FINAL REPORT

# A PROCEDURE FOR DETERMINING AIRTIGHTNESS CHARACTERISTICS OF ATTIC SPACES

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# D I S C L A I M E R

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## 1.0 Introduction

During the 1989/90 Fiscal Year, Canada Mortgage and Housing Corporation will be undertaking some exploratory work on the performance of residential attics. The investigations will involve both field survey work and computing modelling. The objectives will be to gain a better understanding of how typical attic spaces deal with moisture removal. Specific details on air and heat flows will also be investigated.

Ultimately, this research, in conjunction with research completed elsewhere, will assist in establishing a range of conditions possible in attics and in resolving some controversial questions over the optimum types and quantities of ventilation required for Canadian attics. A key part of this research will be a survey of attics in a variety of houses, to determine a typical range of airtightness values for attic roofs, floors and installed vents.

This reports describes a procedure for determining the airtightness characteristics of attic spaces. Section 2 introduces some new terms and concepts for describing attic airtightness, and describes the procedure and equipment used in field trials. Section 3 presents the results of field trials, including data on three test houses where blower door equipment was used to measure airtightness.

Section 4 provides a discussion of the test results and provides a rationale for a recommended test procedure. Section 5 includes a step-by-step outline of the recommended procedure for testing attic airtightness, including an equipment list and illustrated set-up.

# 2.0 Method

## 2.1 Terms and Concepts

Three zones were identified to help describe air flow patterns through attic spaces. These zones are defined below:

> The Attic Zone: contained by the roof, the soffits, and walls, and the ceiling/floor barrier separating the attic from the indoor environment;
>
> The Indoor Zone: the conditioned space of the house contained by the envelope (i.e. the inside surface of the exterior walls, and ceiling, windows, doors and basement floor, and exposed floors); and
>
> The Outdoor Zone.

Under normal home operating conditions, air flows occur between all of these zones, depending on pressure differences created by winds, temperatures and mechanical systems.

These air flows are illustrated in Figure 1. The most complicated air flow paths are from the indoor zone into the exterior wall cavities, (which is part of the outdoor zone), and then into the attic zone, through the top plate of the wall. In this way, air flow from outdoors into the attic can actually carry humidity from indoors.

Another common route between the indoor zone and the attic zone is through attic bypasses, which are channels that extend from the basement or lower floors directly to the attic. These kind of leaks can influence test results if basements are very separate for the rest of the house (eg. a house with a basement suite).

For the purpose of this study we have tried to differentiate between leakage areas in houses that will effect the moisture loading of attic spaces, and those that only influence the ventilation rate of attics. For this purpose we will introduce three more terms:

Interface Leakage - leakage areas that directly connect the attic zone with the indoor zone;

House Leakage - leakage areas that directly connect the indoor zone with the outdoor zone (this excludes the interface leakage); and,

Ventilation Leakage - leakage areas that directly connect the attic zone and the outdoor zone.

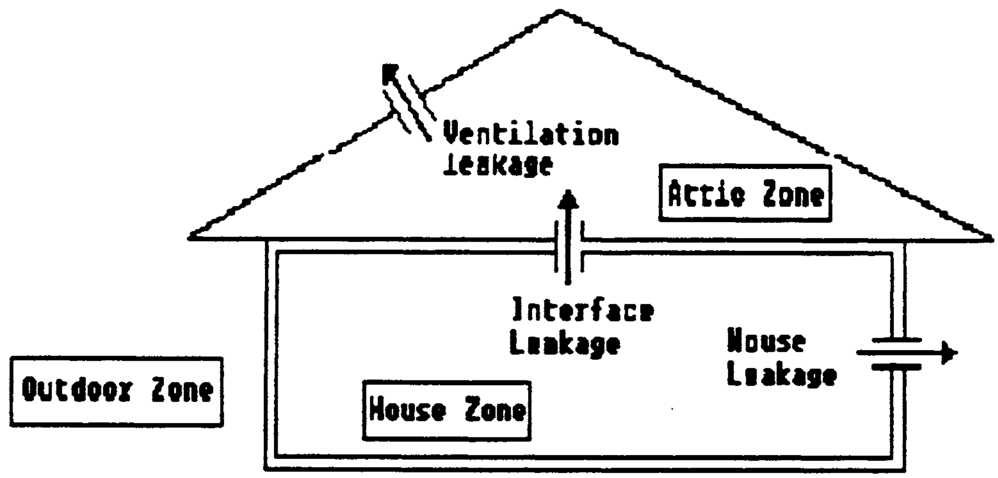
Ventilation Leakage can be further broken down into :

Installed Ventilation - soffit vents, mushroom vents, etc.; and,

Natural (or Unintentional) attic ventilation, - primarily consisting of the cracks in soffit materials, and the joins between the soffit and the roof or walls.

The Natural Ventilation also includes air flows through and around the top plates of exterior wall cavities, which complicates any analysis of attic leakage. Exterior walls are also a route for indoor air to flow into attics. The precise ratio of indoor and outdoor air flowing through exterior walls depends on the leakage areas and pressure differences between walls, house, attic and outdoors, and is thus impossible to characterize. The impact of such variables has been addressed in this project, but no conclusions are made on how exterior wall leakage effects the measurement of natural ventilation rates.

## FIGURE 1 DIVISION OF ZONES AND LEAKAGE AREAS



## 2.2 General Approach

Our general approach to developing a test procedure was to begin with a comprehensive series of tests, and then scale down the procedure to reduce time and equipment requirements. This comprehensive or "field test" procedure was tried out on three very different test houses. The series of tests included a degree of redundancy, to allow for cross-checking of data, and involved a variety of techniques and tools for comparison purposes. In this way, it was hoped that the simplified procedure could be shown as reliable for survey purposes.

The "field test" procedure was designed to resolve a number of outstanding issues, including:

attic and house set-up configurations;
location of blower doors and direction of flow;
wind effects;
separating leakage areas for different house components;
required flow capacities and pressure differentials;
accuracy and repeatability of the test methods;
possibilities for testing cathedral ceiling spaces.

## 2.3 The Basic Field Test Procedures

For the purposes of field trials, a test procedure was developed that appeared to provide all the key data on attic leakage. This basic field test procedure was later found to be error prone and alternative test procedures were developed. Since much of the field testing data is derived from the basic procedures developed initially, these procedures are described in detail below.

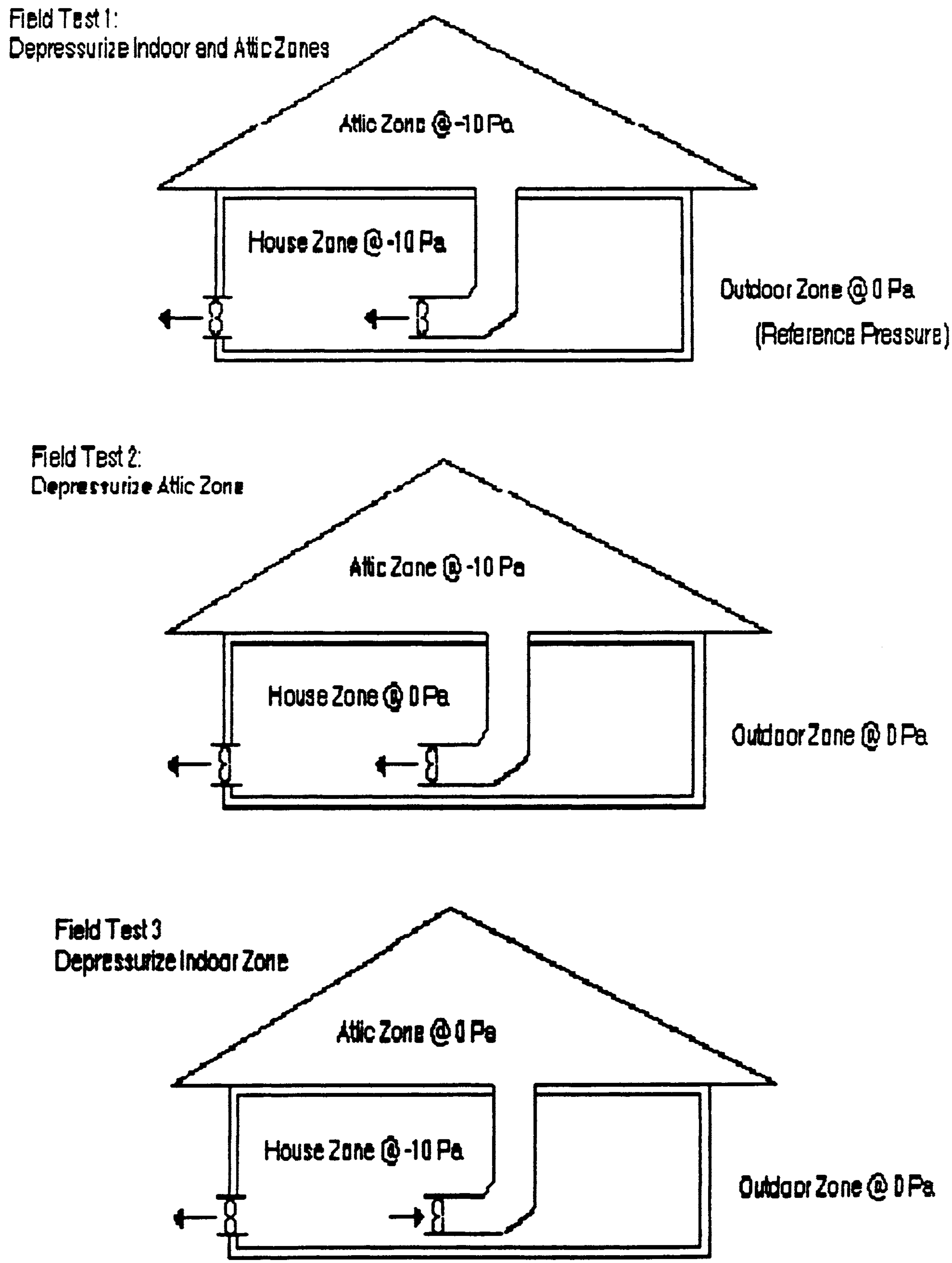
The basic field test procedure required two calibrated flow elements. Three separate tests were used to measure air flows between the three zones, and thereby derive the three leakage areas. A combination of three tests were considered necessary to accurately isolate and cross check each leakage area. A slight variation of one of the tests was included as a fourth test. Its purpose was to derive the area of the installed attic ventilation. A fifth airtightness test was included as a way to obtain a conventional ELA for the house using the CGSB standard procedure (CAN2/CGSB 149.10 M86).

