INFLUENCE OF AIRFLOW ON THE PERFORMANCE OF THE PERFLUOROCARBON TRACER TECHNIQUE FOR MEASURING VENTILATION RATES

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Abstract

The perfluorocarbon tracer technique (PFT) is being extensively used for determining air infiltration rates in residences and office buildings. The method has been evaluated in chamber studies for effects of temperature, variable ventilation rates and orientation of the passive capillary collectors in low air velocities (<0.2m/s) typical of residences. This paper presents the results of chamber studies designed to evaluate the PFT method under conditions of constant temperature and high air velocities (0.8 to 6.4 m/s). The efficiency of the passive capillary collectors was evaluated as a function of air velocity and orientation in the flow. Two different enclosures for the collectors, designed to minimize the air velocity effects, were also evaluated. The results indicate that air velocities above 0.8 m/s and collector orientation affect the efficiency of the collectors. Enclosing the collector and orienting it 180° to the flow minimizes the effect.

Introduction

The determination of air infiltration or ventilation rates in residences or commercial buildings is necessary in order to assess the effectiveness of weatherization programs or efforts to reduce energy consumption and to develop and evaluate models for infiltration or ventilation and assessment of indoor air contaminant concentrations.

The only direct measure of air infiltration or ventilation under normal occupancy conditions is by the tracer technique, either by tracer gas decay method or by steady-state tracer gas method. One steady-state tracer gas method for assessing air exchange rates, developed at Brookhaven National Laboratory and called the Brookhaven National Laboratory Air Infiltration Measurement System (BNL/AIMS) (1), is being extensively employed. The BNL/AIMS method consists of miniature perfluorocarbon tracer (PFT) sources and miniature passive capillary adsorption tube samplers (CATS). The PFT sources emit one of four perfluorocarbon gases at a constant rate. The CATS passive

samplers can sample the PFT for periods of one hour up to several months. After sampling the CATS are thermally desorbed into a gas chromatograph for determination of the PFT. Sampling is done under steady-state conditions and the infiltration/ventilation rate or air exchange rate calculated.

In an earlier report (3) we evaluated the BNL/AIMS method in an environmental chamber. For low air movements (<0.2 m/s), typical of those found in residences, the effect of CATS orientation does not effect the sampling rate. The method performed well under conditions of widely varying air exchange rates and room temperature fluctuations of as much as 8°C can be accounted for.

In this report we present the results of chamber studies designed to determine the effect on the CATS sampling rate in high air velocities and methods to minimize those effects. Quantification of the error or effect due to air flow is important in determining whether the BNL/AIMS system can to measure air volume flows in ducts.

Methods

The experiments were conducted in a fully controlled and well mixed 34m^3 environmental chamber (see ref. 2 for chamber description). A constant temperature (25.0 ± 0.1°C), relative humidity (60 ± 5%), fresh air exchange rate (2.5 air changes per hour, ach) and complete mixing were maintained through all experiments. The top half of Figure 1. shows the measurement setup in the environmental chamber. Three PFT sources were placed in the chamber for all runs. Overall steady-state chamber concentrations of the PFT source were determined by three CATS spread through the chamber for each experiment. The average of these three CATS samples served as the base of comparison for the CATS samplers sampling at various air flows. A 3 m long °.46 m in diameter windtube was placed in the chamber to provide the variable air velocities. CATS samplers were placed at three locations in the cross-section of the windtube (two in the middle and one at an edge) approximately 0.46 m from the end of the windtube. The air flow in the windtube is produced by a fan at the end of the tube and is measured at the locations of the CATS samplers with a TSI model 1650 Air Velocity Meter (for velocities ≤ 3m/s) and with a Pitot tube connected to a manometer (for velocities > 3m/s). Measurements were made for windtube flows of 0.81, 1.75, 2.49, 3.80, 5.14, and 6.38 m/s. All measurements were conducted twice and for the CATS samplers oriented at three different angles to the flow (0°, 90° and 180°). For this set of experiments the CATS samplers were used without any protective enclosures. Each experiment was conducted over a six hour period.

