

VALIDATION TESTS FOR A PASSIVE TRACER GAS TECHNIQUE

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ABSTRACT

In the frame of a Swiss research project, a passive tracer gas technique for the determination of multi-zone air flow and contaminant transport in buildings was tested, based on previous work in several other countries.

First, emission characteristics of the three different sources (PMCP, PMCH and o-PDCH) and the adsorption characteristics of the passive samplers (standard Perkin-Elmer AD400 adsorption tubes) were established. Then, tests were conducted in a 85m³ air flow chamber in order to determine the influence of the source and sampler position in the room on the concentration measurement accuracy. Tests were made with constant and variable air flow and temperature conditions.

First results showed a non-negligible influence of sinks for these tracer gases in the air flow chamber. Additional tests then showed, that sink problems may also to be expected in typical office or residential building rooms.

The paper gives an outline of the research project, summarises the results of these first tests and discusses the influence of the findings on the applicability of the method.

KEYWORDS

Air flow and contaminant transport, passive tracer gas technique, characterisation, validation, sink effects, application

INTRODUCTION

For the determination of average air change rates a passive tracer method using perfluorinated hydrocarbons is widely used, known as the PFT-method (see Roulet & Vandaele (1991) and Roulet & Gehrig (1998) for an overview on the different methods developed).

Diffusive sources of the PFT with known emission rates are placed in the rooms, where an equilibrium concentration of the PFT is established after some time according to the air change rate. This concentrations are measured with passive adsorption tubes.

In the frame of a Swiss research project, it was planned to set up a passive tracer gas technique for the determination of multi-zone air flow and contaminant transport in buildings, based on previous work in several other countries, e. g. in the US, Dietz (1986) and in the Nordic countries, Sateri (1991), Bloemen (1989), Bergsoe (1989) and Stymne & Eliasson (1991).

METHODS

Characterisation of sources and samplers

PMCP, PMCH and o-PDCH were selected as tracer material (Table 1). Sources were made using 2ml glass vials with 5mm opening and screwed cap. Permeation was through a silicon/teflon septum (Varian No. 03-949835-00). The vials contained approx. 0.5ml of one of the PFT materials.

TABLE 1: PFT MATERIAL USED IN THIS PROJECT

Name		Mol mass	Boiling point [°C]	Density [kg/l]
Perfluoromethylcyclopentan	PMCP	300	--	1.70
Perfluoromethylcyclohexan	PMCH	350	76	1.79
ortho-Perfluorodimethylcyclohexan	o-PDCH	400	101.5	1.85

HFE7100 (Methoxy-nonafluorobutan ($C_4F_9OCH_3$)) was tested as an alternative source, but no satisfactory chromatographic solution could be found. The ether group is the reason for the significant higher detection limits compared to the PFTs used.

For each source the emission characteristics were determined gravimetrically. All sources showed very constant emission rates in time. However the absolute permeation rates varied considerably from source to source, thus requiring an individual calibration of the emission rate of each source. Preliminary tests showed a temperature dependence of the emission rate of about 60% for 12K temperature increase.

Standard Perkin-Elmer AD400 adsorption tubes were used as samplers, with Carboxen569 (20/45 mesh, Supelco SA) as adsorbent medium, and analysed on a GC/ECD system Varian 3400. The adsorption characteristics of these passive samplers were established in a stainless steel chamber of 22.4 m³ volume under a constant air change rate of 1 h⁻¹. The supply air was cleaned by active charcoal filter and conditioned to the desired temperature and relative humidity.

More details on the sources and samplers, on the analytical procedure as well as on the influence of temperature on the emission rates of the sources and on the adsorption rates of the samplers, are given in Hill et. al. (2000).

The relation between amount of PFT tracer adsorbed on the sampler and the PFT concentration in the room is characterised introducing the parameter 'virtual probe air flow' q_p [m³/h], defined as

$$q_p = \frac{q \cdot m}{ER \cdot t_{exp}} \quad (1)$$

with q [m³/h] supply air flow rate in the calibration test cell, m [μg] mass of tracer adsorbed on the sampler, ER [μg/h] emission rate of PFT source, t_{exp} [h] time of exposure.

From this, under stationary conditions, the PFT concentration in the room during the experiment can be determined by

$$c_m = \frac{m}{q_p \cdot t_{exp}} \quad (2)$$

Validation tests in EMPA's air flow chamber

Tests in the air flow chamber of EMPA (figure 1) were performed in one zone under constant as well as variable air flow and temperature conditions in order to simulate situations with mechanical ventilation as well as natural ventilation by window opening. All surfaces in this chamber can be conditioned individually. The zone was conditioned with one wall as an external wall including a window. The supply air inlet was under the window panel.