Refer to Figure 2 for a schematic of the test procedures. All leakage areas were measured at 10 Pa of pressure differential relative to outdoors. This was considered the lowest possible pressure for measuring leakage without excessive interference from winds, and is consistent with existing CGSB standards. The value of testing at the lowest possible pressure is the greater potential for obtaining results on leaky attic spaces. Existing blower door equipment can only blow 2,000 to 3,000 L/s. It is estimated that at 10 Pa, 90% or more of attics can be evaluated. Those attics that are not measurable can simply be termed excessively leaky, or can be measured with the installed ventilation sealed, or can be measured at a lower pressure differential.

Field Trial Test 1 : Depressurize Indoor and Attic Zones

The first test was designed to directly measure Ventilation Leakage and House leakage. The indoor zone and the attic zone were both depressurized to 10 Pa relative to outdoors. In an attempt to avoid a requirement for using long ducts between the attic and outdoors, the fans are used in tandem. While one fan blows air from the attic into the house, the other blows a combination of attic

**FIGURE 2: SCHEMATIC OF THE FIELD TEST PROCEDURES**



and the house air to the outdoors. By monitoring pressures, there is no need for hard ducting air from one fan to the other. The attic blower is measuring Ventilation Leakage and the house blower is measuring both the House Leakage and the Ventilation Leakage. If the parameter of Ventilation Leakage is all that is of interest, the house blower would not need to be calibrated.
If the House Leakage is also of interest, calibrated blowers can be used in both locations. The difference in flow between the two blowers is equal to the House Leakage.

**Field Trial Test 2 : Depressurize Attic Zone**

The second test was designed to measure the combination of Ventilation Leakage and Interface Leakage. The attic zone is depressurized to 10 Pa and the envelope zone is maintained at 0 Pa, relative to outdoors. The attic blower is measuring Ventilation Leakage and Interface Leakage, and the house blower is measuring only Ventilation Leakage. Air flow through the Interface Leakage is returning to the attic in a continuous loop. The difference in flow between the two blowers is therefore equal to the Interface Leakage.

**Field Trial Test 3 : Depressurize Indoor Zone**

The third test was designed to measure House Leakage and Interface Leakage. The Indoor Zone is depressurized to 10 Pa and the Attic Zone is maintained at 0 Pa, relative to outdoors. The attic blower is reversed and is measuring the flow into the attic zone to maintain a 0 pressure. The house blower is measuring the House Leakage plus the Interface Leakage. The attic blower is measuring only

the Interface Leakage. The difference in flow between the two blowers is equal to the House Leakage.
For quality control purposes, we can compare the value of Interface Leakage from Tests 2 and 3. Depressurizing the attic zone gives one value of Interface Leakage, while depressurizing the Indoor Zone gives another. If these values agree within, say 10%, the test results might be considered reliable. Some degree of variation can be excepted since the air flows through the interface are in different directions, and could also be affected by one-way leaks.

Variations to these three tests were included as part of the field trials. Variations included the following:

* using a single point pressure tap instead of four taps and a pressure averaging box;
* detecting pressure differentials between zones using a smoke tube;
* measuring pressure differentials with a single gauge, and substituting an electronic transducer for a Magnehelic;
* using a single calibrated blower with a dampered mixing box instead of two separate blowers;
* mounting the attic blower directly in the attic hatch, in a corridor, and in an exterior door way, as opposed to inside the home;
* neutralizing pressures between the indoor zone and attic or outdoors by opening up doors and corridors, instead of using a blower.

These and other variations are explained in more detail as part of the results and discussion sections of this report.

## 2.4 Test Equipment Used On Research Houses

The equipment used for field trials was adapted from a Retrotec Halon Infiltrometer 800 system, designed for testing fire protected spaces in commercial buildings. The Halon test rig was specifically designed for attaching to a 508 mm diameter flex duct and for simultaneously depressurizing two zones, with separate blowers, in order to eliminate flow between the zones.

A special adapter was designed for this project, to mate a 508 mm round duct to a 609 mm x 609 mm box that would fit to the ceiling below an attic hatch. The intention of the design was to reduce the restriction to air flow to a minimum, while still permitting the flex duct to enter the attic. Most attic hatches are designed to fit between the ceiling joists, and are therefore restricted to about 35 cm (14"). Two adjustable supports were designed for holding the adapter in place, so that a tight seal was made to the ceiling.

Sheltair's shop manufactures Retrotec Halon infiltrometer systems, and was used to assemble the equipment. Access to this shop was an advantage in designing and building suitable test equipment.

The Retrotec blower was re-calibrated for measuring flows after attachment to the 508 mm diameter duct. This calibration was performed for purposes of this project, using Sheltair's flow calibration chamber.

A special flow straightener was installed one diameter of the orifice length down-stream of the flow element in the 508 mm diameter duct. Lab tests showed that it was accurately measuring flows, and was relatively insensitive to variations in the flex duct lay-out. The duct and blower unit was therefore calibrated and used as a system. (Details on the calibration procedure and results can be found in the Appendix).

The reference pressure for the orifice of the attic blower was mistakenly taken as the indoor pressure during some of the field tests. All flows recorded in the field were later corrected for the 10 Pa difference, between the indoor and the attic pressures.

As an additional check on the accuracy of the test procedure, it was proposed to install a standard attic mushroom vent in one of the test houses, and measure the resulting change in ventilation area. In preparation for this experiment, the flow calibration chamber was used to measure flow and pressure data for two types of roof vents. The calculated leakage area of the vents at 10 Pascals was 152.5 $cm^2$, and 169.8 $cm^2$, or about 50% less than the open area suggested by the physical dimensions of the vents. (Flow and pressure data can be found in the Appendix). These vents were never installed since an identical vent was already in place in one of the test houses.

# 3.0 Results

## 3.1 Airtightness Test Data

Table 1 presents the results of the initial field tests. These values have been calculated on the basis measured flows through the house and attic blowers. Flows have been converted into leakage areas using a simple rule of thumb, (Flow in L/s * 4 = leakage area in $cm^2$ for air at STP). This is roughly equivalent to the equation used for calculating ELA values in the CGSB Standard CAN2/CGSB 149.10 M86. These approximate leakage areas were thought to be of value in allowing for a comparison of results with other airtightness data on houses, with specifications for attic ventilation and envelope tightness, and with natural infiltration estimates using leakage areas.

**TABLE 1 LEAKAGE AREAS FOR THREE TEST HOUSES**

| | Leakage Areas* ($cm^2$ at 10 Pa) | | |
|---|---|---|---|
| House No. | 1 | 2 | 3 |
| House Leakage | 704 | 1882 | 1716 |
| Interface Leakage | 776 | 76 | 2884 |
| Ventilation Leakage | 2280 | 6945 | 3615 |

*calculated using a similar equation to what is specified in the CGSB Standard CAN2/CGSB 149.10 M86, but with only a single flow measurement at 10 Pa.

The Ventilation Leakage in House No.1 was 35% larger that the combined house and interface leakage. The house leakage was roughly equivalent to the interface leakage.

The Ventilation Leakage in House No.2 was six times greater than the combined house and interface leakage. Interface leakage represented only 5% of the house leakage.

The Ventilation Leakage in House No.3 was equal to the combined house and interface leakage. Similar to House No.1, the interface leakage area was roughly equivalent to the house leakage area.

House No.2 appears to be considerably different in air leakage characteristics than either of the other houses. We think this is adequately explained by the differences in construction techniques described below.

The roof and soffit vents in House No.1 were easy to access and were sealed for one of the tests. This allowed us to estimate the installed ventilation by subtracting the sealed ventilation test from unsealed ventilation test.
The installed ventilation was measured to be approximately 1200 $cm^2$. Sealing the installed vents in House No.2 was impossible because of their large area; House No.3 had vents that were too difficult to access.

## 3.2 House Description

The three test houses are described in Table 2 including details on construction materials, attic type, and installed attic ventilation. An extensive photographic review of the airtightness tests on each of the three houses is presented in

Appendix 1. More detailed information on those construction components that might effect the leakage area of these three attics has been summarized below:

House No.1

House No. 1 was found to have a tight envelope, and a tight attic (House Leakage area = 704 $cm^2$; Unintentional Ventilation area = 260 $cm^2$). The house has a number of construction features that help to explain the tightness of house and attic. Stucco siding mates directly to the concrete foundation wall without the use of metal flashing. Presumably, much of the air flow into the attic through the top plate of the exterior walls would come from inside the house, rather than outdoors.

The attic is enclosed by a hip roof which eliminates gable ends. It is likely that a hip roof would leak less than roofs with gables. The summer heat tends to bond asphalt shingles together, reducing the leakage area of roofs. Gable ends, on the other hand, are expected to be leakier than a typical wall section because they lack insulation and an interior finish. The soffits of the house were fabricated from plywood. Years of repainting the house will have tightly sealed the joints of the plywood and facia board. Both factors would increase the tightness levels of the attic. In general terms, we would expect soffits constructed from perforated aluminum, or wooden slats to have higher leakage areas. The Unintentional Ventilation leakage was the lowest of the three research houses.

House No.2

House No. 2 had a 50 mm wide continuous soffit vent and no roof top vents. The total area of the installed soffit vent was approximately 13,800 $cm^2$ (based on physical dimensions). The roof rafters were covered by plywood with closely butted ends. This type of roof construction was expected to increase the level of tightness of the roof and the attic, leaving most of the leakage area in the soffits and gable ends.

The use of a polyethylene vapour barrier in the ceiling, standard practice in new houses, would presumably increase the tightness of the attic and reduce the interface leakage . House No.2 was the only house with a vapour barrier and, as expected, had the lowest Interface Leakage.
This new house has brick and wood siding on the front wall and stucco on the three side walls. The stucco has metal flashing at the bottom which may allow movement of air into and out of wall cavities, (an opposite case from House No. 1). Any leakage into the attic zone through the top plate of exterior walls may originate from either the outdoor or indoor zone.

House No.3

House No.3 had a gable roof with large shed dormers. Clothing drawers and cupboards have been built into knee wall attics. These construction features contribute to a flow of air from the house to the attic, and help to explain why the Interface Leakage, at 2884 $cm^2$, was the largest of the three research houses.

There did not appear to be a major restriction between knee wall attic spaces and the ridge peak attic. Insulation material was loose blown cellulose, only partially filling the rafter spaces between peak attic and knee wall attics. Pressures differences of 1 to 2 Pa were recorded between the different attic spaces, suggesting that there was only minor restrictions to air flow between the connected attic spaces.

