PMCH		PDCH	
			l/s	std%	l/s	std%	l/s	std%	l/s	std%
I	1	2	19.5	10.0	19.7	5.90	–	–	–	–
	2	1	19.5	10.0	20.8	–	–	–	–	–
II	1	5	9.0	15.0	9.60	4.70	9.90	2.50	3.0	5.40
	2	2	9.0	15.0	10.1	1.30	10.3	4.90	6.0	11.3
	3	2	9.0	15.0	9.90	4.20	8.50	11.7	6.20	27.7
	4	3	9.0	15.0	9.70	8.80	10.9	9.50	12.3	16.3
	5	5	9.0	15.0	6.80	4.90	11.8	4.40	–	–
III	1	8	8.0	10.0	6.50	4.90	6.30	3.30	6.80	6.80
	2	7	8.0	10.0	12.2	8.90	8.40	15.0	10.8	12.4
	3	9	8.0	10.0	8.10	5.10	5.50	2.90	7.60	7.90
	4	9	8.0	10.0	4.0	7.0	7.30	5.30	5.30	12.3
	5	8	8.0	10.0	6.80	6.0	7.30	7.80	3.60	8.70
IV	1	29	10.4	10.0	10.7	8.70	11.1	2.60	15.7	4.20
	2a	23 ^a	6.0	10.0	4.0	30.2	–	–	–	–
	2b	23	6.0	10.0	8.30	27.0	–	–	–	–
	3	47	6.0	10.0	–	–	–	–	7.30	10.6
V	1	6 ^b	27.9	3.0	7.80	2.70	5.40	5.30	16.1	3.80
	2	5 ^c	27.9	3.0	6.10	8.70	3.80	15.0	11.9	16.8
VI	1	5	18.4	2.50	18.3	9.40	21.7	1.40	21.3	3.40
	2	15	18.6	2.50	21.1	2.70	20.8	4.60	19.9	3.60

^aThe parallel samplers at the 23 points in the flat were analysed in two runs (2a and 2b). The system was calibrated between the runs.

^bSamplers before the orifice plate

^cSamplers after the orifice plate

VI This test was made in May 1989 in the test apartment. The sources were placed in the rooms and the samplers in one place in the hall. The air flows were measured as in Set V. 20 samplers were split into two lots after three days, otherwise tests 1 and 2 are similar.

The samples were analysed during the building and testing period of the analysis system. The concentration of the calibration gas was allowed for afterwards for sets I–V. The drift of calibration was not taken into account.

4.2 The results of the measurements

The results of the accuracy tests are presented in table 4 and figure 4.

As Fig.4 reveals. there are some rather high differences from the reference. In particular PDCH seems to give a few unreliable results. While studying the results one should bear in mind that the analyses were made during

