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The AIMS Monitor: Measuring Infiltration, Not Tightness

This new monitor makes it easy to measure the effective infiltration rate in houses over extended periods of time, but it is a poor diagnostic tool.

Weatherization professionals need to know how great a reduction in infiltration rate they have achieved, and the conscientious ones even try to measure the improvement. At the same time, builders, utilities and health officials are concerned about the health impacts of low air change rates: they need to quantify infiltration rates in order to avoid stale and polluted indoor air.

There are two general techniques for measuring air infiltration rates in buildings: 1) *the tracer gas technique*, which relies on measurement of known quantities of an inert tracer gas over time; and 2) *the building pressurization technique*, in which a blower door creates a pressure difference between indoors and outdoors to estimate the leakiness of a house.

The past several issues of EA&R have focused on the use of blower doors to estimate infiltration and detect leaks in single-family housing.[1] However, a new tracer gas technique has been developed that offers different applications for conservation professionals.

In May 1986, the National Association of Homebuilders (NAHB) Research Center began marketing a do-it-yourself tracer gas kit. The kit measures the average infiltration rate in homes for periods of from one week to a year. (It is similar in principle to other passive monitors that test for levels of pollutants such as radon or formaldehyde.) The system, called the Air Infiltration Measurement System (AIMS), is available directly from NAHB (see box). The AIMS will not replace the blower door; rather it will provide additional information on the infiltration rates in houses under actual (occupied) conditions.

The AIMS Monitor

The Air Infiltration Measurement System (AIMS) was developed by Russell Dietz at Brookhaven Laboratory in Upton, New York to provide a reliable, low-cost method for determining the infiltration rate in buildings. In the past, researchers and building professionals have relied on costly and elaborate field tests using an injected tracer gas (often either SF_6, or CO_2), pumps and impingers. This limited the number of houses tested and the duration of tests.

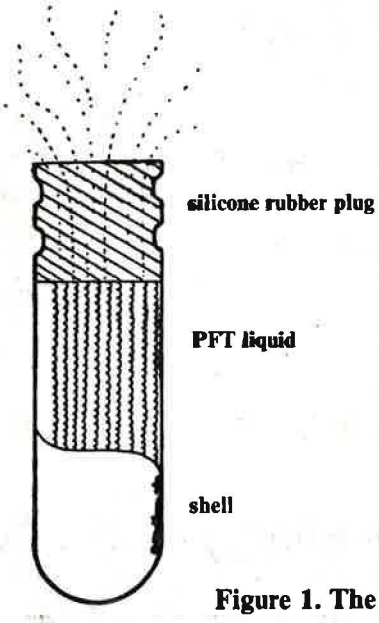
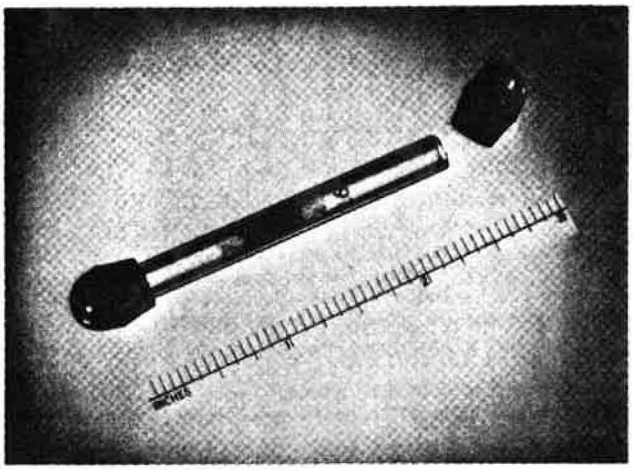


Figure 1. The PFT source.

[1] "Blower Doors: Infiltration is where the Action Is,", Mar/Apr '86; "A Healthy Outlook for the Blower Door Industry," May/Jun '86; "Infiltration: Just ACH_{50} Divided by 20?" Jul/Aug '86; "Blower Doors: Variation in Leakage Measurements," Sep/Oct '86; plus a two-part interview with blower door contractors in the Sep/Oct and Nov/Dec '86 issues.



Courtesy of Brookhaven Laboratory

Figure 2. The passive sampler with polyurethane rubber caps

In contrast, the AIMS monitor is a passive monitoring system that tests for infiltration. It consists of two small cigarette-sized units: the source and sampler (see Figures 1 and 2). The source is a gas-charged device that emits an inert perfluorocarbon tracer gas (PFT) into the air at a constant rate through a silicone rubber plug. The sampler is a glass tube with a charcoal-like adsorbent material that "passively absorbs" the PFT tracer gas over the duration of the test. The samplers have a rubber cap on the end, which is removed at the time of the test. One PFT source with a sampler costs $50 and is enough to test 500 ft^2 of living area.