# TABLE 2 TEST HOUSE CHARACTERISTICS

| | House #1 | House #2 | House #3 |
|---|---|---|---|
| **House Type** | | | |
| Year Constructed | 1957 | 1975 | 1945 |
| Number of Storeys | 1 | 1 | 1.5 |
| Exterior Siding | Stucco | Stucco and Wood | Stucco |
| Foundation Type | Basement | Basement | Basement |
| Interior Wall Facing | Gypsum | Gypsum | Gypsum |
| Wall Construction | Plateform | Plateform | Plateform |

| | | | |
|---|---|---|---|
| **Attic Type** | | | |
| Attic Style | Hip Roof | Gable | Shed Dormer |
| Roof Structure | Rafters | Rafters | Rafters |
| Roofing Material | Asphalt Shingles | Asphalt Shingles | Asphalt Shingles |
| Insulation Type | Fibreglass | Fibreglass | Cellulous |
| Vapour Barrier | None | Polyethelene | Kraft Paper |
| Attic Hatch (mm*mm) | 508 X 508 | 508 X 406 | 350 X 500 |
| Loc. of Attic Hatch | Bedroom | Bedroom | Hallway |
| # of Chimneys | 2 | 2 | 2 |
| # of Plumbing Stacks | 3 | 2 | 2 |
| # of Exhaust Fans | 0 | 2 | 0 |

| | | | |
|---|---|---|---|
| **Ventilation Type** | | | |
| Ventilation Style | Roof and Sofit | Continuous Soffit | Gable Vents |
| Vents (cm*cm) | 300 X 900 | 1100 X 6 | 150 X 250 |
| Signs of Moisture | None | None | None |

### 3.3 Difficulties with Equipment Set-up

House No.1

The attic hatch in House No.1 was located in a narrow closet in the master bedroom. A shelving unit and clothes had to be moved to enable access to the hatch. The transition piece only partially covered the attic hatch. Clear poly tape was used to make a tight fit. It was noted that the attic air flow measurements would not include the sometimes significant leakage that can occur around the attic hatch.

The small size of rooms, doorways and hallways in House No.1 presented a considerable restriction to air flows between the attic blower and the house blower. The attic blower had to be faced into the master bedroom because the turning radius for the flexible duct was too tight for it to exit the room. The 4 meter duct would not reach the closest window.

House No.2

The set up of equipment in House No.2 was relatively easy, because of the lack of furniture in the house. The extremely high air flow from the attic flow element caused the bedroom door to close during one of the tests. This was the highest flow recorded in any of the three research houses. The blower was unstable on its own at these high flows, and needed to be supported. Between tests the householder left a window open and operated both a bathroom fan and a range hood fan. The field crew were lucky to notice these disruptions prior to further testing.

House No.3

The attic hatch in House No.3 was particularly small (350 mm X 500 mm). There was some concern that it would restrict air flows into the flexduct. By removing trim, we could only increase the attic hatch dimensions by 50 mm in each dimension. However, the attic blower was able to blow equivalent flows to the other two test houses, suggesting that this particularly small opening was not too restrictive.

The leakage area of the house was known to be larger than average. A second house blower was set up but was not required. With the basic field test procedure, the house blower was required to handle all the flow of the attic and the house (This is no longer the recommended approach). The maximum flow for the house blower was 2027 L/s, just within the flow capacity of a Retrotec blower unit.

## 3.4 Variations to the Field Test Procedure

To determine whether multiple pressure taps were required in the attic in order to average pressure differences within the space, we repeated one of the standard tests with only a single pressure tap attached to the gauge. This was tried in only one of the three test houses. The pressure difference recorded between the single and multiple pressure tap tests was equal to a 1% change in flow - not significant. However,the multiple pressure taps were considered a better approach in principle, and may help to avoid significant errors in more restrictive attics.

We suspected that the attic envelope restricts air flow into a house during the standard CGSB airtightness test. To eliminate this restriction, and to obtain a more accurate measurement of House and Interface Leakage, we reversed the flow of the attic blower and maintained a zero pressure differential in the attic space during the six different house depressurization readings. This procedure was followed in House No.2 and House No.3. The restriction was insignificant in House No.2 which had 13,800 $cm^2$ of installed ventilation. The restriction in House No.3 was equivalent to 449.2 $cm^2$. (The attic experienced a pressure drop of 4.6 Pa relative to outdoors, when a blower door was used to depressurize the house to 10 Pa.) It is reasonable to assume that whenever the Interface Leakage exceeds the Ventilation Leakage, the attic space will affect the measurement of House Leakage.

To test whether a single fan could be used to do all tests we built a damper box that could alternatively draw air from the house or from the attic and exhaust the air out through a window. By adjusting the damper it was possible to conduct the field tests using only the one blower. We had to add a considerable length of duct to the apparatus in order to reach the closest window. This added length of duct reduced the total possible flows by only 5 to 10%. This test was only done on House No.1. The damper system worked perfectly, replicating the results of the standard procedure. For houses with small attic and House Leakage areas a single blower is a definite possibility. In House No.2, with an excessively large ventilation leakage, extending the duct created enough restriction to prevent the fan from creating 10 Pa in the attic. In House No.3, the nearest window was not operational. The next closest operable window was further away than the length of duct we had brought along (8 meters in total).

We were concerned that by using two gauges to separately measure the house pressure and the attic pressure we would be introducing some error. Minor errors in instrument calibration could translate into major errors in calculated flow measurements. During the attic and house pressure tests, measurements of Ventilation and House Leakage will be less if there is any flow through the interface. Even small pressures in the order of 0.5 to 1.0 Pa can create large flows between the house and the attic if the Interface Leakage is large. The error is doubled because flows are lost from the attic zone and added to the house zone, or vice versa, depending upon the direction of the pressure difference. To eliminate this error we tried using a single gauge and a toggle switch for selecting the tube leading to the attic or the house. The length of tubing and the pressure damping box caused a considerable time delay in matching house and attic pressures when a single gauge was used. (This is a dynamic process, adjusting each blower sequentially, while measuring the appropriate pressure each time.) Practice reduced the time required to achieve a neutral pressure across the interface to under 10 minutes per test.

We expected that pressures could differ between rooms within the house, between attics, and within wall cavities. While conducting the standard three tests we measured pressures in different locations to determine if, in fact, differences could be detected. In House No.2, where a large volume of air was required to depressurize the attic to 10 Pa, pressure differences were indeed recorded within the house. The bedroom with the attic hatch and attic blower was under less depressurization (at 8 Pa) than the kitchen where the house blower element was installed in an exterior door. The living room pressure was 1 Pa less than the kitchen and was identical to the basement. A pressure difference was found in House No.3 between the main floor and the basement, and a difference of 1 to 2 Pa was measured between the peak attic and the kneewall attics.

For comparison purposes, the attic blower was mounted directly in the attic hatch of House No.2, and was used to measure attic flows. The flows were identical to those measured with the blower attached to a flex duct, and confirmed the accuracy of the calibrated system. However the set-up of a blower in the hatch proved to be, as expected, difficult and time consuming.

House No. 2 was initially chosen for testing because it provided an opportunity to adapt the attic airtightness testing procedures to a cathedral ceiling space. House No. 2 had both a cathedral ceiling - over the living room - and a truss attic over the rest of the house. During the basic field testing plans were made to seperately test the cathedral ceiling space by connecting a CMHC Duct Test Rig to the rafter space. However pressure measurements taken during testing of the truss attic revealed that the cathedral ceiling space was not functioning as a seperate space. At the peak of the roof the rafter spaces were left open to the truss attic, and the two spaces had to be tested together.

## 4.0 Discussion of Test Results and Sources of Error

Table 3 presents the detailed data collected on each test for each house, including the air flow in litres per second through the house and attic blowers. Directly measured flows are presented, as well as the calculated flows based on the difference between the blowers.

In general, there was poor agreement between the test results for all of the initial field trials. Discrepancies were encountered between values for the same component, measured in different ways. Discrepancies also existed between the calculated values using different test configurations. For example in house No. 3, where results were especially consistent and repeatable for all the alternative test methods, the Interface Leakage was calculated to be 2884 $cm^2$, on the basis of Test 1, and 2000 cm2 on the basis of Test 3. This represents a 30% error. Such errors were encountered despite extreme care taken with instrument calibration and despite repeated testing to avoid operator errors. We were forced to conclude that the field test procedure was inherently error-prone, and required revisions.

The discrepancies between the different ways of measuring the same leakage area can be explained in a number of ways. A first possible explanation for error in the test procedure is that pressure differences within the house zone were affecting total flow from the house and the attic. The pressures differences may be caused by hallways and doorways in houses with large air flows (eg. 1804 L/s in House No.2). The only sure way of eliminating this effect is to hard duct the attic flow through the house by extending a duct from the attic hatch to a window or door.

# TABLE 3 MEASURED AND CALCULATED FLOWS DURING FIELD TRIALS

| Test Number | Measured Flow (L/s) House Blower | Measured Flow (L/s) Attic Blower | Calculated Flows (L/s) | Comments on Leakage |
|---|---|---|---|---|
| **House #1** | | | | |
| 1 | 743 | | | House and Ventilation Leakage |
| | | 570 | | Ventilation Leakage |
| | | | 173 | Envelope Leakage |
| 2 | * | 764 | | Ventilation and Interface Leakage |
| | | | 174 | Interface Leakage |
| 3 | 370.7 | * | | House and Interface Leakage |
| **House #2** | | | | |
| 1 | 2193 | | | House and Ventilation Leakage |
| | | 1735 | | Ventilation Leakage |
| | | | 458 | House Leakage |
| 2 | 1785 | | | Ventialtion Leakage |
| | | 1754 | | Ventilation and Interface Leakage |
| | | | 31 | Interface Leakage |
| 3 | 334 | | | House Leakage |
| | | 0 | | Interface Leakage |
| | | | 334 | House and Interface Leakage |
| **House #3** | | | | |
| 1 | 1240 | | | House and Ventilation Leakage |
| | | 900 | | Ventilation Leakage |
| | | | 340 | House Leakage |
| 2 | 653 | | | Ventialtion Leakage |
| | | 1332 | | Ventilation and Interface Leakage |
| | | | 679 | Interface Leakage |
| 3 | 500 | | | House Leakage |
| | | 428 | | Interface Leakage |
| | | | 928 | House and Interface Leakage |

* Data not recorded for test as described

A second possible explanation for discrepancies in the field test data is that leakage through exterior wall cavities was swinging sometimes to the attic and sometimes to the house depending on the type of house and the test. Considerable time was spent in the office and in the test houses trying to measure the impact of swing leakage. Unfortunately, wall cavity leakage seems impossible to measure accurately, and there is no way to confirm this phenomenon. It would also be difficult to determine when it was having an influence on house-to-attic flows and when it was not, since this would vary with test procedures and with house constructions. As a result we decided to avoid this issue altogether and accept some degree of error in the cross-checking of leakage areas.

A third possible explanation for error in the test procedure is that the procedure does not accurately measure pressure differentials between the house and the attic. Magnehelic gauges are only accurate to 0.6 Pa (although they can usually be read to within 0.3 Pa if you are only trying to achieve identical pressures in different locations as in our situation). A Magnehelic gauge may not be accurate enough for this test procedure because of the doubling of error that is introduced if the pressures are not exactly equal (as was discussed earlier). One solution is to use an electronic transducer in place of the magnehelic. A second possibility is to simply eliminate the test that required both the attic and the house to be at equal pressures.