A more limited number of experiments were conducted to determine if air flow effects could be minimized by partially enclosing the CATS samplers in protective containers. Six measurements, at the three angles to air flow in the center and at the edge of the windtube, were made with the CATS samplers placed in a plastic tube with the front end open (enclosure A in the lower portion of Figure 1). Another three measurements, at the three angles to air flow in the center of the windtube, were made with the CATS samplers in a tin enclosure with the front end open (enclosure B in the lower portion of Figure 1.). In these experiments one CATS sampler in the chamber was enclosed in the same protective enclosure as that being used in the windtube. The enclosures were evaluated at a windtube air flow.

Results and Discussion

The results of all experiments are presented in terms of the relative error, presented as a percent. The relative error is PFT concentration measured by the CATS samplers in the wind tube minus the PFT concentration measured by the CATS samplers in the chamber divided by the PFT concentration measured by the CATS samplers in the chamber. The 95% confidence interval for samples collocated at the center and edge of the windtube were calculated to be 7.6% and 9.6% respectively.

The relative error of the CATS sampler concentrations due to air flow around the samplers for the three angles to flow in the center and at the edge of the windtube as a function of air velocity is shown in Figure 2. Also shown in Figure 2 is the estimated reliability interval for the six air velocities at which the experiments were conducted. The CATS samplers in the windtube recorded higher concentrations of PFT for almost all air flows, locations and sampler orientations relative to the levels measured in the chamber. All measurements with the air velocities over 0.81 m/s had relative errors greater than the calculated 95% confidence limits.The relative error of samplers located in the windtube generally increased with increasing air velocities, with the effect greatest at the edge of the windtube. The least impact was seen for CATS samplers oriented at 180° to the flow and at the center of the windtube, where the relative error reached a maximum of 16%.

The results of the measurements with the CATS samplers in enclosures is shown in Figure 3. The PFT concentrations measured by the CATS samplers in the enclosures and located at the center and edge of the windtube at the three orientations for an air velocity of 6.41 m/s are compared to the chamber concentrations measured by CATS samplers with and without the enclosures. The CATS sampler with the enclosure in the chamber was found to be 16% lower in PFT than the unenclosed CATS sampler in the chamber. Both enclosures reduced the relative error compared to the results without enclosures (Figure 2 - 6.41 m/s condition). The tin enclosure was better than the plastic enclosure in reducing the relative error. The relative error is less when the unenclosed chamber CATS samplers are the base of comparison (striped bars in Figure 3).

The impact on the results of variations in the chamber conditions (degree of mixing, temperature, ventilation, etc.) is probably very small as is errors associated with chemical analysis of the CATS samplers (2). The impact of of air flow around the CATS samplers in the chamber (locations 4, 5, and 6 in Figure 1.) due to the windtube is more notable. At the high windtube flow rate (6.41 m/s) CATS sampler 4 (closest to the air exiting the windtube) was 7.8% higher than CATS sampler 5, leading to a small underestimate of the relative errors.

In general there are two major reasons for a change in the sampling rates of the CATS samplers: pressure and turbulence. In order to determine the impact of pressure we made a limited number of measurements of the pressure differences between the pressure in the sampler and the pressure in the chamber and compared the results to the relative errors of the measured concentrations. The pressure was determined in the center of the windtube at the full range of air flows by removing the caps from the CATS samplers, emptying the absorbent from the tube and connecting it to the a manometer. Measurements were taken at the three orientations to flow (0°, 90° and 180°) and the angle where the pressure is zero. Pressures in the CATS samplers were lower than the static pressure at an angle of 90° and 180° and higher at 0° with the differences increasing with increasing flow. The angle of zero pressure was 62°. Measured PFT levels (relative error) in the CATS samplers in the windtube for all orientations, including a run for the angle of zero pressure on the sampler were higher than the levels measured in the chamber.

This indicates that for these concentration differences, pressure is not the major contributor to the change in sampling rates, in agreement with theory that indicates no pressure dependence (2). It is most likely that turbulence is the primary reason for the increased sampling rate of the CATS samplers in flows above 0.81 m/s.

It is not known why a 16% difference in general chamber concentrations of PFT was found between the enclosed and open CATS samplers when the windtube flow was 6.41 m/s (the enclosed sampler being lower). Both types of samplers were at position 4 (Figure 1). Since the highest air velocity was used for these measurements and the average amount of PFT collected at position 4 was 7.8% higher than at position 5, it is possible that the difference between the amount of PFT collected by the sampler without an enclosure and with an enclosure is caused by an error in the sampling rate of the sampler without the enclosure. The sampling rate would be higher in the sampler not enclosed due to turbulence. This error would have the potential effect of increasing the true relative errors for at least those experiments conducted at the higher flow rates, including those experiments assessing the effectiveness of various enclosures.