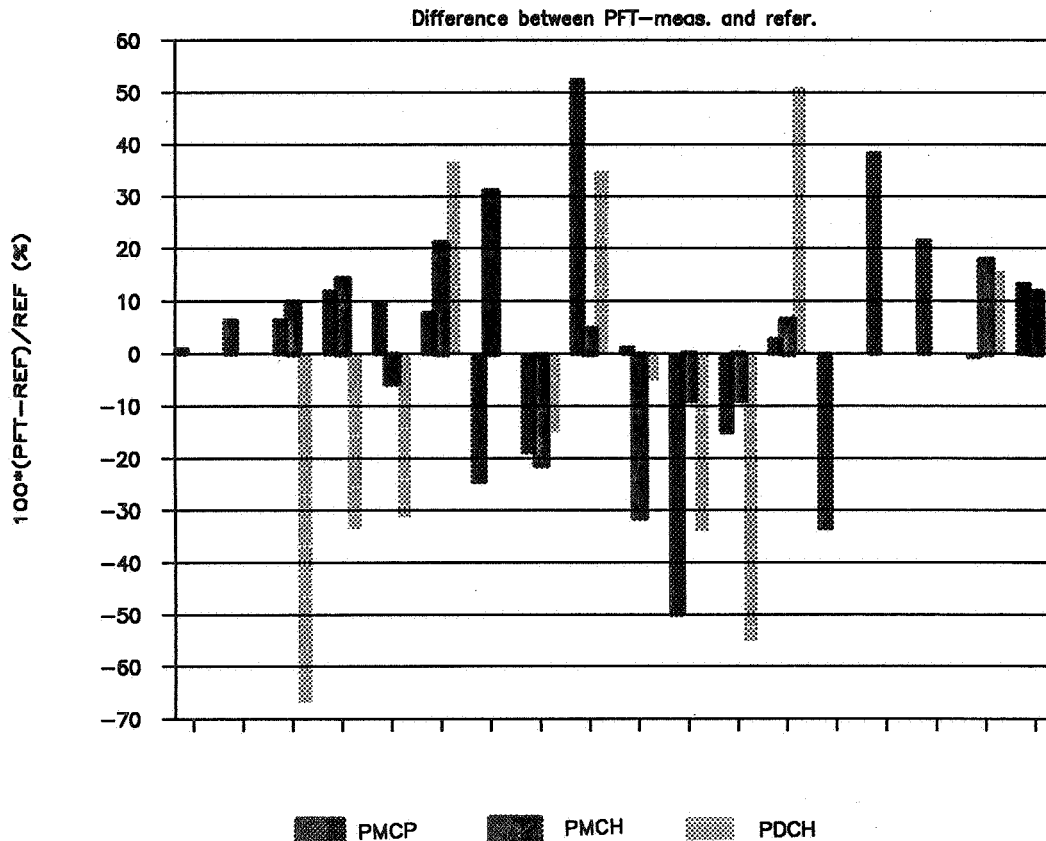


Figure 4: Summary of the accuracy tests in chambers

the building and testing of the system. The best results are gained with the BNL-system, but the system of our laboratory also gives better results towards the end of the testing. It should also be noticed that the air flow rates were quite low, which easily increases the relative differences. Considering also the confidence limits for both PFT- and reference measurement, the relative errors become more acceptable. The results are distributed evenly on both sides of the zero line. Thus, with few exceptions, the inaccuracy of the PFT-method can be estimated to be approximately $\pm 20\%$, when PMCP or PMCH are used. For PDCH the inaccuracy is somewhat higher. Improving the calibration procedure and allowing for the drift of calibration should improve the accuracy of the method. This was indicated by the last test set (VI), where the inaccuracies vary from $-0,5\%$ to $+17,9\%$.

Test V is markedly different from the other measurements. It seems that the sampling rate in a duct increases. This gives higher concentrations and lower air flow rates. The increase in the sampling rate can be due to the dynamic pressure of the flow. The difference between simultaneous tests 1 and 2 is explained by the tilting of the samplers. The samplers in test 1 were tilted so that their opening was on the leeward side of the flow, while the openings of the other samplers were on the windward side. The samplers in test 1 had a lower dynamic pressure on their opening than the other samplers, which gave lower concentrations and thus higher air flow rates. This test implies that the use of the method should be limited to room flow conditions

Table 5: The mixing of tracers in test 1

Tracer in:	Measured volume in:					
	Room 1		Hall		Room 2	
	<i>pl</i>	std-%	<i>pl</i>	std-%	<i>pl</i>	std-%
Room 1	177.3	3.9	112.4	10.4	99.2	5.4
Room 2	26.9	3.9	79.4	7.4	94.5	9.2
Both	111.1	2.7	126.6	5.4	134.2	6.6

Table 6: The mixing of tracers in test 2

Tracer in:	Measured volume in:					
	Room 1		Hall		Room 2	
	<i>pl</i>	std-%	<i>pl</i>	std-%	<i>pl</i>	std-%
Room 1	173.2	20.4	153.6	8.6	169.3	11.8
Room 2	2.9	8.1	294.4	11.1	574.5	7.4
Both	254.4	10.4	482.9	3.2	346.8	7.1

until further research has been done.

5 THE MIXING OF TRACERS WITHIN ZONES

5.1 The measurements in the laboratory

The measurement model assumes that there is instantaneous uniform mixing within each zone. In field measurements this assumption is almost never fulfilled. Poor mixing will cause high deviations in the concentrations, which can yield an ill-conditioned system with unacceptably high errors⁶. The best available estimate of the room concentration is the room average concentration. Sandberg and Stymne⁷ have shown that the use of the average concentration can also cause severe errors in the results, but the errors can be minimized with correct placement of sources and samplers.

The mixing within zones was studied with field and laboratory measurements. The laboratory measurements were carried out in February and March 1989 in the test flat of Helsinki University of Technology. Two different tests were made. In the first test there was only mechanical exhaust from the hall and room 2. In the second test the air was supplied to room 1 and exhausted from room 2. There was one-directional air flow between the rooms. In both tests three tracers were used, one in each room and the third in both rooms. The door between room 1 and the hall was closed but had a 60 cm² opening at the top. Other interior doors were open. The concentrations were measured at 23 points in the apartment. The supply and exhaust air flows, pressure differences and temperatures were recorded using a data-logger system. The results of these tests are presented in tables 5 and 6 and figures 5 and 6.