To resolve the above problems it was decided to test House No.1 over again to see if an alternative procedure would give more accurate results. This allowed us to collect data that was missed during the first test, and to compare the new procedure with the old procedure in an identical house.

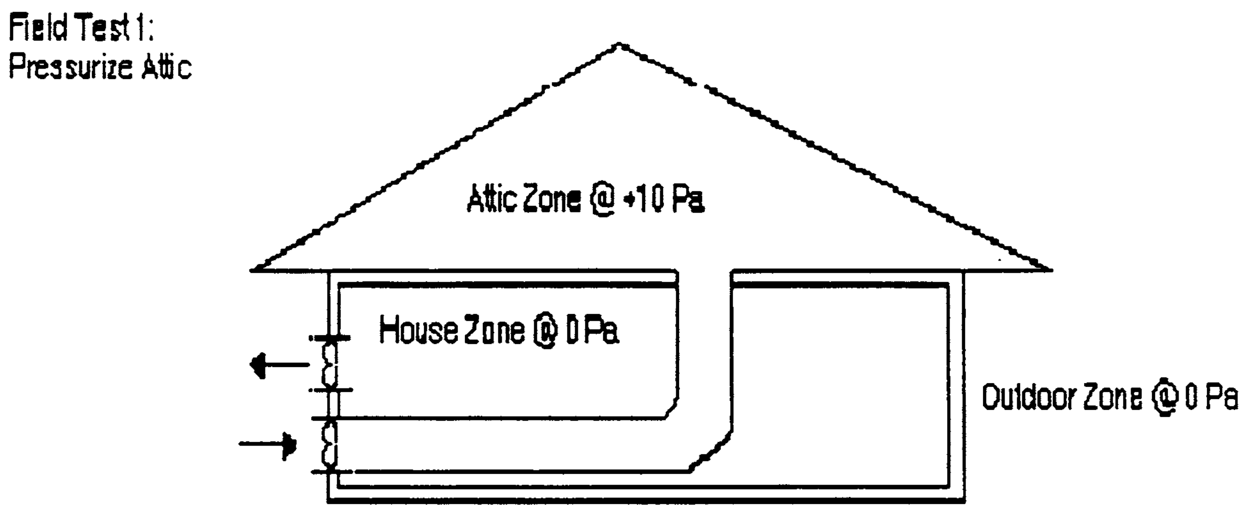
The new procedure was designed to eliminate all or most possible causes of the measured discrepancies in the initial field trials. The test set-up was altered in two ways:

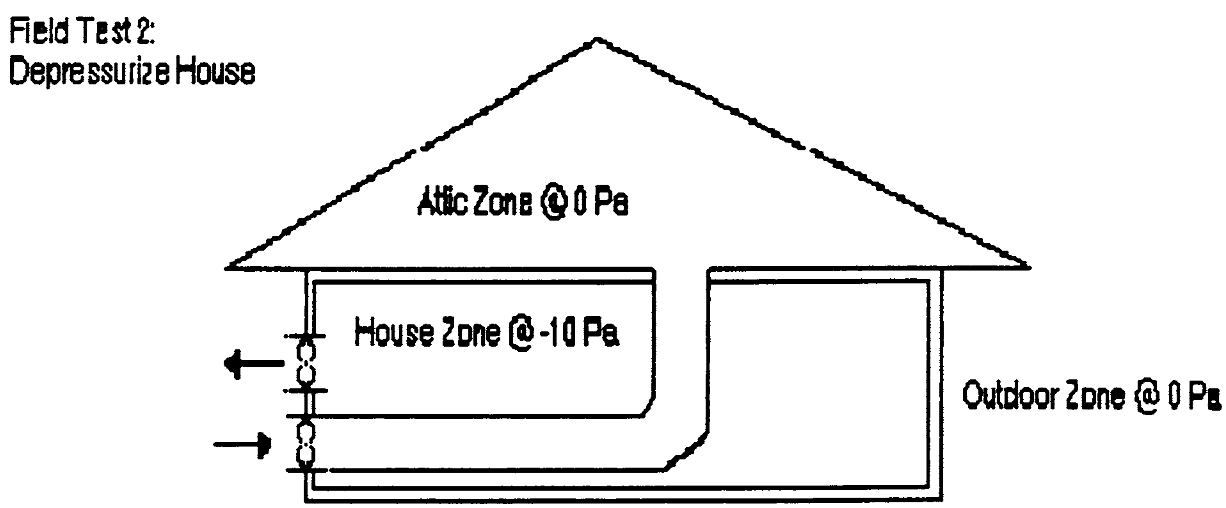
- An electronic pressure transducer was used for measuring pressures between the zones.
- The air flow to the attic was hard ducted to the exterior doorway to avoid pressure differences within the envelope. This required 12 meters of flex duct, with specially fabricated junctions. After considering various house plans and configurations, it was concluded that 12 meters of duct would be sufficient to reach an exterior doorway in most one or two storey houses.

The test requiring the house and attic to be at identical pressures was eliminated. Instead, the attic was pressurized relative to the house, or maintained at a neutral pressure in relation to outdoors. This approach reverses the normal direction of flow through the interface, but offers a major advantage in that no special calibration of the blower is required. The attic blower has a duct extending from the outlet of the orifice, which has little or no effect on its flow measurement system.

Only two tests were used to calculate the leakage areas. The tests are described below. Please refer to Figure 3 for an equipment set up schematic.

## FIGURE 3 REVISED FIELD TEST PROCEDURE



Revised Test No.1 - Pressurize Attic

The attic zone is pressurized to +10 Pa, relative to outdoors and the house zone is maintained at zero. The attic blower is mounted in an exterior door and blows air from outdoor into the attic through a long flex duct. The attic blower is measuring both the Ventilation Leakage and the Interface Leakage. The house blower is blowing air out of the house and is measuring only the Interface Leakage (i.e. the air that is flowing from the attic into the house). The difference between the blowers is the Ventilation Leakage.

Revised Test No.2 - Depressurize House

The indoor zone is depressurized to -10 Pa, relative to outdoors, and the attic zone is maintained at zero. The house blower is blowing air out of the house and is measuring the House and Interface Leakage. The attic blower is blowing air from outside through the duct to the attic, and is measuring only the Interface Leakage (i.e. the air that is flowing from the attic to the house). The difference between the blowers is the House Leakage.

Interface Leakage is measured directly in both tests, and provides a convenient cross-check for operator errors.

A major advantage to this new procedure is that it only requires one set up for the two tests. Also the air is always travelling in the same direction through the interface, avoiding confusion from one-way leakage. A disadvantage is that we are mixing pressure tests with depressurization tests. However air tends to flow into houses and out of attic ventilation areas, which is consistent with the direction of flow in these tests. Only the Interface Leakage direction is contrary to normal operation of the house.

The results of the second field trials can be found in Table 4. There was only a 6% difference between the Interface Leakage measurements of the two tests. We considered this to be excellent. The numbers are within the same range as the original data collected on the house, but with an obvious improvement in accuracy. This revised field test procedure satisfies many of the initial objectives for a practical survey procedure, and has formed the basis for the recommended procedure outlined in the following section.

## TABLE 4 RESULTS OF REVISED TESTS ON HOUSE NO.1

| Test Number | Measured Flow (L/s) | | Calculated Flows (L/s) | Comments on Leakage |
|---|---|---|---|---|
| | House Blower | Attic Blower | | |
| House #1 | | | | |
| 1 | 157.5 | | | Interface Leakage |
| | | 632.2 | | Ventilation and Interface Leakage |
| | | | 474.7 | Ventilation Leakage |
| 2 | 423.6 | | | House and Interface Leakage |
| | | 147.6 | | Interface Leakage |
| | | | 276 | House Leakage |

| Check on Results: | | |
|---|---|---|
| Interface Leakage Test 1 | 157.5 | L/s |
| Interface Leakage Test 2 | 147.6 | L/s |
| 6% Error between Tests 1 and 2 | 9.9 | L/s |

# 5.0 Recommended Procedure

## 5.1 Overview

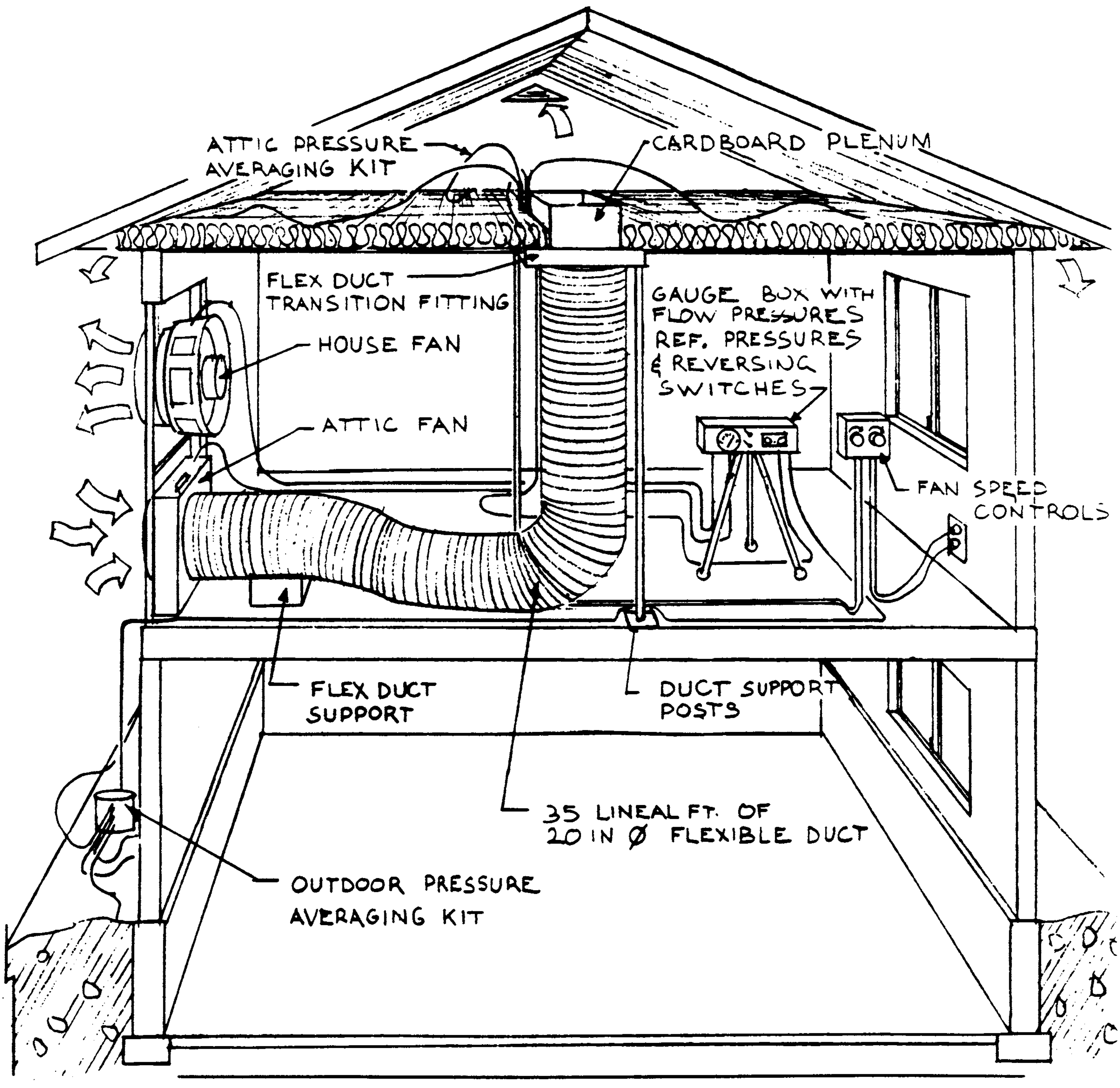
The following outline provides detailed directions for anyone wanting to measure the airtightness characteristics of attic spaces in homes. The step-by-step procedure covers home set-up, test methods, clean-up, and data analysis. The procedure has been shown to be suitable for most types of new and existing homes. Standard blower door equipment requires modifications and specialized accessories for this purpose. A complete equipment list, and an equipment set-up schematic, is provided.

