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Fan Pressurization of Buildings: Standards, Calibration, and Field Experience

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ABSTRACT

The fan pressurization method has been widely used by groups working with building retrofits and with new construction to evaluate the air tightness of building envelopes. To ensure uniformity in the testing method ASTM Standard E779-81 was developed. This standard is reviewed with commentary on practical aspects of its application. Calibration of the fan pressurization systems, often referred to as blower doors, will also be discussed, pointing out where calibration difficulties have arisen and the implications on field inspections. Use of fan pressurization together with infrared scanning is one of the best methods to pin-point air leakage sites in building envelopes. The applications of such methods in a variety of buildings will be discussed in order to demonstrate the utility of the methods in the evaluation of building tightness, including seasonal variations; effectiveness of envelope sealing; and the location of problem areas in the building envelope.

INTRODUCTION

It is well known that the natural pressurization of buildings takes place because of the speed and the direction of wind at the building site combined with pressures caused by air buoyancy due to the difference in the air temperature inside versus outside the building (ASHRAE 1981). However, these wind and stack effects that encourage air leakage through the building envelope tend to be too unpredictable to adequately document building tightness. Instead, fan pressurization has been used for many years by the research community to measure the air tightness of buildings. More recently the technique has found wider application in evaluating building envelopes in order to meet air tightness goals in new construction and to choose appropriate retrofit options in existing buildings.

This paper briefly discusses ASTM Standard E779-81 (ASTM 1984), which outlines a standard procedure for conducting fan pressurization tests, describes the equipment currently available, emphasizes the importance of appropriate calibration, and presents field experiences that point out both the potential applications and the necessary cautions using fan pressurization.

ASTM Standard E779-81 was developed in order that consistent procedures be followed to compare the air leakage rates through a building envelope. The standard is primarily intended for one-story buildings. A number of cautions are expressed in the use of the standard procedure including the need for appropriate weather conditions. Basically the procedure involves fan airflow measurements at specified pressure differences across the building envelope. The resulting pressure-flow profile is used to evaluate building tightness. Figure 1 from the ASTM standard illustrates such a pressure-flow profile. The information derived from the test procedure is related to the air leakage flow through the building envelope. The standard is currently being updated. Questions such as how to best express building air tightness, e.g., emphasizing Equivalent Leakage Area (ELA) rather than air exchange rate at a specified pressure difference is being considered.

The choice of equipment for fan pressurization and how the equipment is calibrated are keys to the viability of the method. The calibration of the equipment will be discussed later in some detail. Here our comments will be confined to the available equipment. First it should be

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recognized that although fans existing in the building could provide at least a part of the necessary pressure difference, these may be inadequate to satisfy the ASTM standard, which calls for pressure differences in steps up to 0.30 inches of water (75 pascal). To satisfy the requirements appropriately sized, variable speed fans typically mounted in doors (blower doors) have been used extensively. Window-mounted fans have found fewer applications. The standard calls for measurement of the resulting airflow at each pressure step. Fan pressurization systems thus have been designed with flow measurement capabilities built in, or have relied on flow calibration charts or algorithms based on measured fan speed. Use of standard flow nozzles has been one widely used approach in direct flow measurement. Thus, depending on the measurement features and the design concept the fan pressurization systems have resulted in the use of a wide variety of geometrical shapes and construction materials. Within the past few years more than a dozen manufacturers have produced blower doors in the U.S. and Canada.

STANDARDS

The ASTM Standard E779-81 (ASTM 1984), for measuring air leakage is "primarily intended for use in one-story buildings." The proposed Canadian Standard (CGSB 1984), "is applicable to small detached buildings." Many other types of buildings are encountered by the research and contracting communities during the course of retrofitting and new construction activities. These buildings can present a number of problems that are not dealt with in either of these standards.

For instance, the ASTM standard requirement to maintain a "uniform pressure" in the conditioned space to within the prescribed 20% of measured inside to outside pressure difference is difficult using a pressurization device located at one place in the thermal envelope of larger or leakier structures. Field experience has shown that the pressure drop within the building interior will place sections of the envelope outside the bounds of this requirement, e.g., at locations on the second or third floors of a large house, distant from the pressurization device. Moreover, field tests show that sealing major leak sites remote from the blower door can show little or no change in flow through the pressurization device. Major leakage sites close to the fan can also influence the pressure drop across other sections of the envelope, and make it difficult to meet the uniform pressure requirement. The ASTM standard (ASTM 1984), points out that it is intended for one-story buildings and that additional stories add stack effect pressures on the order of two pascals per floor for a 40F temperature differential.