The source and sampler are prepared and shipped out from a lab at NAHB and then deployed at the house by a researcher, builder or homeowner for a known amount of time. (The PFT sources are shipped separately from the passive samplers to avoid contamination.) Instructions for using the AIMS monitor are simple enough that the untrained homeowner can use it.

The source (which does not have to be uncapped, since it is always emitting tracer gas) is placed within three feet of an outside wall, usually on a piece of furniture. It can be taped onto the leg of a table or chair, or even hung from a chandelier. Only one sampler is needed for each PFT source, since the test assumes that the PFT concentration is uniform throughout the test area.[2]

The user just takes the cap off *one* end of the sampler and places it at least two feet from any wall, floor or ceiling and six to eight feet from the PFT source. The user then records the start and finish time of the test, the temperature of the house during the test, and the volume of the house and area sampled.

When the test is over, both the source and the sampler are sent back to the the lab (the source can be used again or the gas can be recycled), where technicians extract gas from the adsorbent in the sampler and analyze it for PFT content using a gas chromatograph. Figure 3 is a sample computer printout of a test that used one source and four passive samplers in different rooms.

TUBE POS.	CATS NO.	MFG. SAMP.	INTEGRATOR AREA, CTS/1000 PMCH	PDCH	PFT VOL.,pL PMCH	PDCH	PFT CONC. pL/L PMCH	PDCH
1	250	476.0		11340.0		32.463		8.744
2	262	476.0		14357.0		41.092		11.069
3	256	476.0		14646.0		41.917		11.290
4	258	476.0		15582.0		44.584		12.008

HOUSE NO.	NO. SOURCES	T(cent)	LAST TUBE POS.
LBI	2	22	4

HOUSE NO.	HOUSE VOLUME liters	SOURCE RATE mL/min	AVG. CONCENT pL/L	INFILT. RATE L/min	AVG. AIR CHANGE per hr	REL. STD. DEV. %
LBI	481383	27.2	10.8	2526	0.31	13.1

Figure 3. Sample printout from a set of AIMS measurements. In this test, there were two PFT source tubes and four passive samplers. The average concentration in the samplers was 10.8 pL/L and the average effective air change rate was 0.31 ACH. Note the variation in the concentrations in the four different samplers.

How Accurate is AIMS?

While scientists have sampled over 3,000 homes since the AIMS monitor was developed at Brookhaven a few years ago, it has yet to be extensively field tested by homeowners. Several controlled studies by researchers have compared AIMS measurements of infiltration rate with injection-decay tracer gas tests and found agreement within 10 percent. Figure 3 shows the results of a study conducted by researchers from Lawrence Berkeley Laboratory. They installed one in a 2,000 ft^2 house equipped with an automated SF_6 tracer decay system that measured the infiltration rate every 90 minutes. Two sources and four samplers were set up in the house over the same three-week period. Using the average of the four sampler concentrations, the scientists estimated an effective infiltration rate of 0.31 ACH, which compares closely to the 0.33 ACH average infiltration rate of the SF_6 measurements. (It is important to note that using just one or two samplers, instead of four, could have shifted the AIMS results 10-15 percent in either direction.) In a University of Wisconsin study, AIMS and SF_6

[2] This is an important and not always accurate assumption. Most of the researchers we spoke with recommended using at least two samplers with a source to minimize the likelihood of errors. See the section on accuracy.

test results were compared in nine houses. Again, the average of the AIMS measurements (0.39 ACH) was close to the average of the SF_6 measurements (0.37 ACH).[3]

The Pierce Foundation in New Haven, Connecticut tested the reproducibility of the samplers rather than comparing it to SF_6 results.[4] The AIMS monitor gave very consistent, reproducible results, with a standard deviation of less than two percent. Also, the orientation of the sampler did not have a significant effect on the results, which were consistent over a three-fold test range of ventilation rates.

The research community is nevertheless skeptical of the accuracy of AIMS and will probably remain so until further field evaluations are conducted. As Dietz himself says, "The accuracy of these tests under field conditions is at best 10-15 percent. The principle of AIMS is to put the source into a zone of well-mixed air. However, if the source is not well mixed, or if the source or sampler is improperly deployed, then the test results become inaccurate."