The basic approach to measuring the airtightness characteristics of attics involves two tests using a two-fan blower door. Each of these tests is briefly summarized below. The equipment set-up is illustrated in Figure 4.

Test No.1 - Pressurize Attic

The attic zone is pressurized to +10 Pa, relative to outdoors and the house zone is maintained at zero. The attic blower is mounted in an exterior door and blows air from outdoor into the attic through a long flex duct. The attic blower is measuring both the Ventilation Leakage and the Interface Leakage. The house blower is blowing air out of the house and is measuring only the Interface Leakage (i.e. the air that is flowing from the attic into the house). The difference between the blowers is the Ventilation Leakage.

**FIGURE 4 RECOMMENDED EQUIPMENT SET-UP**



Test No.2 - Depressurize House

The indoor zone is depressurized to -10 Pa, relative to outdoors, and the attic zone is maintained at zero. The house blower is blowing air out of the house and is measuring the House and Interface Leakage. The attic blower is blowing air from outside through the duct to the attic, and is measuring only the Interface Leakage (i.e. the air that is flowing from the attic to the house). The difference between the blowers is the House Leakage. Interface Leakage is measured directly in both tests, and provides a convenient cross-check for operator errors.

Several options to this procedure may be included where appropriate:

Option 1 - CGSB Test: A standard CGSB airtightness test can be carried out in accordance with CAN2/CGSB 149.10 M86. This test can be conveniently performed either before of after the two attic airtightness tests. Note that the CGSB ELA value may not correspond with the sum of the House Leakage and Interface Leakage. CGSB flows are based on a regression fit of flow and pressure data; CGSB procedures do not maintain the Attic zone at outdoor pressures; CGSB set-up requires blocking of the primary flue; and, CGSB test results normally include leakage around the attic hatch which cannot be included in the attic test procedure.)

Option 2 - Plugged Ventilation Test: The Ventilation areas of the Attic can be separated into Unintentional and Installed Ventilation. This option is viable only in houses where the vents are accessible and can be temporarily plugged. Where desired, the most convenient way to exercise this option is to repeat Test No.1 with the vents plugged. The corresponding reduction in the attic blower flow represents the Installed Ventilation. This option is briefly outlined in the procedure.

## 5.2 Step-by-Step Procedures

**House Set-up**

1. Close all windows and exterior doors, open interior doors. Leave primary flues unplugged, but otherwise prepare the house as per CGSB 149.10M86.

2. Adjust vented appliances to stand-by.

3. Notify occupants that exhaust fan operation and door openings are not permitted.

4. Cover any ashes in the fireplaces with plastic, and close dampers.

5. Inspect the house to ensure that any exposed polyethylene is properly supported.

6. Complete a House Description Form, recording all relevant information including indoor and outdoor temperatures, and wind speed.

7. Measure the physical areas of the house shell in meters squared:

   Interface $A_i$
   House (envelope-interface) $A_h$
   Roof (attic enclosure - interface) $A_r$

**Equipment Set-up**

1. Transport equipment into house and allow it to warm up or cool down.

2. Remove obstructions below attic hatch (or install an attic hatch if no hatch is present).

3. Set-up a pressure averaging kit in the attic space (casting tubes to four corners if possible), and feeding the primary tube into the house.

4. If warranted, fabricate and install a cardboard plenum above hatch to prevent disrupting the insulation (use a utility knife, cardboard, and poly tape).

5. Connect flex duct to attic hatch, using braces and transition (feed pressure tap through collar of transition).

6. Tape any gaps between collar of duct and ceiling.

7. Extend flex duct to nearest doorway to outdoors, using extension ducts as warranted.

8. Set-up a second pressure averaging kit, placing four taps around house and feeding the primary tube through doorway.

9. Install expandable panel into doorway, (with inserts for two blowers).

10. Fit blowers into panel : top blower is House Blower and blows to outdoors; bottom blower is Attic Blower, and blows indoors (or into the attic when ductwork is attached). Leave both blowers plugged or covered for now.

11. Using flex duct support, connect open end of flex duct to outlet of the Attic Blower.

12. Set-up the gauge panel (or gauge box) next to the doorway, and level and zero the gauges. Connect the electronic gauge (or gauges) to house power.

13. Connect both pressure averaging kits to the pressure manifold. Connect the pressure tubes from the two blowers to the flow gauges. Measure and record any off-set pressures between indoors and outdoors (Po house), and between attic and outdoors (Po attic). Now zero the gauge(s) to ensure that the offset pressure is maintained during subsequent testing.

14. Connect the two speed controls for blowers to the house power.

**TEST 1 : Pressurize Attic**

1. Unplug and operate both blowers.
2. Adjust fan speeds to achieve:
   10 Pa of pressure differential between attic and outdoors; and,
   0 Pa between house and outdoors. (This requires patience and skill. Use toggle switches on manifold to choose zones for the electronic transducer, and wait for readings to stabilize.)

3. Record flow pressure for:
   Attic Blower ($Q_{iv}$), and
   House Blower ($Q_i$)

**TEST 2 : Depressurize House**

1. Adjust fan speeds to achieve:
   0 Pa of pressure differential between attic and outdoors; and
   10 Pa between house and outdoors.
2. Record flow pressure for:
   Attic Blower ($Q_{i2}$), and
   House Blower ($Q_{ih}$)
3. Shut off blowers, plug blowers, and record off-set pressure (indoor-outdoor).

**Optional Test 1: CGSB TEST**

Conduct a standard CGSB airtightness test.

**Optional Test 2: PLUGGED VENTILATION TEST**

Repeat Test 1 with installed Attic Vents PLUGGED, and record flow for Attic Blower ($Q_p$).

**Clean-up**

1. Detach the pressure averaging kits and record the offset pressures (Po attic and Po house). For consistent results, the offset pressures should be the same as those recorded at the begining of the test.

2. Pack-up equipment and complete a clean-up checklist.

3. Return house to condition in which it was found.
Remember to:
   * re-set appliances
   * remove plastic from fireplaces
   * vacuum any mess.

**Analysis**

1. List (and calculate if necessary) the following flows (L/s):

| | | |
|---|---|---|
| Interface and Ventilation | ($Q_{iv}$) | __________ |
| Interface 1 | ($Q_i$) | __________ |
| Attic Ventilation | ($Q_{iv}$ - $Q_i$) | __________ |
| Interface 2 | ($Q_{i2}$) | __________ |
| Interface and House | ($Q_{ih}$) | __________ |
| House | ($Q_{ih}$ - $Q_{i2}$) | __________ |

2. Cross-check the Interface values from both tests and calculate the percentage error:

$$\frac{(Q_i - Q_{i2})}{Q_i} * 100 \qquad \_\_\_\_\_\_\_\_\_\_$$

3. If Attic Vents were blocked as part of Optional Test 2, calculate the Ventilation components as follows:

| | | |
|---|---|---|
| Accidental Attic Ventilation | $(Q_p - Q_i)$ | __________ |
| Installed Attic Ventilation | $(Q_{iv} - Q_p)$ | __________ |

4. Convert the flows to approximate leakage areas as follows:

Leakage Area in $cm^2$ = Q * 4
where: Q = flow in L/s at 10 Pascals

5. Convert the leakage areas to normalized leakage areas (NLA) by dividing the leakage area ($cm^2$) by the corresponding area envelope ($m^2$) as follows:

NLA Interface = Interface Leakage Area / $A_i$
NLA Ventilation = Ventilation Leakage Area / $A_v$
NLA House = House Leakage Area / $A_h$

**Suggested Equipment List**

| Item | Quantity Required | Estimated Total Cost for one complete system ($) |
|---|---|---|
| *Calibrated box-type blowers with speed controlled, 120 VAC fans capable of blowing 0 to 2000 L/s at 60 Pa | 2 | 1392.00 |
| *Low flow nozzle or plate for blower | 2 | 165.00 |
| *Expandable panel system for doorway designed for mounting 2 blowers | 1 set | 622.50 |
| *Speed control for 120 VAC blower (hand-held) | 2 | 186.00 |
| *High pressure Magnehelic gauges for measuring flow pressures across blower | 2 | 240.00 |
| *Electronic pressure transducer and voltmeters for measuring interzone pressures (0 to 5 VDC, -60 to +60 Pa, +-0.1 Pa) | 1 | 250.00 |

