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FIELD MEASUREMENTS OF VENTILATION RATES IN 130 HOMES FOR INDOOR AIR QUALITY ASSESSMENTS

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Abstract

Three different types of methods for estimating ventilation rates in residences have been presented and the results of each method discussed. Field measurement experiences have helped to identify the potential errors of these methods. To date, the best correlations obtained have been between the constant emission tracer methods involving perfluorocarbon and tracer gases. It is expected that a better understanding of the parameters that affect all of the techniques, specifically, mixing volume, will lead to improved accuracy.

Introduction

The field assessment of ventilation rates using several methods has been conducted in a total of 130 homes. The methods used were the fan pressurization technique (2,4,5,10), grab bag SF_6 tracer decay measurements (6), continuous SF_6 emission tracer methods (12) and perfluorocarbon tracer (3). The data set consists of homes from three studies. All four types of assessment were not conducted in every home.

Twenty-four homes were tested in conjunction with a wood smoke study in Waterbury, Vermont during January and February of 1982 using grab bag SF_6 tracer decay methods and fan pressurization techniques. Details of the results and methodology for the air pollution measurements have been presented elsewhere (9,13).

In a second study, fifty-nine homes were tested during a follow-up visit to homes in the Portage, Wisconsin area in February and March of 1983 using the grab bag SF_6 decay method and fan pressurization technique. The detailed results of the air pollution measurements are presented elsewhere (11).

Fifty homes were tested as part of an energy conservation weatherization study in the Madison, Wisconsin area during the winter of 1982-1983. The techniques used included fan pressurization tests, constant emission SF_6 tracer tests, and grab bag SF_6 tracer decay and perfluorocarbon tracers (PFT) in a subset of the homes (8).

Methods

Fan Pressurization: The fan pressurization (blower door) tests in the three studies were performed using a blower door supplied by Energyworks of Newton, Massachusetts, USA. In general, the tests were performed in accordance with ASTM method #E779-81 (2) and methods developed at Lawrence Berkeley Labs (5). Since many of the tests were performed in the coldest months of the winter they were conducted at the limit or just above those limits specified by ASTM section 8.11. For example, the indoor/outdoor temperature difference was in excess of 28^{o}C in many of the Portage, Wisconsin and Waterbury, Vermont homes. For a few homes the wind speeds approached 4.5 m/s. In homes where wood burning was the primary source of heat, building depressurization was not conducted as recommended by ASTM. Fan calibration data (in accordance with ASTM) was provided by the door manufacturer for determining flow rates as a function of RPM and pressure difference.

Tracer Decay (SF_6): Grab bag tracer decay measurements were performed in 93 of the study homes. These measurements were performed in accordance with the methods used by NBS (6) and Princeton University (7). Contamination-free gas sample bags were used to collect four samples over a two to four hour time interval, after allowing for mixing to occur.

Constant Emission Tracer (SF_6): Using a method developed University of Wisconsin (12), integrated average ventilation rates were obtained for approximately 24-hour periods. SF_6 tracer gas was released at a constant rate and integrated samples were collected in contamination-free sample bags using a timed sampling mechanism. These measurements were performed on the fifty Madison area weatherization retrofit homes during both winter seasons (1982-1983 and 1983-1984), although the discussion here is limited to the first set of these measurements.

Constant Emission Perfluorocarbon Tracer: Average ventilation rates were obtained on a small subset of the Wisconsin weatherization homes during the winter of 1982-1983 (8) using methods developed at Brookhaven National Labs (3). During the 1983-1984 heating season these measurements were increased to include all fifty homes. The method uses two to four constant emission perfluorocarbon (PFT) sources and passive capillary absorption tube samples (CATS). Because of the high sensitivities involved in the method, special precautions were taken to avoid contamination during shipping and storage.

Results and Discussion

The results and discussion which follow present the possible sources of error for each method and suggestions for improving the accuracy of each method. The results are presented in Tables 1 and 2.