The standards consider detached houses, but with the rising housing prices and availability of land in many areas, townhouse and condominium construction has become a dominant part of the residential market. There is a possibility of significant airflow between the attached dwellings. Swedish researchers (Nylund 1979-80, Lundin 1981) have observed additional airflow rates of 6% to 25% from the adjacent row houses to the row house under measurement. Examples of such intercommunication are currently being seen in the application of the fan pressurization method to the air infiltration reduction programs of U.S. military family housing. The ASTM standard procedures in a modified form are being used by the military. The military specification generally states that no air infiltration reduction measures will be done to a housing unit that has an initial air leakage of less than 10 air changes per hour (ACH) at 50 Pa. With air leakage between units, the choice as to whether or not retrofitting will take place can be directly affected. The standard at present does not consider such effects and more data are needed.

Before discussing approaches to redress this problem, other examples from field testing more complex buildings should be considered. In testing a 20-year-old masonry, multifamily building, individual apartments measured 2 to 3 ACH at 50 Pa (Harrje et al 1983). Testing in other masonry, as well as frame construction apartment buildings, levels of 15 to 30 ACH or more were evident. The airflows measured include the combination of inside air from the adjacent apartments and outside air from leakage through the envelope. The low end of this scale would indicate that indoor air quality problems can easily result with the windows closed (the condition for measuring envelope tightness). The low end numbers are useful to pinpoint possible indoor air quality problems, while the higher values have considerable uncertainty because of possible interaction with adjacent spaces. Evaluation of the volume of air entering from the adjacent areas would be possible with the use of multiple blower doors, allowing pressurization to take place in unison, or by estimating flows based on pressure measurements taken in the adjoining space as has been demonstrated by Swedish researchers (Nylund 1979-80, Lundin 1981). Nylund (Nylund 1980), has proposed a method to integrate the tightness tests from a number of individual, interconnected zones to arrive at individual tightness levels.

CALIBRATION

Leakage measurement of buildings using fan pressurization demands accurate flow measurements over a wide range of flow conditions. The flow measurements are generally related to fan rpm and pressure difference. Typical houses may vary from small, tight structures to large leaky homes and, thus, one can anticipate flow rates ranging from 6500 CFH at 0.05 of water (12.5 Pa) to 415,000 CFH at 0.30 of water (75 Pa) (Persily 1984). This flow range would normally exceed the capabilities of a single fan.

Where do we obtain such extensive flow and pressure calibration data with associated accuracy information? Manufacturers of fans will usually provide limited flow data at specific rpm and pressure differences. The rpms chosen are normally those of standard motor speeds, i.e., 1725 and 3450 rpm. These values may be based on actual calibration data or could result from calculated values based on fan design, or extrapolated by the use of fan laws. The best data we can expect from the fan manufacturer are flow values that were produced by calibrating the fan according to ASHRAE (ASHRAE 1975) or AMCA standards (AMCA 1967). Knowing how much air is flowing through the fan at a given set of conditions unfortunately proves to be insufficient. The above standards require the fans be installed in a test chamber in a specific manner with flow straighteners, settling screens, inlet bells, or ducts, etc. Because of the portability and ease of installation requirements of the blower doors, such flow conditioning features are not used and, therefore, the flow at a specific rpm and pressure difference will not be the same as the factory calibration value. Protective screens or other obstructions to fan flow are also installed in the fan stream, which changes the flow characteristics. Some blower door practitioners have used manufacturers' data and the fan laws to generate a family of "calibration curves." Others have used unique calibration facilities such as a house or a "tight room" to develop flow information.

Table 1 illustrates how discrepancies between carefully conducted calibrations can easily arise. The data tabulated in Table 1 are listed under the general heading of normal (design) fan rotation and reverse fan rotation. The reason for this is that, used in a blower door, electrically reversing the variable-speed fan motor is normally easier than reversing the entire blower door or fan component to pressurize the building.

The listing under "Princeton" is a series of blower door calibrations conducted by CEES personnel in a rooftop enclosure originally used for thermal testing (Persily and Blomsterberg 1979). The 18-inch-diameter fan, used in the blower door deployed by Princeton University and various house doctors, was tested as a blower door assembly mounted in the doorway of this eight-foot-square, twelve-foot-high enclosure. A series of sharp-edged orifices were placed in the walls of the structure, and inside-outside pressure measurements were made with sensitive instruments. The pressure difference across the orifice allowed one to determine the flow rate. Tests were done under very calm wind conditions to lessen the effect of any drafts or gusting on the orifice which would introduce significant errors.