The main factors influencing accuracy of AIMS are:

temperature,
air mixing,
occupancy.

Temperature can affect the reliability of the AIMS results, and it is important to regularly record the temperature over the course of test. All sources are reported at 25°C (77°F) The PFT emission rate increases rapidly with temperature. For example, a 3°C increase in temperature will increase the emission rate of PFT from the sampler by 16 percent.[5] However, the laboratory analysis can correct for temperature changes. Dietz claims that "if the user measures the average temperature to within 5°F, there shouldn't be an error greater than 10 or 15 percent."

Air mixing adds to the potential for temperature-induced error. One of the key assumptions behind the AIMS measurement, which relies on the diffusion of the inert tracer gas, is that the gas is perfectly mixed and evenly distributed throughout the test area (usually a floor or a room on a floor). Since the air flow within a house is hardly uniform, the placement of the AIMS monitor is critical, and can greatly affect the test results.

Of course, occupant activities play a major role in the infiltration rate of a house. Although the stack effect (infiltration due to an inside-outside temperature difference and the tendency of warm air to rise in a heated space) is greater during the winter, infiltration rates measured using the AIMS monitor are likely to be higher during the summer than during the winter because doors and windows are opened much more frequently.

Ordering the AIMS Monitor

Currently NAHB National Research Center is the sole licensee of the AIMS passive infiltration monitor. It can be ordered from NAHB for $50, which includes the costs of shipping and laboratory analysis.

NAHB is still organizing its analysis laboratory. In the meantime, BNL will process the samplers. Unfortunately, BNL has a very poor reputation among researchers for slow processing of the samplers.

For more information, contact Larry Zarker of NAHB Research Foundation, P.O. Box 1627, Rockville, MD 20850: (301) 762-4200.

AIMS vs. Blower Doors

Comparing blower doors and the AIMS is like listening to a blind person describing different parts of an elephant. They perform different functions but, in many cases, can be used together to provide more information.

Tracer gas systems, including AIMS, measure the concentration of an inert tracer gas. From tracer gas measurements, scientists can estimate the infiltration rate—the amount of air entering and leaving the house during the period of time. This *infiltration rate* is a function of the leakiness of the house (including the effects of opening the doors and windows and operating mechanical ventilation equipment) and of weather conditions (i.e., wind, temperature) during the period of the test.

Blower doors measure tightness of the envelope, which is a property of a house, just as R-value is a property of insulation. Blower door measurements are thus less dependent on tempera-

[3] Both of these studies are cited in: Dietz, R. R. Goodrich, E. Cote, and R. Wieser, "Detailed Description and Performance of a Passive Perfluorocarbon Tracer System for Building Ventilation and Air Exchange Measurements." Reprinted by American Society for Testing and Materials, Philadelphia, PA, 1986.

[4] Leaderer, B.P., L. Scaap, R. Dietz, "Evaluation of the Perfluorocarbon Tracer Technique for Determining Infiltration Rates in Residences." Environmental Science and Technology, 19:1225, 1985.

[5] A good companion technology for AIMS would be a passive average temperature sensor. Alternatively, several laboratories in Sweden have experimented with temperature controllers to maintain the PFT source at a constant temperature and thus stabilize the emission rate.

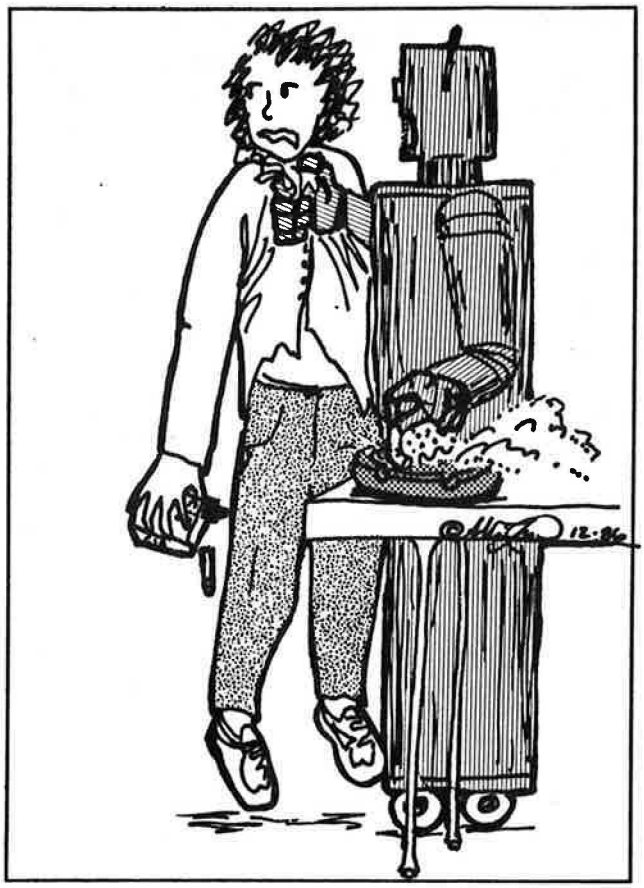
ture and weather conditions (although these factors can introduce errors of up to 20 percent (see "Blower Doors: Variations in Leakage Measurements", **EA&R**, Sep/Oct '86). In addition, the blower door performs a function the AIMS monitor cannot: it is a diagnostic tool that the retrofitter can use to find and seal leaks.