The results show that the mixing was good, the relative standard deviation

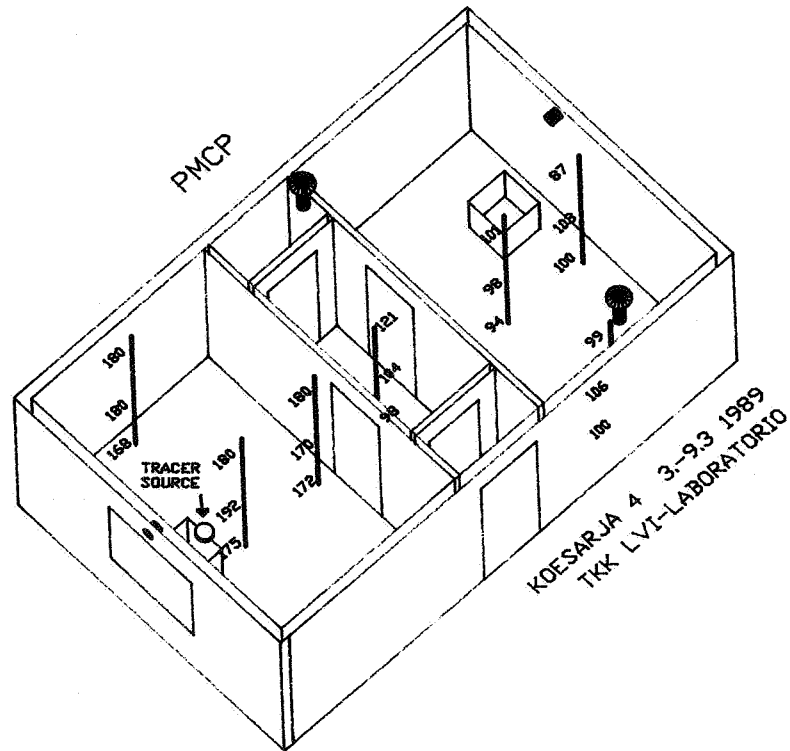


Figure 5: An example of mixing in test 1

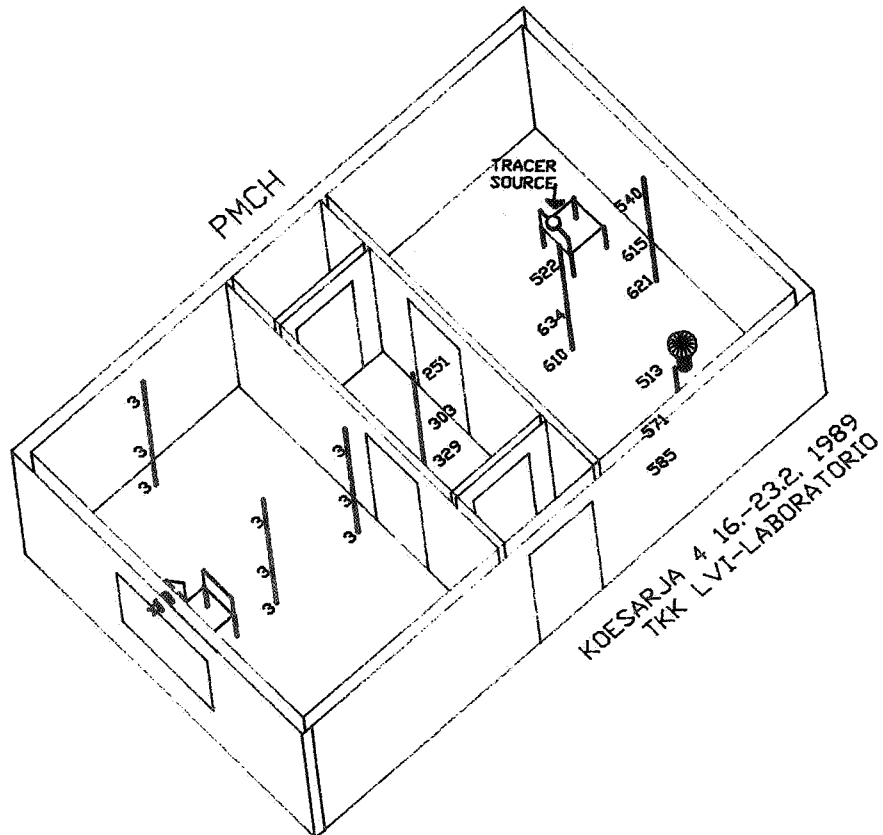


Figure 6: An example of mixing in test 2

Table 7: The distribution of measured homes

	natural ventilation	mechanical exhaust	balanced ventilation	total
single-family	1	1	4	6
semi-detached	7	9	6	22
flat	7	8	7	22
total	15	18	17	50

being generally below 10%. The higher values are caused by samplers placed too close (less than 1 m) to the source. Regardless of the fact that the samples were taken from extreme points in the room, no stratification could be found. The location of the samplers in respect to the sources and the air flows gives a reasonable explanation for the deviations.