The column "Chamber" refers to testing done in a dedicated test chamber specifically designed for blower door calibration. This chamber is four-foot-square by eight-foot-long, terminating in an 18 1/2 inch diameter duct that houses flow-measuring orifices, flow-straightening devices, and a variable-speed exhaust fan. Following the ASHRAE 51-75 recommendations (ASHRAE 1975), the flow was directed through the appropriate settling screens in the chamber. The orifice pressure drops and chamber pressure levels were measured using the recommended pressure tap arrangements.

The last column, labeled "NBS", provides calibration points obtained from the calibration by Persily using a twelve-foot-long by twelve-foot-wide by six-foot-high test chamber at the National Bureau of Standards (Persily 1984). His measurement technique used a constant flow of tracer gas into the exhaust duct. The method relied on tracer gas concentration measurements at the duct exit, with the degree of dilution of the upstream injected tracer gas providing a direct measure of the airflow. The result of these tests was a relationship for flow as follows:

$$Q = (74.57\omega)\exp(-459{,}052\,\Delta P/\rho\omega^2) \qquad (1)$$

where

Q is the flow rate, cubic feet/hour
ω is the fan, rpm
ρ is the air density, lbs/ft^3
$\Delta\rho$ is the pressure difference, inches of water

This form of the flow equation is different from the calibration equations resulting from the "Princeton" and "Chamber" results. These equations are as follows:

"Princeton"	Q	=	$(135.66\,\omega)-(212237\ \Delta P)$ normal	(2)
	Q	=	$(92.86\,\omega)-(158602\ \Delta P)$ reversed	(3)
"Chamber"	Q	=	$(126.6\,\omega)-(195297\ \Delta P)$ normal	(4)
	Q	=	$(103.93\,\omega)-(181202\ \Delta P)$ reversed	(5)
	$Q_{\text{Fan B}}$	=	$(165.95\,\omega)-(243389\ \Delta P)$ normal	(6)

Table 1 also includes data on another fan (Fan B) for both chamber tests and manufacturers' data for the normal (design) fan rotation. The important points we wish to make using the tabulated data are:

- The manufacturer' flow rate figures, for normal fan rotation, are at times far in excess of blower doors at similar conditions in the various calibration chambers. For example, at 1725 rpm and 0.125 of water, the factory values are 42% higher than the Princeton calibration, and 51% higher than the chamber calibration (the range of all cross comparisons show differences of 38% to 69%). The same conditions for fan B indicate 16% difference, however, over the entire range of conditions noted in Table 1, the differences vary from 7 to 33%.

- Comparisons between the three enclosure tests show that, if care is taken, flows measured by tracer gas, orifices in walls of a chamber, or orifices making use of an exhaust fan technique can result in close agreement. For the normal rotation this is 4% to 7%. For the reverse rotation, the range is 1% to 11%, using the median value as the comparison. Best to worst calibration comparisons raise this to 15%.

Low flow conditions

Although one would wish for simple, unidirectional flow through a fan, as flow rates are reduced, reverse flow becomes evident. Smoke tracers or wool tufts placed in the flow path reveal these phenomenon. With such events taking place one might anticipate calibration problems at low flow. This portion of the fan calibration charts is illustrated in Figure 2. Figure 2(a) from Persily (Persily 1984), points out the flow calibration trends from Equation 1. Figure 2(b) shows that often no indication of this transition zone is evident in the normal calibration data with the fan blade run in reverse direction, yet it may show up running the fan in the normal direction, see Figure 2(c). In Figure 2(d), data from Fan B is presented; this alternative fan blade design shows no evidence of the onset of flow changes even when data from lower flow rates are plotted.

Realizing that at zero rpm and zero differential pressure a "no flow condition" must result, rapid flow changes are to be expected in this regime. A number of variables may influence the flow in the low flow regime. These include: fan blade shape, rigidity of the blade, blade tip clearance, direction of fan rotation, and especially local flow conditions including flow disturbances (such as wind gusts), and direction of entry flow (cross flow or other flow oddities from upstream or downstream obstructions). Measurements of flow on site may suffer even more from these same problems, and because measurements of flow are made on site is no guarantee the suitable accuracy has been achieved.

Applications Using Fan Pressurization

There are a number of ways in which fan pressurization has proved useful in both the quantitative and qualitative evaluation of building performance. We have already discussed the evaluation of building envelope tightness, but tightness is more than a value at a single point in time.