Pressurization Tests: In several homes the direction of the motor (forward or reverse) was changed rather than physically turning the fan around. The motor was calibrated, RPM vs. pressure difference, for both directions. However, because the fan was not physically turned around, but run in reverse, there is a potential error in the determined Effective Leakage Areas (ELAs - building leakiness expressed as area open to outdoors). Fifteen homes in the Portage, Wisconsin study were pressurized or depressurized with the fan running in both the forward and reverse direction, so that the principle differences should be attributable to random error or to the effect of fan direction (Table 1). The average absolute difference in calculated ELAs when fan was reversed was found to be 5.2% (standard deviation 3.0%), indicating that this was not a major source of error in these measurements. For a total of 69 homes (Table 1) the mean difference was 11.7% (standard deviation 23.8%). Other possible errors can result from pressure-induced openings or closings during testing. All of the data reported here was scanned for differences exceeding 20%, and then checked for evidence of openings (upward sloping) or closings (downward sloping) in the test plots. Only pressurization measurements were conducted in homes with wood stoves or fireplaces for safety reasons (Waterbury, Vermont).

Fan Calibration: The accuracy of calibration of the fan, in both directions, directly relates to the accuracy of the test results. This may not be a linear relationship (square root of pressure differences is used in calibration equation). There appears to be some variability in the flow at a given RPM at different pressurizations. This may also be effected by the wind (gusting).

Model Estimates: Wind and temperature influences on infiltration do not act independently (1). See Table 2. In addition, the relationship of infiltration to wind may not be linear; logarithmic and quadratic relationships have been suggested.

The model does not include active ventilation (e.g., exhaust fans, door and window openings) or the influence that furnace or other combustion appliances have on natural air infiltration. It also does not include the passive or active stack flow through a chimney. These factors would increase the infiltration estimate, while the differences we are observing (Table 2) appear to have the LBL model over-predict the ACH (air changes per hour).

Tracer Decay Measurements: A potential source of error is the assumed mixing volume. Typically, we are assuming that the air leaving the home has the same average tracer gas concentration as the air inside of the home. Incomplete mixing will give errors in the air infiltration estimated by this test. These mixing problems include the incoming air not being evenly dispersed throughout the structure and the existence of dead spots, possibly in separate rooms or in partitioned sections of the same room. The former has been described as "plug flow" which possibly results from the tracer containing air being pushed without mixing. These problems are suggested by curve portions of the trace decay lines plotted on semilog paper. The dead air problem seems to be more related to the question of an effective vs. physical volume.

Approaches to this problem are: 1) use the furnace fan (if present) or floor fans to improve initial mixing of the released tracer gas into the structure; 2) leave the doors between rooms open (also doors to cabinets or other partitioned spaces); 3) take the air sample from various points in the home. This requires identifying the exact zone that should be tested, based on the type of heating system and the pathways available for exchange of air between various zones (e.g., first and second floors). If air cannot move freely between these zones, you may only be testing the air flow out of one zone and not for the entire structure. When these limits are determined, the tracer gas release and collection should occur in the same testing zone. Some researchers use multiple sources and collectors for different floors.

<u>Constant Emission Tests (SF_6 and PFT)</u>:

Effective Volume - The model used for these tests (with a single) assumes a single compartment, while the homes being tested may have several compartments. This problem is noted when comparing the results of these tests with the estimates given by the blower door measurements. Blower door measurements dynamically include a large proportion of the physical volume of the home, including basements and the pathways for air flow often found in (hollow) interior walls. Tracer tests operated at the equilibrium pressures, so the pathways available for air flow might be more limited and the effective volumes less than that calculated for the LBL model estimates.

There are several home-to-home differences that make the estimation of an effective volume difficult. These include the type of heating system used in the home (forced air, convection, electric baseboard, floor furnace, hydronic, etc.) and the physical layout of the home (doors to rooms and stairways, number of floors, type of foundation, etc.).

Placement of Collectors and Sources - At the beginning of the study, some sources were placed in the same room as the collector (min. of 12 ft. apart). Later, the collectors were located in a separate room from the source. This procedure was used to avoid air flow moving within a room from the source to the collector, without mixing with the rest of the room or home air. During the last monitoring cycle we used multiple collectors in most homes (co-located with the BNL collectors) to check for mixing problems. Results will be presented at the conference.

Special precautions must be taken to avoid contamination of the CATS samplers used in the PFT method. Samplers and emitters should not be shipped in the same package, or even on the same day (as was done with those used in our study). Control field blanks (for contamination in transit to and from homes) and tight caps that should be routinely used.

Source Flow Rates - With the SF_6 method there are possible errors introduced in measuring the source flow rates using the micro-pipette. We were taking three on/off flows, and averaging these to estimate the source flow rates. This may have been more of a problem with the earlier tests (fall). For both the PFT and SF_6 methods there are unresolved questions regarding the influence of changes in the source flow rates over time attributable to temperature variations in the homes (or to the decay in SF_6 pressures), larger SF_6 flow rates would minimize these problems.