5.2 Field measurements

Field measurements were made in typical Finnish homes during the heating season of 1987–1988. The study included 50 homes, the distribution of which is shown in table 7. Ventilation measurements using the passive perfluorocarbon technique were carried out twice during the spring of 1988. The first measurement was in January and the second was in April, the measurement period being two weeks. The buildings were divided into one to three ventilation zones according to the following main principles:

- different floors are different zones
- the sauna section, the door of which is closed most of the time, is one zone
- the master bedroom, the door of which is closed during the night, is one zone

The instructions given by Brookhaven National Laboratory⁸ were applied in the placement of sources and samplers. In the second field measurement period several samplers were placed in zones larger than one room. The standard deviations of the concentrations were calculated in order to see how well the assumption of uniform internal mixing was fulfilled. The results of these measurements are shown in figure 7.

When the interior doors within the zone were kept open during the measurement, the concentration distribution was uniform. The standard deviations of concentration varied from 1% to approximately 25%. The deviations caused by the adsorption rate of samplers and the reproducibility of the analysis system are included. The estimated deviation of 10% gives a fairly good estimate of the errors due to non-homogeneous mixing. The case was more complicated when some of the interior doors within the zone were closed. When a sampler was placed in the same room as the source and the door

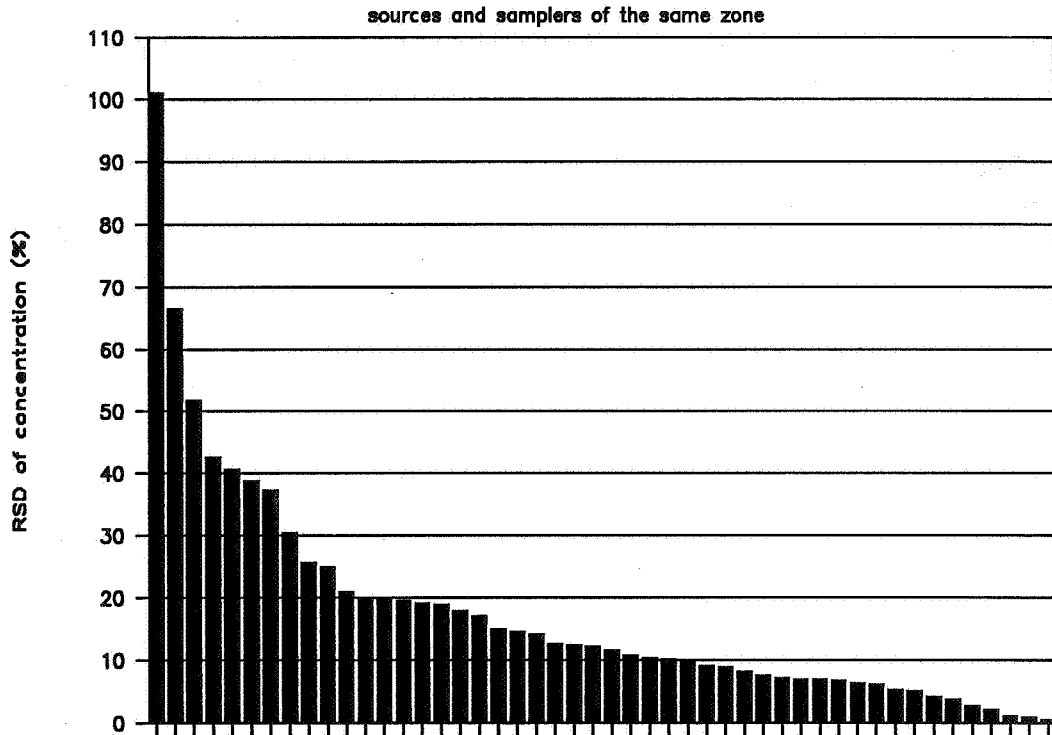


Figure 7: The relative standard deviation of concentration

was closed, the concentration in that sampler was, of course, higher than in other samplers in the same zone. The same problem occurred when a sampler was placed in a small closed space. In these cases the standard deviations of concentration varied from 25% to 100%. The solution to these problems is usually found by modifying the measurement model, but each dwelling is an individual case, so it is difficult to give general instructions.