- Envelope tightness over the year. Use of fan pressurization in a series of measurements throughout the year allows one to determine if weather, and particularly moisture levels, have influenced the building envelope tightness. A limited amount of data are available on this subject, pointing out seasonal tightness variations ranging from zero to 40% (Nagda et al. 1984, Harrje 1984, Persily 1982, Warren and Web 1980, and Kim and Shaw 1984). The studies indicating the greatest seasonal variation point to the low absolute humidity conditions of midwinter as that period when the building envelope is most leaky. Wood shrinkage is the suggested cause for these seasonal changes.

In the most recent series of year-round tests performed on two test homes in Gaithersburg, MD, the effect of weather was minimal (Nagda et al 1984, Harrje 1984). As Figure 3 points out, the only effect is a few percent change in tightness that is taking place during the initial "drying out period" following house construction. The extensive use of a polyethylene vapor retarder is believed to be responsible for the year-round tightness stability. The blower door tests indicate an air leakage of approximately 10 ACH at 50 Pa* and fluctuate over a narrow band (order of ± 2% to 4%). The "experimental house" was retrofitted midway in the test period, resulting in an immediate reduction in air leakage, i.e., from 10 ACH to 6 ACH. It is this type of reduction using fan pressurization, that provides the feedback to the retrofitter attempting to tighten a building.

When these same test data were used to determine the equivalent leakage area (ELA) at four pascals differential pressure, data scatter was seen to noticeably increase (± 5% to 11%). Figure 4 illustrates the ELA values, which are plotted in square centimeters, for the same two test houses. Although ELA may provide an easier concept to understand as a measure of air leakage, the increase in the error band should also be recognized (Persily 1983, Persily and Grot 1985). This results when extrapolating from fan pressurization values ranging from 12.5-75 Pa down to the 4 Pa level (representative of natural pressure differences influencing envelope leakage on smaller buildings) (Sherman and Grimsrud).

- Specific leakage site detection. The question of overall envelope tightness must also deal with specific leakage sites if existing building stock is to be improved, and if new construction is to incorporate design specifications that eliminate undesirable air leakage.

Within the E-6 Committee of ASTM, one effort over the last two years has been the generation of standard practices to detect air leakage sites in the exterior surface of buildings. That proposed standard practice focuses on infrared thermography, smoke tracers of various types, air velocity measurements, and the use of sound sources and detectors. The first three proposed methods rely heavily on fan pressurization. Without fan pressurization wind and stack effects cause great uncertainty as to whether airflow will be inward or outward at a given leak site (although with stack effect alone airflow tends to enter the lower portion of the building and exit at the upper portion, i.e., below and above the neutral pressure plane) (ASHRAE 1981). Using fan pressurization or depressurization, all airflow can be forced outward or inward.

Since infrared leak site detection depends upon measuring temperatures on the surfaces near the leak site that are cooled or heated (depending on outside weather conditions, including solar influences) by leaking air motion, the use of fan depressurization assures that outside air will be drawn through all openings in the envelope. Viewing interior wall surfaces with the sensitive infrared equipment allows for rapid room surveys of those critical surfaces. The leak sites in the outer walls will become evident if even a 10F differential temperature is present across the building envelope. Choosing the right time of the day can result in the use of this technique throughout most of the year (Gadsby et al 1982), as shown in Figures 5 and 6. Fan depressurization of 25 Pa results in rapid cool down (or heat up) of the interior surfaces, i.e., order of five minutes (Odmansson 1981). Note that, depending on the location of the leak sites, interior walls may also be part of the air leakage path and should be scanned (Harrje et al 1979).

Fan depressurization also works effectively when using a local air velocity probe. In contrast with the infrared technique, which surveys entire surfaces, the velocity probe must be moved across the suspected leakage areas searching out the increased local velocity caused by air jets at the leak sites. Depending on the nature of the airflow (shape of jet, etc.), these measurements may provide quantitative estimates of leak severity.

Pressurization has proven to be effective when using smoke tracers. Again we must move our detector across the building surfaces, especially in those areas of suspected leakage. Since the fan provides outward flow, the smoke tracer seeks out the leakage site. Again, as with the two alternate techniques just described, the only way this technique can work reliably is when the airflow direction is assured. Fan pressurization achieves this goal.

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*I/S on each dashed line indicates the intercept and slope followed by the average value and standard deviation.

BUILDING TIGHTNESS STANDARDS

Countries such as Sweden have initiated programs that specify building tightness standards in new construction (Jackman 1984). The maximum air leakage rate is 3 ACH at 50 Pa for single-family and linked houses, 2 ACH for other residential buildings of not more than two stories, and 1 ACH for multi-family buildings of three or more stories. Fan pressurization is used to check compliance.