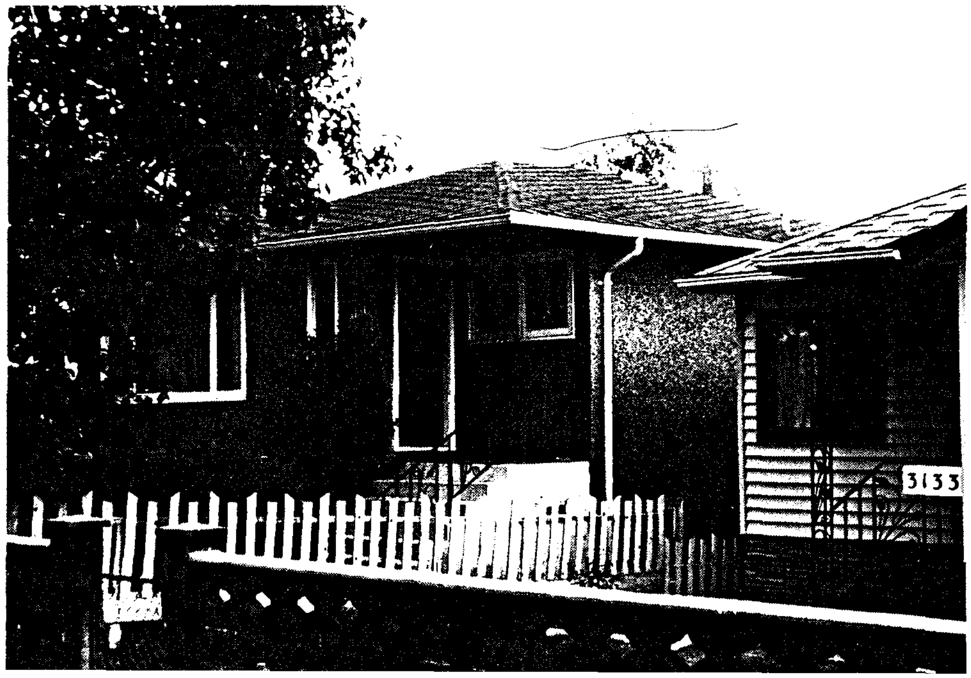
| | | |
|---|---|---|
| *Panel or box for mounting and levelling pressure gauges and transducer | 1 | N/C |
| *Flexible duct, 500 mm diameter | 1@ 8m<br>1@ 4m | 270.00 |
| *Collar to fit flex duct to blower | 1 | N/C |
| *Junction to connect flex duct sections | 1 | 20.00 |
| *Flex duct support (used next to blower) | 1 | N/C |
| *500 mm diameter to 609 x 609 transition (for mating duct to ceiling around attic hatch) | 1 | 45.00 |
| *Floor to ceiling adjustable brace (to hold transition against ceiling) | 2 | 50.00 |
| *Pressure averaging kit with 75 m of tubing | 2 | 100.00 |
| *Pressure tube manifold with toggle switches (for selecting two of three zones for pressure transducer) | 1 | 50.00 |
| *Hand tools and misc. supplies kit (flashlight, step ladder, poly tape, vacuum, reciprocating saw) | 1 | N/A |
| *Cardboard squares (for hatch plenum) | 4 | N/A |
| | | 3390.50 |

# A P P E N D I X 1

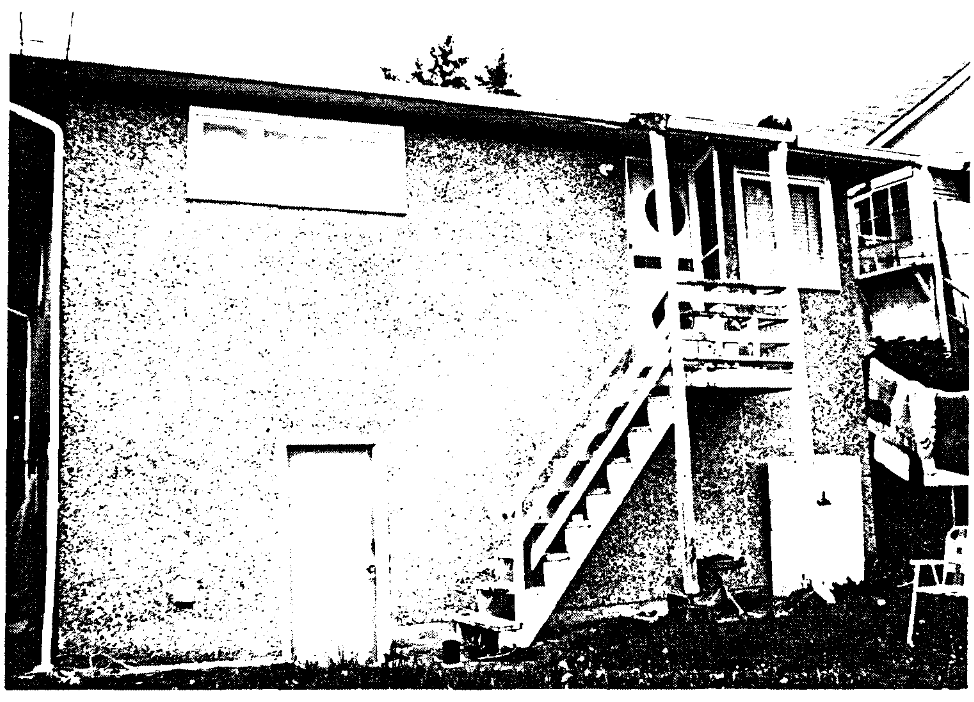
# PHOTOGRAPHIC REVIEW

# OF ATTIC AIRTIGHTNESS TESTS

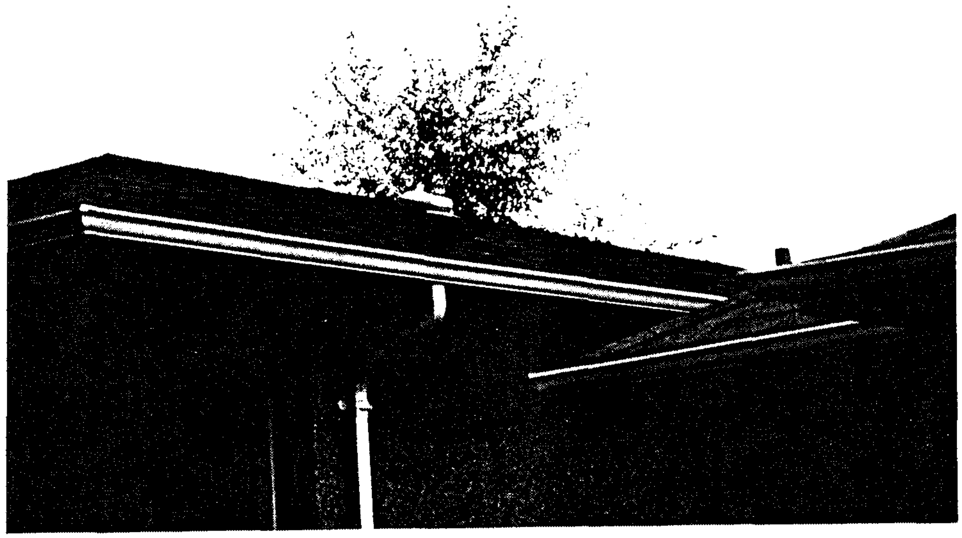
# ON THREE TEST HOUSES.



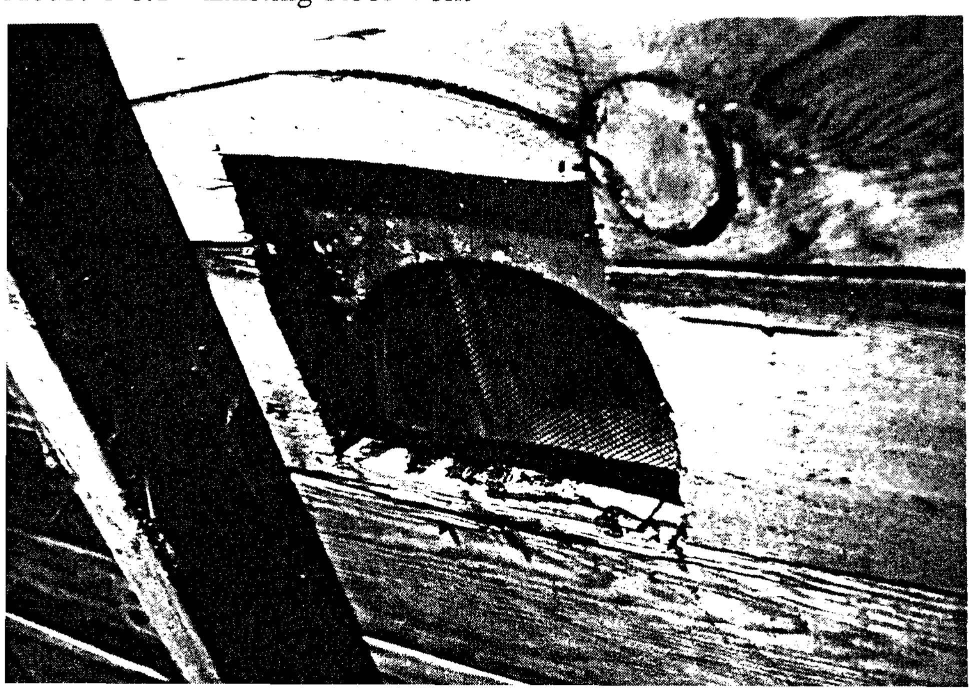

House No.1 - Front View Showing Hip Roof



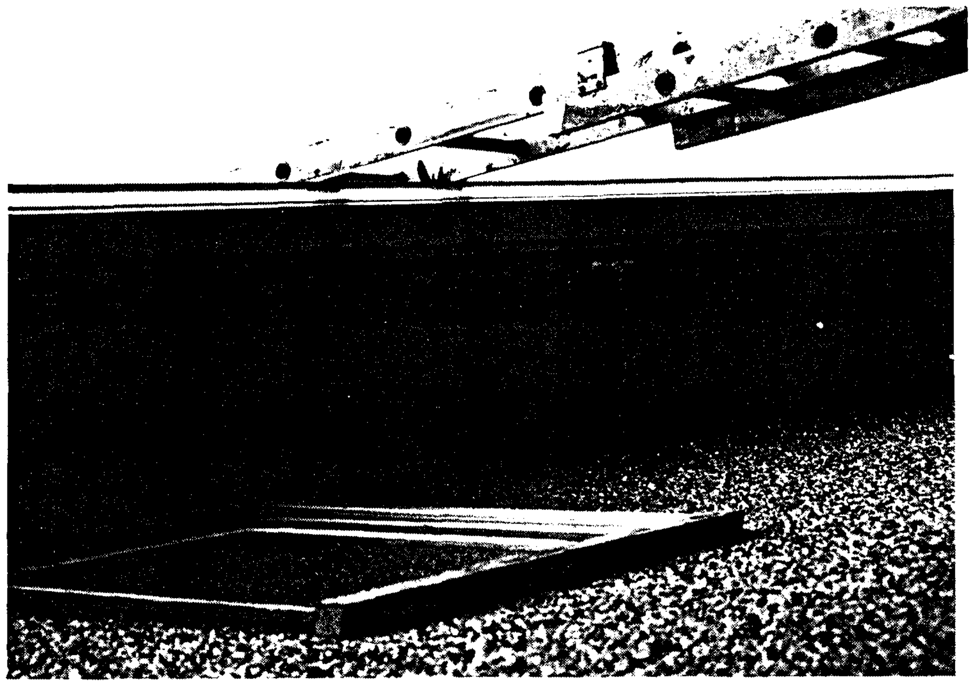
House No.1 - Rear View Showing Stucco and Blower Door