Conclusion

Our chamber experiments conducted on the impact of air flow on the CATS samplers used in the BNL/AIMS infiltration/ventilation measurement method indicate that: 1) air flows above 0.8 m/s will result in higher sampling rates, resulting in a underestimate of infiltration/ventilation rates; 2) the error will increase with increasing air flows; 3) the error will be most pronounced when the CATS samplers are oriented at 0° and 90° to the flow and minimized with and orientation of 180°; 4) the positive errors are likely due to turbulence; and, 5) protective enclosures for the CATS samplers and orientation at 180° to the flow will minimize the sampling error. This study indicates that more work needs to be done to identify the most efficient type of enclosure for the CATS samplers under a wider range of air flows.

References

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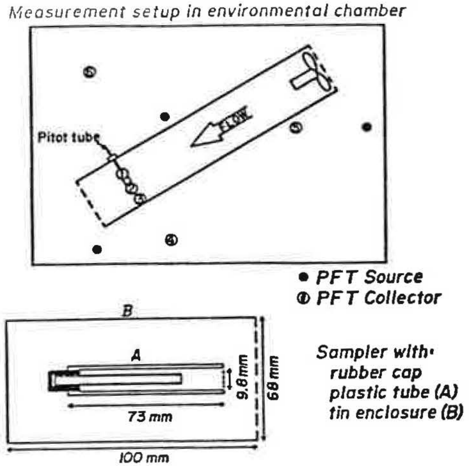

Figure 1. Plane view of chamber experimental setup for evaluating effects of air flow on the CATS sampler (PFT collector) and the various enclosures for CATS samplers. Top part of figure shows the location of the windtube in the environmental chamber, location of the PFT sources and collectors. Bottom half of figure shows the PFT collector and the size of the two types of enclosures tested.

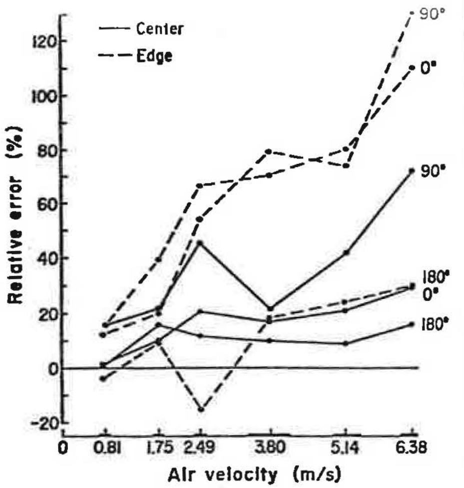

Figure 2. The measured relative error due to air flow around the CATS sampler as a function of air flow, sampler orientation to flow and location (center or edge) of the windtube. Also shown on the x-axis is the reliability interval of each of the six air velocities used.

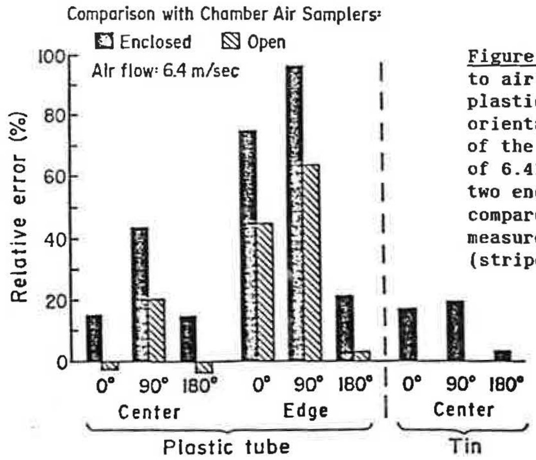

Figure 3. The measured relative error due to air flow around the CATS samplers in a plastic and tin enclosure for three different orientations to flow, at the center and edge of the windtube for the high air flow setting of 6.41 m/s. Windtube measurements with the two enclosures for the CATS samplers are compared to both the chamber concentrations measured with (solid bars) and without (striped bars) the enclosures.

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