Currently, ASHRAE members through SPC 119, Air Leakage Performance for Residential Buildings, are investigating what role tightness standards might play in new U.S. and Canadian buildings. The proposed approach is viewed as a link between Standard 90, Building Energy; and Standard 62, Building Ventilation, and "contains a classification scheme that groups building tightness into categories depending on envelope leakage, floor area, and building height" (Sherman 1984). The use of fan pressurization is contemplated to play an important role in evaluating the envelope leakage.

CONCLUSIONS

We have tried to point out in this paper some of the current happenings in what has become a very active field. Standards are being written and revised in the U.S., Canada, and Europe. Instrumented audits are being conducted in a variety of buildings using the fan pressurization method. The building diagnostics includes evaluation of overall tightness, pinpointing leakage sites, working in conjunction with infrared scanning procedures, etc. The fan pressurization method when used properly can greatly assist evaluating both new and existing buildings. The equipment used for this diagnostic approach has generated new business opportunities and a challenge to provide high quality equipment.

Through appropriate standards that outline procedures and practices, as well as required calibrations of the equipment involved, the fan pressurization method has become a vital part of building diagnostic procedures. The method can play an important role in upgrading our existing buildings and insuring that new buildings are properly constructed from an air tightness point of view.

REFERENCES

AMCA. 1967. "Test code for air moving devices," AMCA Standard 210-67. Air Moving and Conditioning Assoc. Inc. Arlington Heights, Il.

ASHRAE, 1975. "Laboratory methods of testing fans for rating," ASHRAE Std. 51-75.

ASHRAE, 1981. ASHRAE Handbook 1981 Fundamentals, Chapter 22, Ventilation and Infiltration, ASHRAE, Atlanta, GA, 1981.

ASTM. 1984. "Standard test method for determining air leakage rate by fan pressurization - ASTM Standard E779-81,: 1984 Annual Book of ASTM Standards, ASTM, Philadelphia, PA, pp. 798-807.

CGSB, 1984. "Determination of the equivalent leakage area of buildings by the fan depressurization method," Canadian General Standards Board, Eighth Draft.

Gadsby, K.J., Harrje, D.T. and Dutt, G.S., 1982. "Year-round use of thermography in house doctoring," Thermal Infrared Sensing Diagnostics - Thermosense V, SPIE, Bellingham, WA., pp. 133-136.

Harrje, D.T., Dutt, G.S. and Beyea, J., 1979. "Locating and eliminating obscure but major energy losses in residential housing," ASHRAE Transactions, Vol. 85, Part 2.

Harrje, D.T., Dutt, G.S. and Gadsby, K.J., 1983. "Energy use in a mid-rise apartment building - performance and recommended retrofit action," Princeton University Center for Energy and Environmental Studies.

Harrje, D.T., "Air exchange in buildings," 1984. Indoor Air Quality Seminar - Implications for Electric Utility Conservation Programs, EPRI, pp. 3-1, 3-10.

Jackman, P.J., 1984. "Review of building airtightness and ventilation standards," The Implementation and Effectiveness of Air Infiltration Standards in Buildings - 5th AIC Conference Air Infiltration Centre, AIC Document AIC-PROC-5-84, Berkshire, U.K., pp. 1.1-1.23.

Kim, A. and Shaw, C.Y., 1984. "Seasonal variation of two detached houses," Measured Air Leakage Performance of Buildings - ASTM Symposium, Philadelphia, PA.

Lundin, L., 1981 . "Air tightness in terraced houses," 2nd AIC Conference, Building Design for Minimum Air Infiltration, Air Infiltration Centre Document AUIC-PRO-2-81, 1981, pp. 185-195.

Nagda, N.L., Koontz, M.D. and Rector, H.E., 1984. "Energy use, infiltration, and indoor air quality in tight, well-insulated residences," Draft Final Report, Geomet Technologies, Report ERF-1461.

Nylund, P-O., 1980. "Tightness and its testing in single and terraced houses," Tyrens Technical Memorandum 1979:5, A.I.C. English Translation No. 4. Also 1st AIC Conference, Air Infiltration Instrumentation and Measuring Techniques Air Infiltration Centre Document AIC-PROC-1-80, pp. 159-170.

Nylund, P-O., 1980. "The application of reciprocity in tightness testing," 1st AIC Conference, Air Infiltration Instrumentation and Measuring Techniques, Air Infiltration Centre Document AIC-PROC-1-80, pp. 143-156.

Odmansson, E., 1981. "Different methods for evaluating air leakage using thermography," Thermal Infrared Sensing Applied to Energy Conservation in Building Envelopes - Thermosense IV, SPIE, Bellingham, WA., pp. 64-67.