Blower doors do not measure infiltration, although blower door measurements can be used to *estimate* air infiltration rates (see "Infiltration: Just ACH_{50} Divided By 20?" in the Jul/Aug '86 issue of **EA&R**). The AIMS monitor relates changes in concentration of the tracer gas to air movement into and out of the house. Thus both techniques have experimental errors. The error in blower door measurements results from the extrapolation of air leakage at high pressures to air leakage under natural (low pressure) conditions. The error in AIMS measurements results from a variety of factors: leaks in the sampler cap, lab analysis, poor air mixing, and temperature variation over the course of the test.

The BPA Field Tests

In one of the few side-by-side comparisons of blower doors and the AIMS sampler, the Bonneville Power Administration (BPA) in Portland, Oregon, studied the natural infiltration characteristics of houses in four northwestern states. BPA examined houses built in the Residential Standards Demonstration Program (RSDP).[6] Researchers compared estimates of the infiltration rate derived from blower door tests and from tests with the AIMS monitor. They conducted the tests in control houses (houses built at the same time as the RSDP houses, but built according to "current building practice" in the Northwest). The comparisons had to be done on the control houses because mechanical ventilation systems in the RSDP houses (such as air-to-air heat exchangers) would tend to make the PFT test overestimate the effective ventilation rate.

BPA researchers conducted blower door tests on 421 houses and AIMS tests on just 79 houses. They were puzzled by the initial results of the blower door/AIMS comparisons, which indicated that blower doors tended to greatly overestimate the infiltration rate compared to the AIMS monitor. "One would expect the AIMS technique to show a higher infiltration rate since it is in place when occupants are entering and leaving the house, and opening and closing windows," says



"Hey! I thought you said that you bought a *passive* monitor.

Mike Lubliner of the Washington State Energy Office, who participated in the project.

After further analysis of the data, it appears that the blower door and AIMS estimates of infiltration rate agree within 20 percent, on average. But the results often differ drastically for individual houses. A review of the test conditions and calculations revealed systematic errors in both the blower door and AIMS estimates.[7] In the reevaluation they found:

- There were significant errors in the methodology used to calculate blower door estimates of the natural air change rate: specifically, incorrect adjustments for climate and terrain factors.
- The AIMS air change rates varied significantly with the type of heating system in the house. Houses with electric forced-air heating systems had higher average infiltration rates than houses with baseboard or radiant electric heating.

[6] Over 400 houses were built as part of the RSDP. The houses were constructed according to the Model Conservation Standards, one of the strictest energy-efficiency guidelines for builders in the country.

[7] Parker, D. "Infiltration Characteristics of Houses in the RSDP Program: Work Status Report." November '86.

Table 1. A comparison of the uses of the AIMS infiltration monitor and blower doors.

AIMS	Blower Doors
• a spot check of infiltration	• a spot check of tightness
• passive, extended-term test	• active, short-term test
• measures average concentration of a gas	• measures inside-outside pressure difference
• calculates effective infiltration rate	• calculates average infiltration rate for arbitrary conditions chosen by the user
• useful for indoor air quality studies	• useful for estimating heating or cooling load in a closed house
• includes occupant behavior and furnace operation	• does not include occupant behavior or furnace operation
	• yields seasonal estimate of infiltration (heating load) for the measured conditions

- The AIMS air change rates also varied significantly with the type of house construction, including the number of stories, and the presence of a heated basement.
- Installation of the AIMS source and sampler within the same room probably underestimates the actual average air change rate because of improper mixing.