6 DISCUSSION

The use of passive perfluorocarbon technique for air flow measurements has been developed and tested. The project was divided into two tasks: building and testing of the analysis system and testing of the reliability of the method. Building the system demanded quite a lot of work, because complete, working systems were not commonly available. Each system is an individual, which has its own demands. Building and testing the system took approximately one year. The most difficult problems were the desorption of samples in the rack, desorption from the re-concentration trap and the timing of the system. Once these problems had been overcome and the system calibrated the reproducibility of the analysis was tested. The results show that the relative standard deviation of the analysis for parallel samples is less than 7% for each tracer in most of the cases. The calibration procedure of the system was found to be sensitive to errors, because determination of the curve was based

on only one sample per point. In future the number of samples per point will be increased in order to decrease the uncertainties. A drift of calibration was noticed, but the drift can be allowed for by using reference samples with known amounts of tracers.

The accuracy of the method was tested in controlled laboratory conditions. The results reveal some rather high differences from the reference. Some explanation can be made. It should be noted that most of the analyses were made during the building and testing of the system. If the confidence limits for both PFT- and reference measurement are considered, the relative errors are more acceptable. The results are distributed evenly on both sides of the zero line. Thus, with few exceptions, the inaccuracy of the PFT-method can be estimated to be approximately $\pm 20\%$, when PMCP or PMCH are used. For PDCH the inaccuracy is somewhat higher. Improving the calibration procedure and allowing for the drift of calibration should improve the accuracy of the method.

The test made in a duct flow is markedly different from the other measurements. It seems that the sampling rate in a duct increases. The increase in the sampling rate can be due to the dynamic pressure of the flow. This test implies that the use of the method should be limited to room flow conditions until further research has been done.

The mixing of tracer within zones is crucial to the accuracy of the model. The mixing was tested in laboratory and field conditions. The results of the laboratory measurements show that the mixing was good, the relative standard deviation being generally below 10%. The higher values are caused by samplers placed too close (less than 1 m) to the source. Regardless of the fact that the samples were taken from extreme points in the room, no stratification could be found.

Field measurements were made in typical Finnish homes during the heating season of 1987-1988. The study included 50 homes. The instructions given by Brookhaven National Laboratory were applied in the placement of sources and samplers. When the interior doors within the zone were kept open during the measurement, the concentration distribution was uniform. The standard deviations of concentration varied from 1% to approximately 25%. The case was more complicated when some of the interior doors within the zone were closed. In these cases the standard deviations of concentration varied from 25% to 100%. The solution to these problems is usually found by modifying the measurement model.

In spite of the problems, the PFT-technique can be used to study the ventilation of dwellings. The technique is best suited to studies concentrating on the health and comfort of the people living in the house. If the energy use of ventilation is studied, the use of an integrating technique should be limited to cases with little temporal variation. Further research is needed on the temporal efficiency of air flows before the PFT-technique can reliably be applied in all cases.

The technique is applicable to large field surveys of ventilation. The restrictions mentioned above should be noticed. Anyhow, the complexity of

room ventilation limits the number of potential users of the method. It is important to have enough knowledge of room ventilation in order to be able to conduct the measurements properly and to interpret the results correctly. This holds true for any ventilation measurement method, of course.

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Discussion

Paper 5

N. Bergsoe (Danish Building Research Inst.)

How often do you calibrate your instrument?

J. Sateri (Helsinki University of Technology)

The system is calibrated for every new lot of samples, and/or every two weeks.

N. Bergsoe (Danish Building Research Inst.)

The rubber cap on the sampler may collect tracer gas during a measurement and release it to the adsorption material in the tube later - i.e. if the tube is stored for some time before analysis. This effect may contribute to the positive drift of the calibration.

J. Sateri (Helsinki University of Technology)

Yes, this requires further research.

Saffa Riffat (Loughborough University, UK)

Did you have any problems with the use of PFT's as tracer gases?

J. Sateri (Helsinki University of Technology)

The problems caused by small amounts of analysed tracers and thus danger of contamination were minimised by taking appropriate precautions in the transport and handling of the equipment. The most difficult problems existed with the calibration gases and the determination of the concentration of the gas standard.