Persily, A.K. and Blomsterberg, A., 1979. "Test chamber handbook," Princeton University Center for Energy and Environmental Studies, Report 48.

Persily, A.K., 1982. "Understanding air infiltration in homes," (Ph.D. Thesis) Princeton University Center for Energy and Environmental Studies, Report 129.

Persily, A.K., 1983. "Repeatability and accuracy of pressurization testing," Thermal Performance of the Exterior Envelopes of Buildings II, ASHRAE SP-38, pp. 380-390.

Persily, A.K., 1984. "Air flow calibration of building pressurization devices," National Bureau of Standards, Report NBSIR 84-2849.

Persily, A.K. and Grot, R.A., 1985. "Accuracy in pressurization data analysis," ASHRAE Transactions, Vol. 91, Part 2.

Sherman, M.H. and Grimsrud, D.T., 1980. "Measurement of infiltration using fan pressurization and weather data," First Symposium of the Air Infiltration Centre, Windsor, England, also LBL Report 10852, 1980.

Sherman, M.H., 1984. "Description of ASHRAE's proposed air tightness standard," The Implementation and Effectiveness of Air Infiltration Standards in Buildings - 5th AIC Conference, Air Infiltration Centre, Document AIC-PROC-5-84, Berkshire, U.K., pp. 7.1-7.25.

Warren, P.R. and Webb, B.C, 1980. "Ventilation measurements in housing," CIBS Symposium, Natural Ventilation by Design, London.

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TABLE 1

Fan Flow Calibrations

	Pressure			FLOW, CFH X 1000					
				Normal Rotation			Reverse Rotation		
	Inches H_2O	(Pascals)	RPM	Princeton	Chamber	Mfg.	Princeton	Chamber	NBS
FAN A	0.05	(12.5)	1000	88.2	82.9		57.4	63.4	54.8
	0.05	(12.5)	2000	223.9	209.5		150.3	167.3	138.0
	0.125	(31.25)	1725	159.0	149.3	225.0	104.1	115.2	99.3
	0.125	(31.25)	1850	175.9	165.2	243.0	115.7	128.2	110.1
	0.20	(50)	1000	40.7	39.3		21.9	22.9	21.7
	0.20	(50)	2000	176.4	165.9		114.8	126.8	109.5
	0.25	(62.5)	1725	127.9	120.7	207.0	80.9	88.7	76.6
	0.25	(62.5)	1850	141.5	133.4	225.0	90.2	99.1	85.7
FAN B	0.05	(12.5)	1213		115.2	153.6			
	0.05	(12.5)	1487		160.7	195.6			
	0.125	(31.25)	1719		199.2	230.7			
	0.125	(31.25)	1988		243.9	270.3			
	0.2	(50)	2255		288.2	309.3			

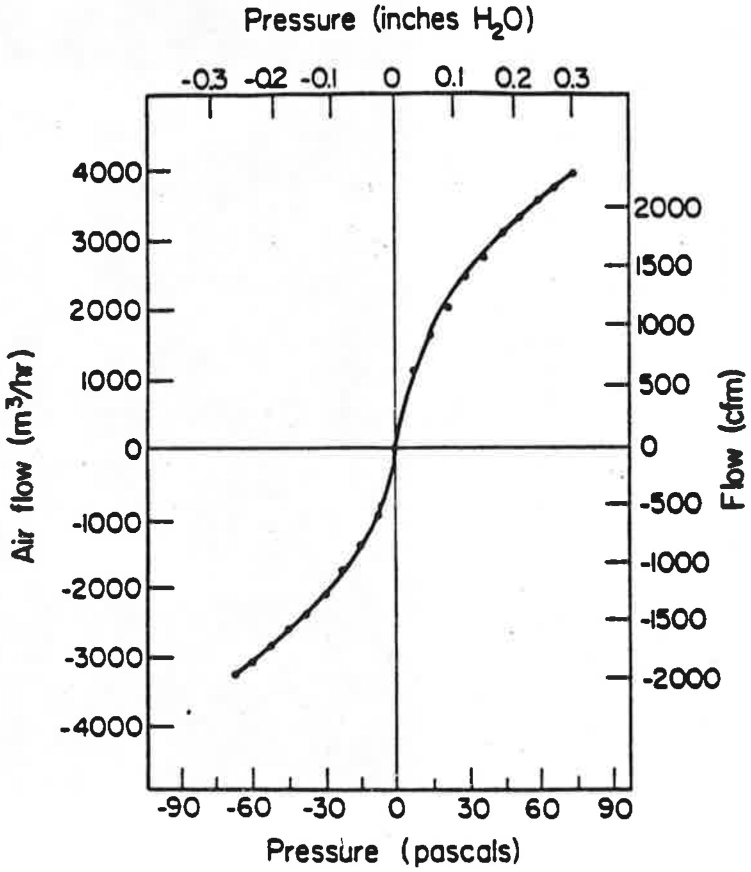

Figure 1. Typical flow versus pressure characteristic obtained using fan pressurization