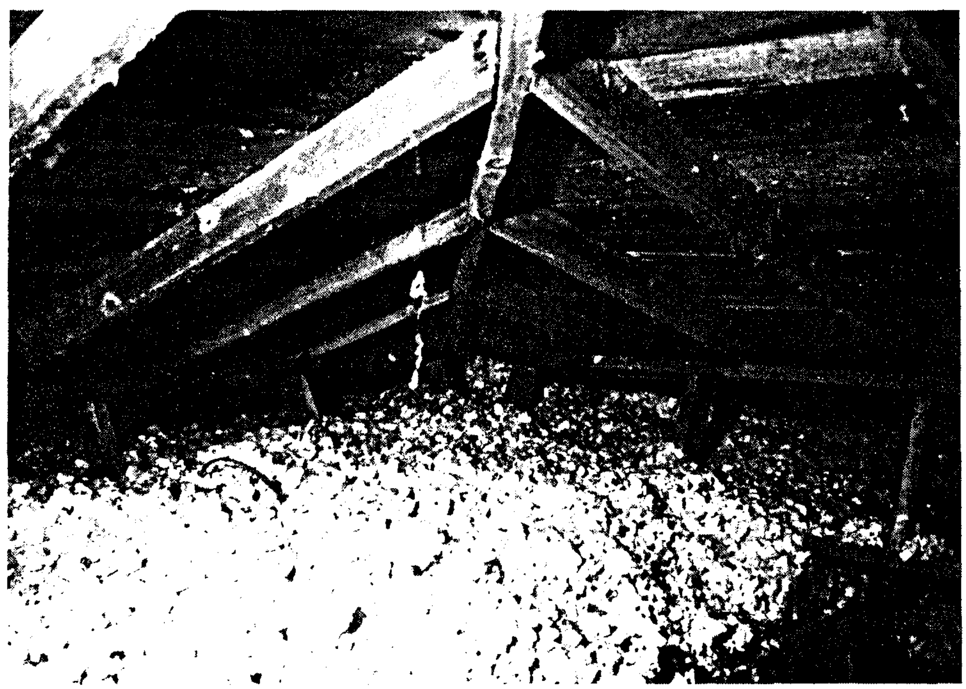
House No.1 - Existing Roof Vent



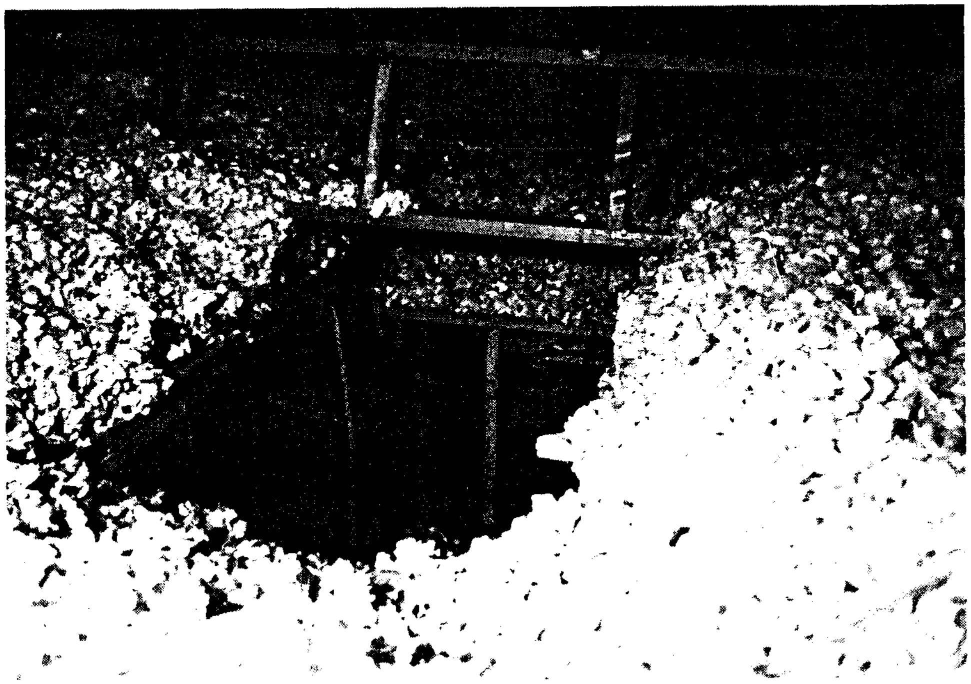
House No.1 - Existing Roof Vent From Inside Attic



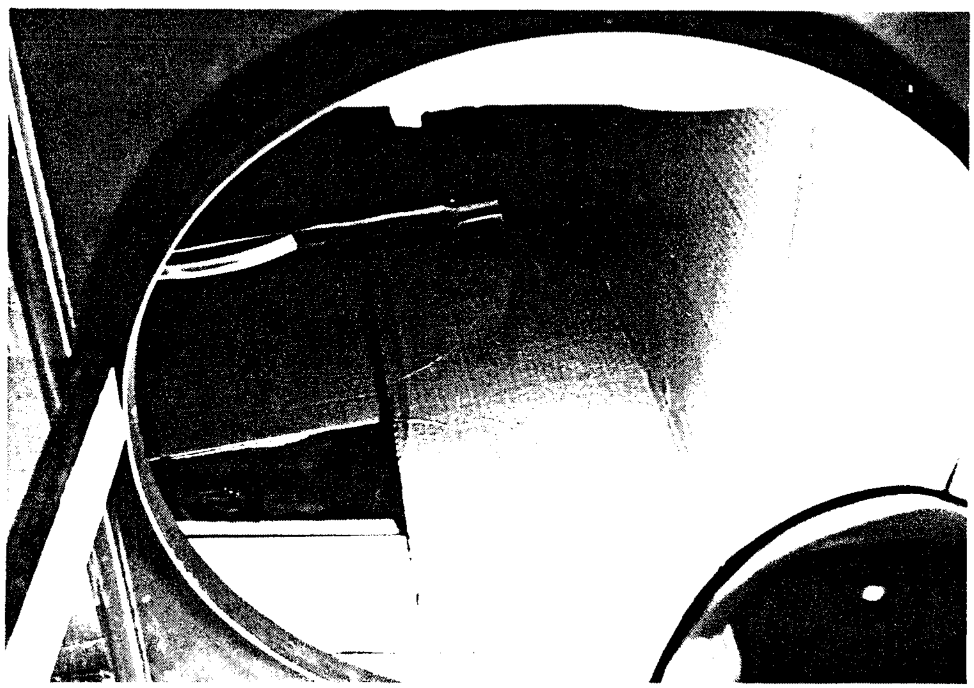
House No.1 - Soffit Vent Blocked For Test