Collectors - The sampling rate of the CATS collectors is assumed to be constant. Some consideration should be given to changes in the collection rate with temperature or face velocity. The SF_6 collector samples at a set rate (with some variation between collectors in the frequency and duration of the sampling), although there have been problems with connecting and opening the bags and with obtaining enough air in the sample for the required testing.

Analysis - Both systems use gas chromatographic analyses. Accuracy of the GC analysis procedures used depends on preparation and use of standards and columns as well as the volume of sample injected. For the PFT method, there is some concern over interferences from other freons in the home.

Both of the constant emission techniques estimate the average infiltration rate over some sampling interval. If there are some changes in the infiltration rate during this time, this will change the concentration of the tracer from the steady-state concentration which may introduce some errors into the estimates.

Acknowledgments

The authors wish to thank all of the volunteers who participated in the three studies for their cooperation and assistance in making these measurements. We also wish especially to thank David Bearg of Life Energy Associates, Russell Dietz of Brookhaven National Laboratories, and Bruce Dickinson and David Grimsrud of Lawrence Berkeley Laboratories. This work was conducted under NIEHS (ES01108), US EPA 68-02-3201 and 2974, and by the Wisconsin Power and Light Company.

References

1. Blomsterberg, A.K., Harrje, D.T. Evaluating air infiltration energy losses. ASHRAE Journal, May 1979, 25-32.
2. Committee E-6 Performance of Building Constructions, "Standard practice for measuring air leakage by the fan-pressurization method" #E, 779-81, ASTM, Philadelphia, PA..
3. Dietz, R.N. and Cote, E.A. "Air infiltration measurements in a home using a convenient perfluorocarbon tracer technique." BNL #30797R, Department of Energy and Environment, Brookhaven National Laboratory, Upton, NY.
4. K.J. Gadsby, G.T. Linteris, G.S. Dutt, and D.T. Harrje. The blower door. Princeton University Center for Energy and Energy Studies, Report #124, October, 1981.
5. Grimsrud, D.T., Sandregger, R.C., Sherman, M.H. Infiltration Measurements in Audit and Retrofit Programs" LBL-12221, EEB-epb-81-10. Presented at the International Energy Agency (IEA) Energy Audit Workshop, Elsinore, Denmark, April 13-15, 1981, pp. 2-6.
6. Grot, R.A. "A Low-Cost Method For Measuring Air Infiltration Rates in a Large Sample of Dwellings." ASTM Special Publication 719, Philadelphia, 1980, pp. 50-59.
7. Harrje, D.T., Gist, R.A., Grimsrud, D.T. "Air Infiltration Site Measurement Techniques" Second A.I.C. Conference B.D.F.M.A.I. Royal Institute of Technology, Stockholm, Sweden. September, 1981. pp. 124-5.
8. Quackenboss, J.J., Kanarek, M.S., Kaarakka, P., Duffy, C.P., Flickenger, J., Totzke, D., Turner, W.A. "Residential Indoor Air Quality, Structural Leakage and Occupant Activities for 50 Wisconsin Homes" To be presented at Indoor Air 1984, Stockholm, Sweden, August, 1984.
9. Sexton, K., Spengler, J.D., Treitman, R.D., Turner, W.A. Winter Air Quality in wood-burning community: A case study in Waterbury, Vt. Accepted for publication in Atmospheric Environment, 1984.
10. Sherman, M.H., Grimsrud, D.T.. "Infiltration - Pressurization Correlation: Simplified Physical Modeling" ASHRAE Transaction. 86: 778-807.
11. Spengler, J.D., Duffy, C.D., Letz, R.E., Tibbets, T.W. and Ferris, B.G. Jr. Nitrogen Dioxide inside and outside 137 homes and implications for ambient air quality standards and health effects research. Environmental Science and Technology, 17:164-168, 1983.
12. Totzke, D., Quackenboss, J.J., Kaarakka P., Flickinger, J. A modified tracer Gas infiltration method for use in a residential indoor air quality/weatherization study. To be presented at Indoor Air 1984, Stockholm, Sweden, August, 1984.
13. Turner, W.A., Treitman, R.D., Bearg, D., Sexton, D., Spengler, J.D. Home Energy Efficiency and Indoor/Outdoor Air Pollution in a Predominantly Wood Burning Community. Presented at the Second International Congress on Building Energy Management, June, 1983, Ames, Iowa. Proceedings published by Iowa State Research Foundations, Ames, Iowa.