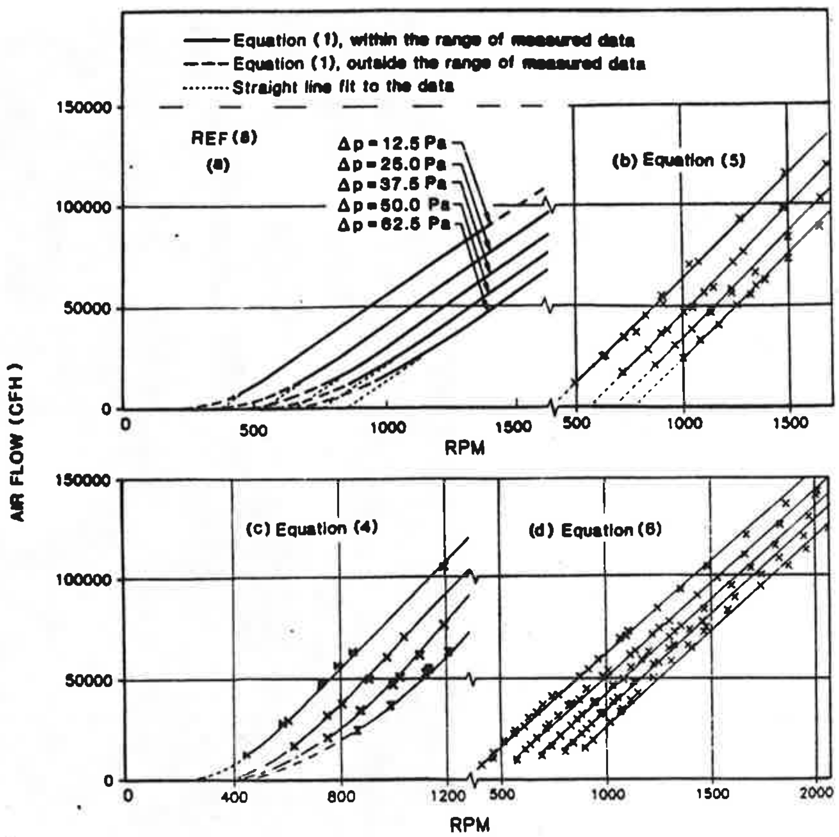

Figure 2. Fan calibrations emphasizing the low flow regime

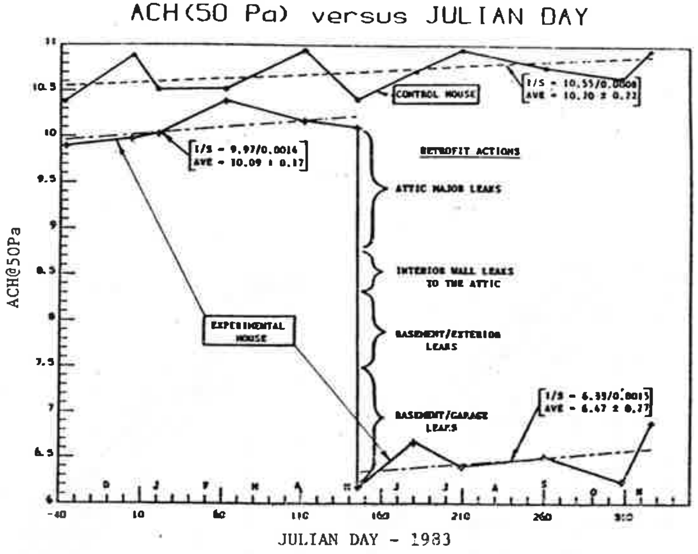

Figure 3. Air change rate per hour at 50 Pa versus Julian day

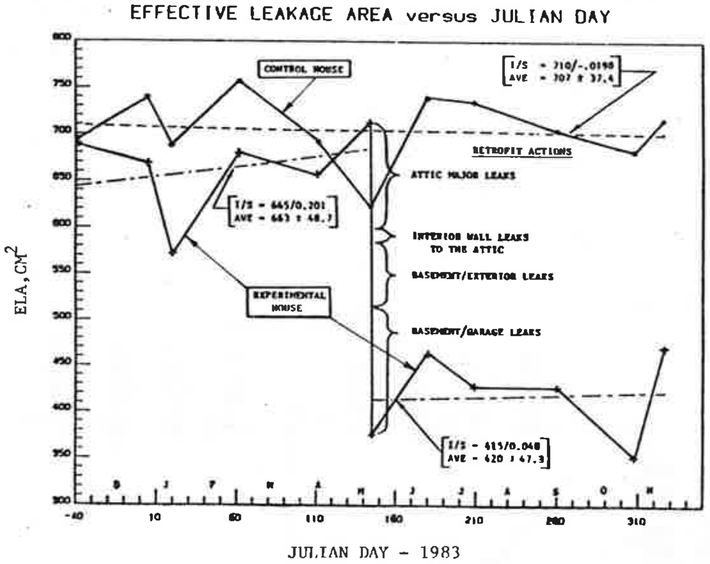

Figure 4. Equivalent leakage area (ELA) versus Julian day

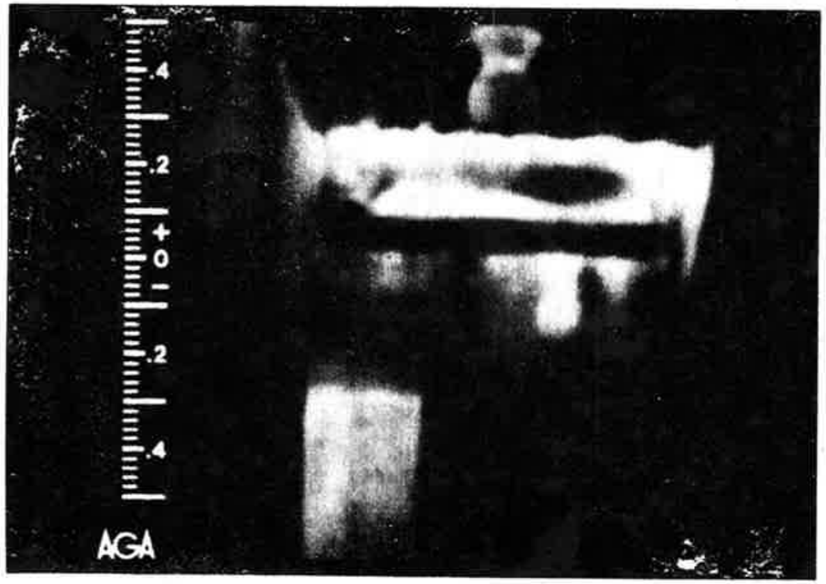