The AIMS air change rates had to be adjusted upwards over 30 percent to account for the above sources of error! The final report on the BPA comparisons is due in early 1987.

Who Needs AIMS?

Currently, NAHB is the exclusive licensee of the AIMS monitor, although it may become available through other distributors. For example, **EA&R** has learned that Battelle Laboratories may also enter the market. NAHB has identified a diverse market of potential AIMS users in the building and energy community:

- builders,
- local housing authorities,
- building inspectors,
- energy and indoor air quality researchers,
- electric utility weatherization programs.

The best way to decide on a monitoring strategy—whether one is a utility manager or a contractor interested in infiltration—is to examine the strengths and weaknesses of the measurement systems. Table 1 lists the attributes of blower doors and the AIMS monitor. The key difference is that the AIMS monitor just measures the average concentration of a gas in the house over a certain time period and is greatly affected by variables such as temperature, mixing, and occupant activities. It can yield a fairly accurate estimate (within 20 percent) of the effective ventilation rate, but this cannot be extrapolated to other seasons nor can it be used to obtain an annual average. AIMS is an excellent tool for researchers or builders exploring the relationship between infiltration rate and levels of indoor pollutants.

The blower door, by contrast, provides an estimate of the average infiltration rate of a house under arbitrary conditions based on a property (the tightness) of the house. It does not measure the effects of occupants on actual infiltration, but is probably a better tool for estimating seasonal infiltration rates and heating loads.

Recommendations

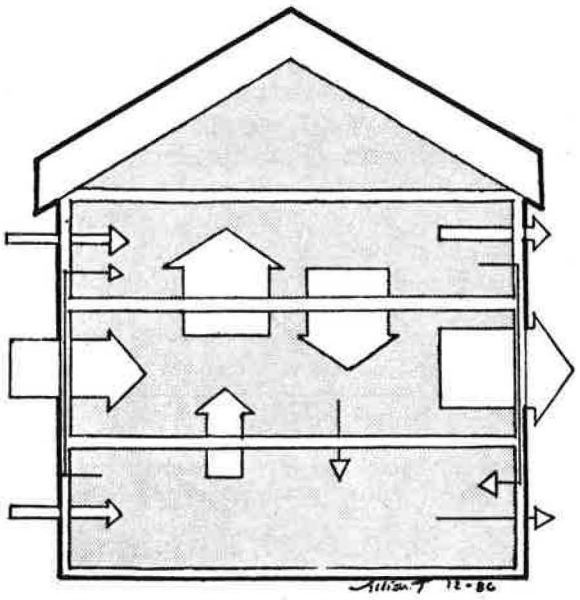
The AIMS infiltration monitor and blower doors have complementary uses. The AIMS monitor provides a picture of the infiltration rate in a house over the period of the measurement. AIMS will be a useful tool for builders, housing authorities, building inspectors, and utility program managers who need to accurately assess and quantify the impact of weatherization and shell-tightening measures on building performance.

Blower doors measure a property of buildings, leakiness, under pressurized conditions and, through extrapolation, provide rough *estimates* of

Multiple Zones

Unlike the blower door, the passive monitor can be used to measure infiltration over long periods of time and in different zones of a house.* The figure below illustrates a simplified example of a multi-zone test. The sketch shows the infiltration and exfiltration of air on each floor of the house, as well as the air flow rate *between* each floor or zone of the house. The size of the arrows is proportional to the air flow rate between any two zones. It is possible to measure up to four different zones in a building using the AIMS system. The NAHB kit comes with up to four different modifications (flavors) of the PFT tracer gas, so that a separate source and sampler can be set up on each floor or zone. However, this technique has not been evaluated, and researchers question the accuracy of the multi-zone measurements provided by AIMS.

* A *zone* must have well mixed air in order for the AIMS results to be accurate. Each floor in a multi-story house is usually considered to be a separate zone, since there is usually very good mixing of air on one floor or level—if all doors are open—and a much smaller amount of air exchange between the air on different floors.



natural infiltration rates for any given weather conditions. They have several different uses: 1) identifying leakage sites while a building is being weatherized; 2) providing a measure of the tightness of the building shell; and 3) providing an index for comparing the performance of the building shell before and after retrofit.

"A lot of blower door contractors are worried about losing their business to suppliers of the AIMS monitor," says Lubliner. "But they shouldn't feel threatened. In most cases they can add the AIMS monitor to the list of services they offer. After weatherizing a house, using a blower door to identify leaks and cracks, they can install a monitor to check the home's long-term performance."

– Peter duPont