PFT source were positioned a) near the air inlet, b) on a leg of the table in the middle of the room, c) at an internal wall. Samplers were positioned on all walls, at the opposite table leg and in the exhaust.

Room air flow characteristics and air flow rates were determined online using a Bruel&Kjaer 7620 active tracer gas measurement equipment. N₂O was injected in the supply air and SF₆ at the location of one of the PFT sources. Concentrations were measured in the supply inlet, at the positions of the PFT

samplers and in the exhaust. Such, the history of indoor air condition was fully recorded and analysed for later comparison with the PFT sampler results. In addition, a person dummy (80W) was placed besides the table (figure 2).

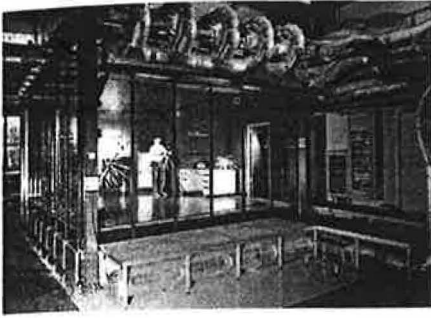


Figure 1: Air flow chamber at EMPA

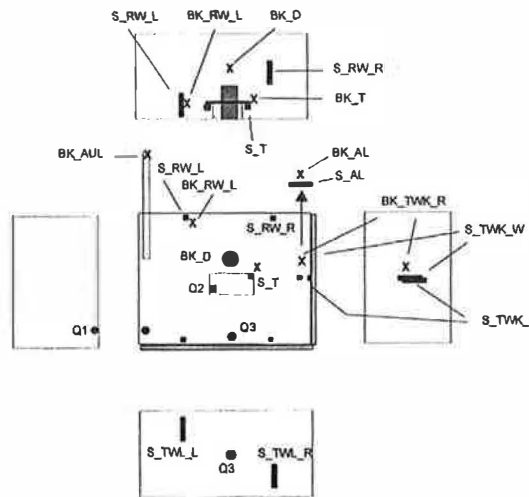


Figure 2: Positions of sources (Q.), passive samplers (S...) and Bruel&Kjaer active tracer technique sampling points (BK...)

Sink tests

In the air flow chamber

Preliminary results and checks of the PFT concentrations measurements showed discrepancies to the results of the Bruel&Kjaer tracer gas measurements. Crosschecks indicated a sink problem in the air flow chamber for all three PFT types, although not to the same degree. Therefore, the planned test were abandoned and sink test were performed under constant temperature and air flow rate condition. The PFT sources were placed in the test chamber and active adsorbent sampler probes (with a constant probing flow induced by a calibrated pumping system) were taken at regular time intervals of 12 to 24 h.

Sink tests in two office rooms

Since the air flow chamber with its two air conditioned transparent acrylic glass walls is not very representative for normal housing rooms, additional sink tests were performed in two office rooms at EMPA. The first room (LA125) was a fully operational office equipped by furniture, computer, books etc., and naturally ventilated through a small window gap. The second room (BA 245) was an empty office room with a supply fan installed to keep the outdoor air flow at a more constant rate (0.73 to 0.80 h⁻¹). Additional small fans were used in the room to assure complete mixing, see figure 3. The measurements were made during a time period of 200h.



Figure 3: Test set up in the room BA 245

RESULTS

At an outdoor air change rate of approx. 1 h⁻¹, PFT concentration in the air flow chamber were measured over a period of several days. As shown in figure 4, the measured concentrations were well

below the expected theoretical steady state concentration c_0 , as calculated from the PFT emission rate ER [$\mu\text{g}/\text{h}$] and the average supply air flow rate q [m^3/h], assuming no sinks in the room:

$$c_0 = \frac{ER}{q} \quad (3)$$

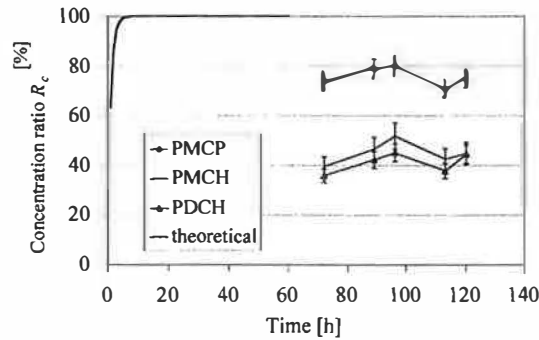


Figure 4: Concentration ratios R_c in function of time for the three PFT's used, as measured in the air flow test chamber, and the theoretical R_c . Air change is constant at a rate of 1.0 h^{-1} . Error bands are 95% confidence intervals.