Figure 5. Thermogram of attic hatch and wall ceiling joint air leakage with T_i = 76 F, T_o = 83 F and the house depressurization to 12.5 Pa

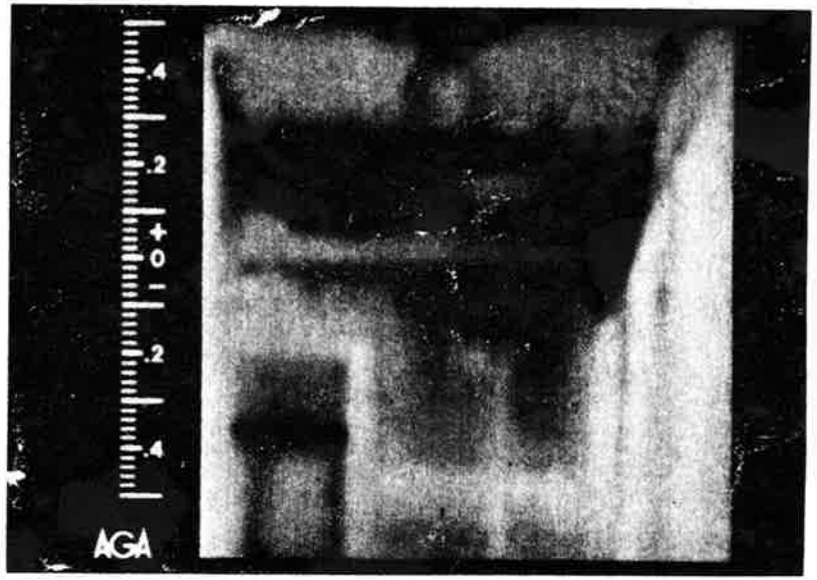

Figure 6. Thermogram of attic hatch and wall-ceiling joint air leakage with T_i = 68 F, T_o = 45F and the house depressurized to 12.5 Pa