Table 1. Summary Statistics for Air Infiltration and Leakage Measurements.

Study	Measurement	n	Mean	Median	Std. Dev.	Percentiles 25%	Percentiles 75%
Combined	ELA (sq.cm)	133	1298	1189	643.	945	1561
	ACH-50 Pa	133	21.1	18.6	12.0	12.4	28.0
	Diff. ELAs(%)	63	11.7	8.80	23.8	-7.9	25.4
Wisconsin 50 Home Study	ELA	49	1262	1144	487.	977	1515
	ACH-50 Pa	49	26.4	24.8	0.61	17.8	24.8
	Diff. ELAs(%)	34	10.5	6.14	25.2	-13.3	26.4
	PFT ACH	9	0.45	0.36	0.27	0.28	0.55
	Tracer Decay	9	0.37	0.21	0.43	0.08	0.88
	Constant Flow SF_6 ACH	108	0.53	0.43	0.49	0.29	0.60
	LBL Model	132	1.14	1.01	0.51	0.76	1.42
Portage, Wis	ELA	59	1407	1257	757.	980	1601
	ACH-50 Pa	59	18.8	13.5	12.2	10.3	25.5
	Diff. ELAs(%)	29	13.2	10.7	22.4	-2.5	25.4
	Tracer Decay	57	0.33	0.20	0.41	0.09	0.40
	LBL Model	59	0.97	0.78	0.75	0.49	1.26
Waterbury, Vt	ELA	25	1111	1130	586.	698	1332
	ACH-50 Pa	25	16.5	17.4	6.89	11.3	21.3
	Tracer Decay	25	0.72	0.55	0.55	0.40	0.90
	LBL Model	25	1.07	1.13	0.48	0.65	1.42

Diff. ELAs = Pressurization - Depressurization ELAs as a percentage of the larger.

ELA = Effective leakage area (sq.cm) calculated from fan pressurization tests.

ACH-50 Pa = Air exchange rate per hour calculated from a pressurization test at 50 Pa pressure differential.

Diff. ELAs(%) = Calculated percentage difference between the ELA obtained for fan pressurization and fan depressurization of a home.

PFT ACH = Air exchange rate per hour calculated from the integrated perfluorocarbon tracer method.

Tracer Decay = Air exchange rate per hour calculated from grab bag SF_6 trace method.

Constant Flow SF_6 ACH = Air exchange rate per hour calculated from the constant release SF_6 tracer method.

LBL Model = Air exchange rate per hour calculated from fan pressurization tests using LBL Model.

Table 2. Comparison of Infiltration Estimates and Measurement Results.

Study /Infiltration Measurement		Infiltration Estimate			Flows		
		LBL Model	ACH(50 Pa)/20	ELA	QW	QS	n
Waterbury, Vt /Tracer Decay	Corr.	0.55	0.65	0.44	0.28	0.64	25
	R-sq.	0.31	0.42	0.19	0.08	0.42	
	Mean Diff.	0.35	0.10				
Portage, Wis /Tracer Decay	Corr.	0.67	0.69	0.72	0.61	0.71	57
	R-sq.	0.44	0.48	0.52	0.37	0.51	
	Mean Diff.	0.64	0.60				
Wisconsin /Constant Flow SF6							
All Seasons Combined	Corr.	0.30	0.32	0.13	0.21	0.20	102
	R-sq.	0.09	0.10	0.02	0.05	0.04	
	Mean Diff.	0.58	0.76				
1. Fall	Corr.	0.10	0.15	0.05	0.37	0.02	24
	R-sq.	0.01	0.02	0.00	0.14	0.00	
	Mean Diff.	0.78	0.74				
2. Winter	Corr.	0.53	0.46	0.42	0.44	0.58	38
	R-sq.	0.28	0.21	0.18	0.20	0.34	
	Mean Diff.	0.63	0.80				
3. Spring	Corr.	0.09	0.11	0.12	0.23	0.26	40
	R-sq.	0.01	0.01	0.01	0.05	0.07	
	Mean Diff.	0.55	0.85				
/Tracer Decay	Corr.	0.58	0.80	0.59			
	R-sq.	0.33	0.65	0.34			
	Mean Diff.	0.96	0.89				
/PFT (BNL/AIMS)	Corr.	0.82	0.48	0.78			
	R-sq.	0.68	0.23	0.61			
	Mean Diff.	0.81	0.62				