Quite similar results could be observed in the two office rooms. Figure 5 gives results for the office room BA 245. Air change rate values are calculated in function of time from the concentrations of the different tracer gases. The values for N_2O represent the actual outdoor air change as measured continuously with the Bruel&Kjaer 7620 equipment by constant-emission method. The other values are determined from the results of the actively sampled adsorption probes. The starting values are too high because the concentrations have not reached steady state values yet.

Table 2 and figure 6 give values for the concentration ratio R_c as the ratio of the measured steady state concentration c_m to the theoretical expected steady state concentration without sink c_0 , for the three PFT's and for the three measured spaces.

TABLE 2: RESULT SUMMARY OF THE SINK EXPERIMENTS

Room	Volume [m^3]	Air change rate [h^{-1}]*)	Temperature [$^{\circ}\text{C}$]	Concentration ratio R_c [%]		
				PMCP	PMCH	PDCH
Calibration chamber	22.4	1.0	22	100 **)	100 **)	100 **)
Air flow chamber	85.4	1.0	20	80	52	45
Furnished office LA 125	77.9	0.12	22	84	74	62
Empty office BA 245	98.7	0.79	19	62	55	58

*) Average air change rate determined by N_2O decay or constant emission technique

***) The method is calibrated in the stainless steel chamber, assuming no sinks in this chamber

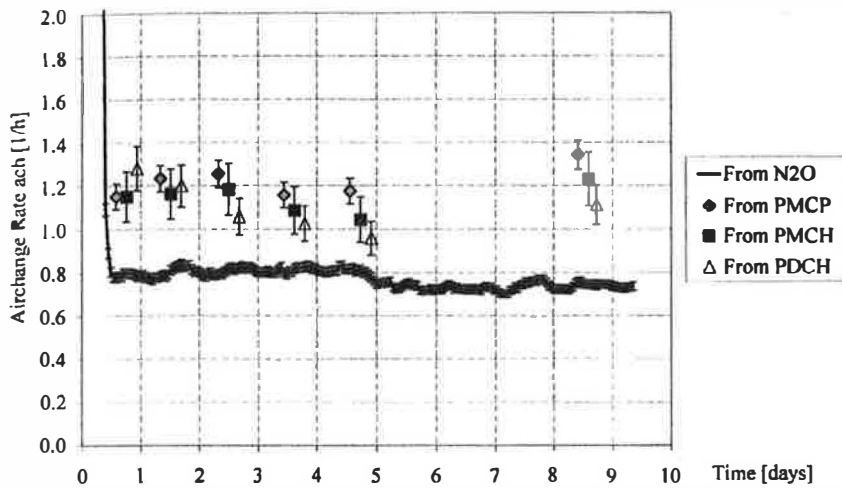


Figure 5: Air change rate values in function of time in the office room BA 245, as determined from the concentrations of the different passive tracer gases (with two adsorption tubes at one time, values separated in time in the figure for clarity). The values for N_2O represent the effective outdoor air change. Error bands are 95% confidence intervals.

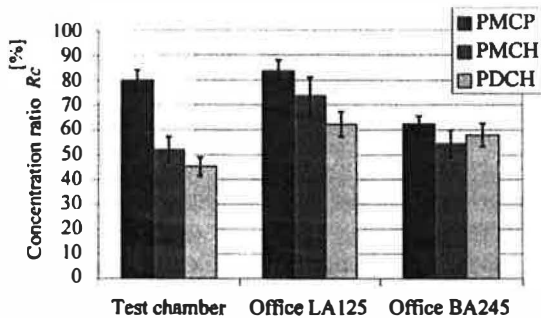


Figure 6: Concentration ratios R_c for the three PFT's used, as measured in test chamber and the two office rooms. Error bands are 95% confidence intervals.

CONCLUSIONS

During validation tests for a passive tracer gas method in an air flow test chamber, sink effects for the PF tracers used have been observed and then further studied under steady conditions in two office rooms. Concentrations repeatedly measured over a period of several days are well below the expected steady state concentrations without sinks. Thus, when determining air flow rates by passive sampling with the three source gases used, the air flow rates will be overestimated by a factor in the range of 1.2 to 2.2. Additional tests, documented in Hill et al. (2000), have also shown significant temperature sensitivities of both tracer emission rates and sampler adsorption rates. This indicates that the tracer substances used in this project can hardly be further considered as useable for such applications.

While problems of errors associated with tracer gas measurements have been treated by a number of authors, also for passive methods, e.g. by D'Ottavio et al. (1987) and Sherman (1989), only few has been found in the literature on sink effects of passive tracers.

Therefore, further work has to focus on the sink characteristics and the underlying chemistry, on temperature effects, and on tests with other source gases. An extended evaluations of the calibrations and the experiences made with existing methods and tracers used may also be considered.

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