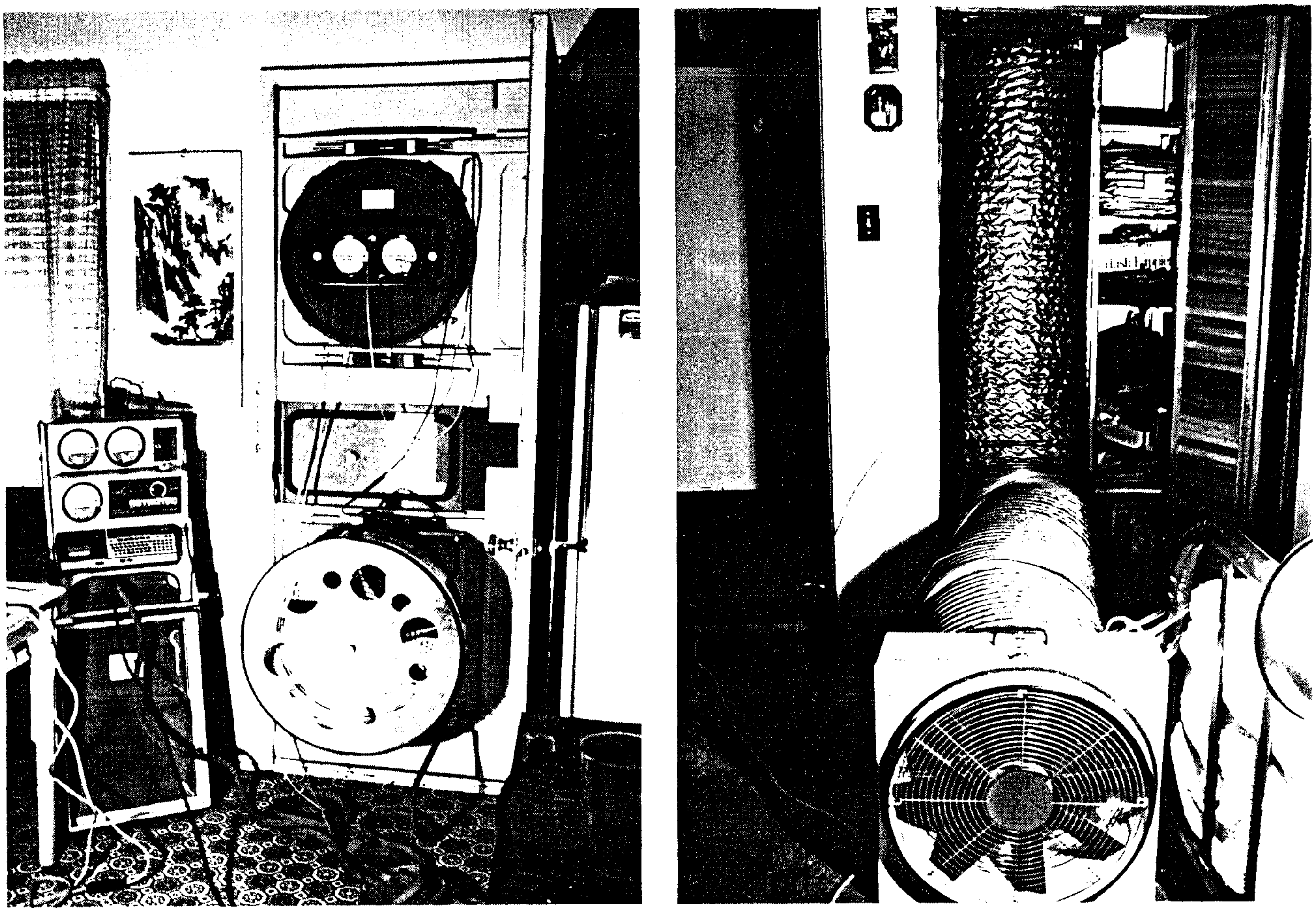
House No.1 - Attic Interior



House No.1 - Attic Hatch

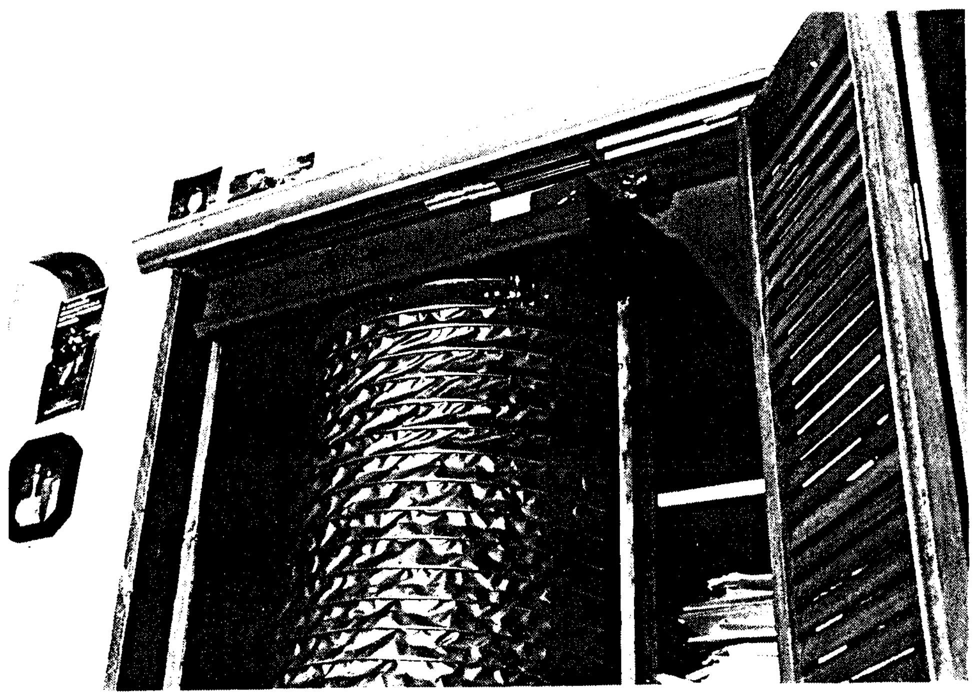


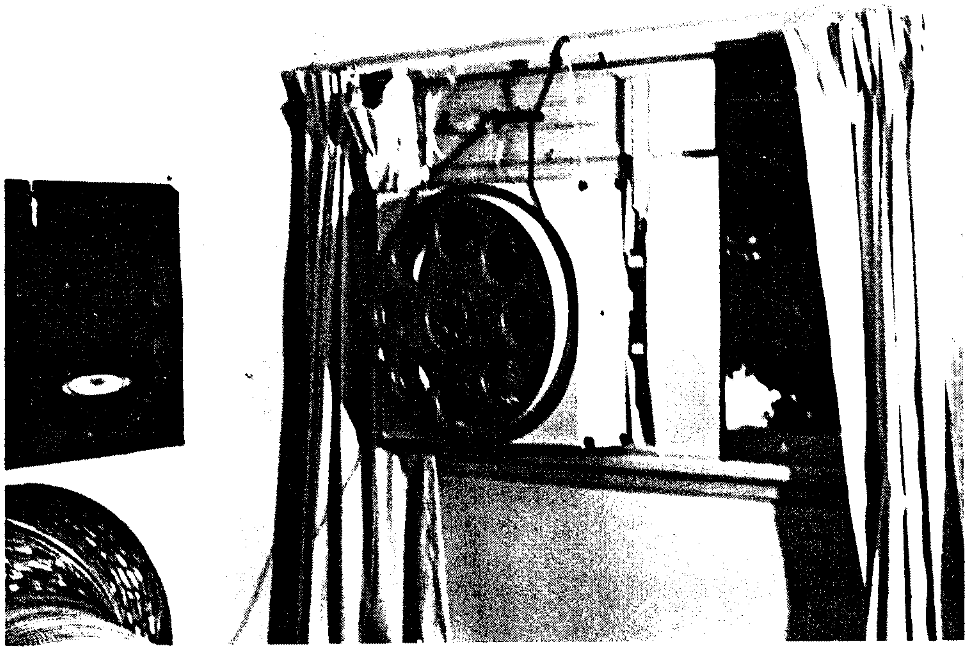
House No.1 - Attic Hatch With Baffles and Transition



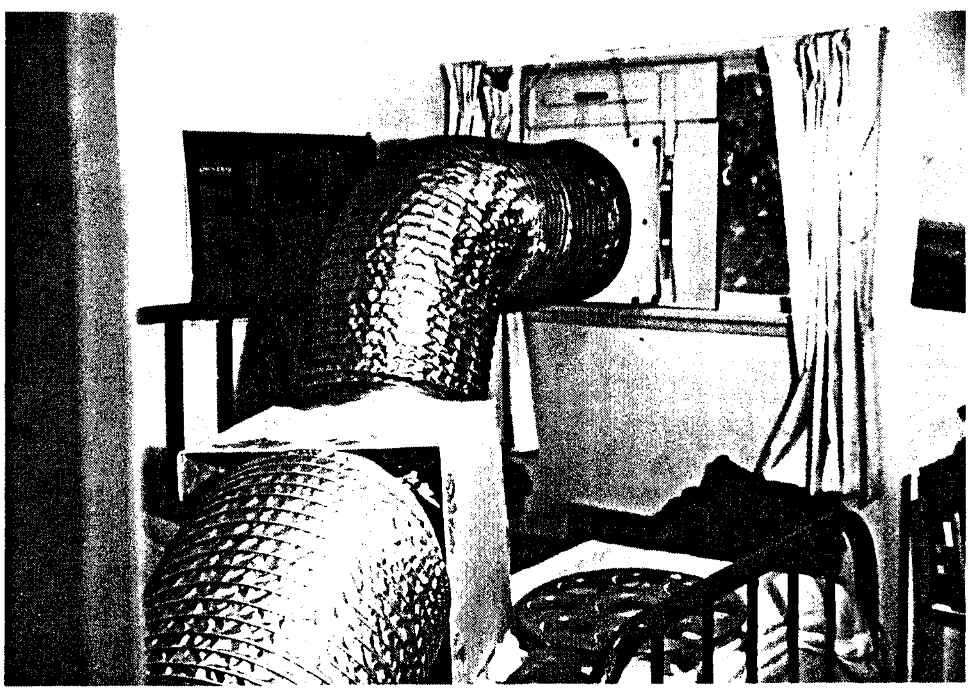
House No.1 - Equipment Set-up

House No.1 - Equipment Set-up





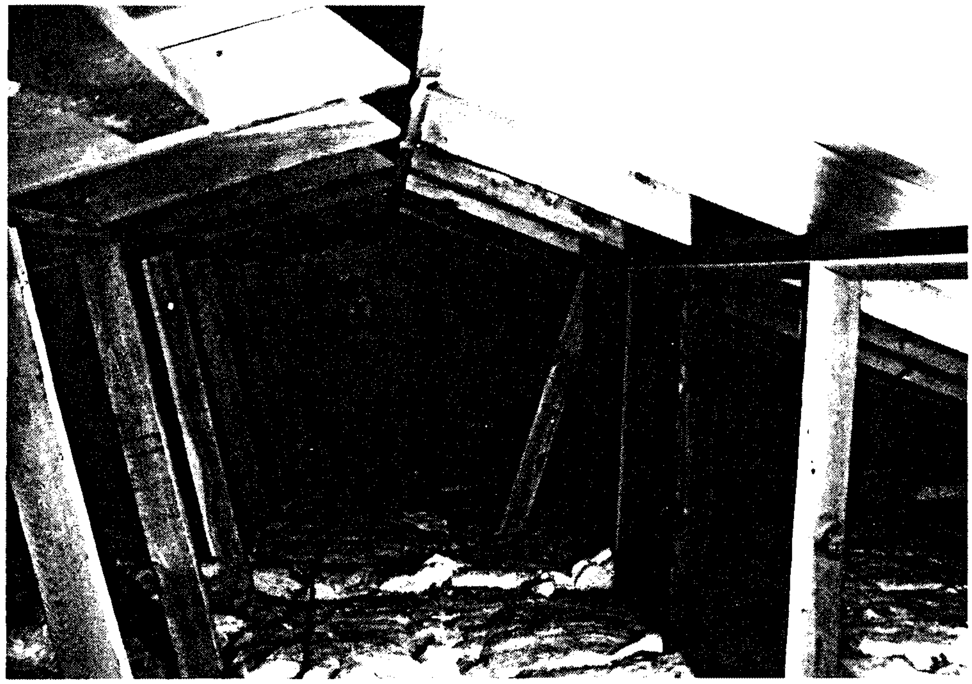
House No.1 - Window Fan Option



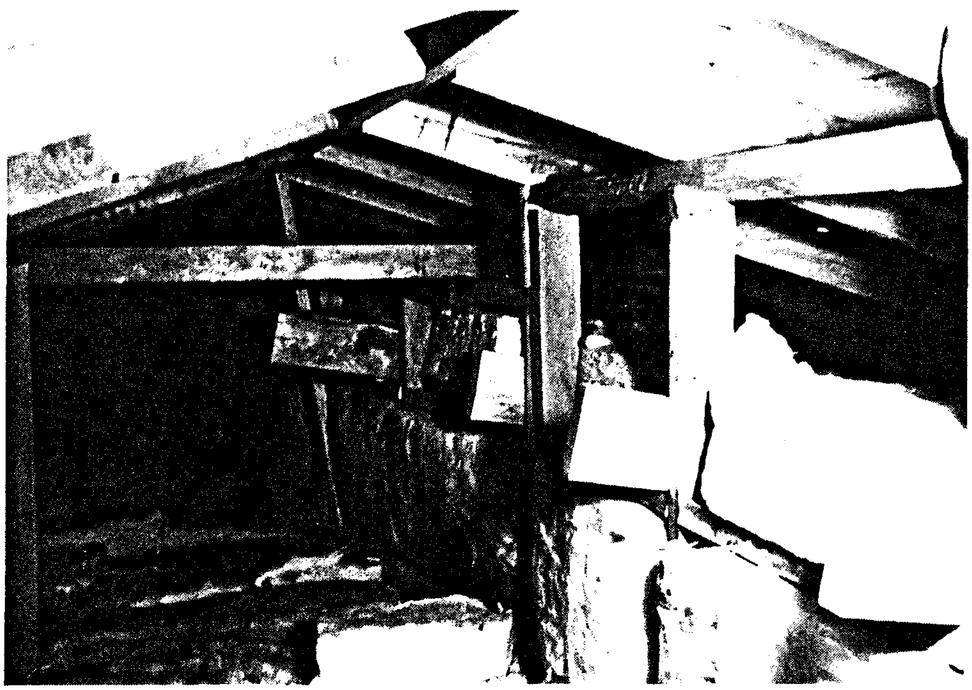
House No.1 - Single Blower With Mixing Box

House No.2 - Front View

House No.2 - Continuous Soffit Vent

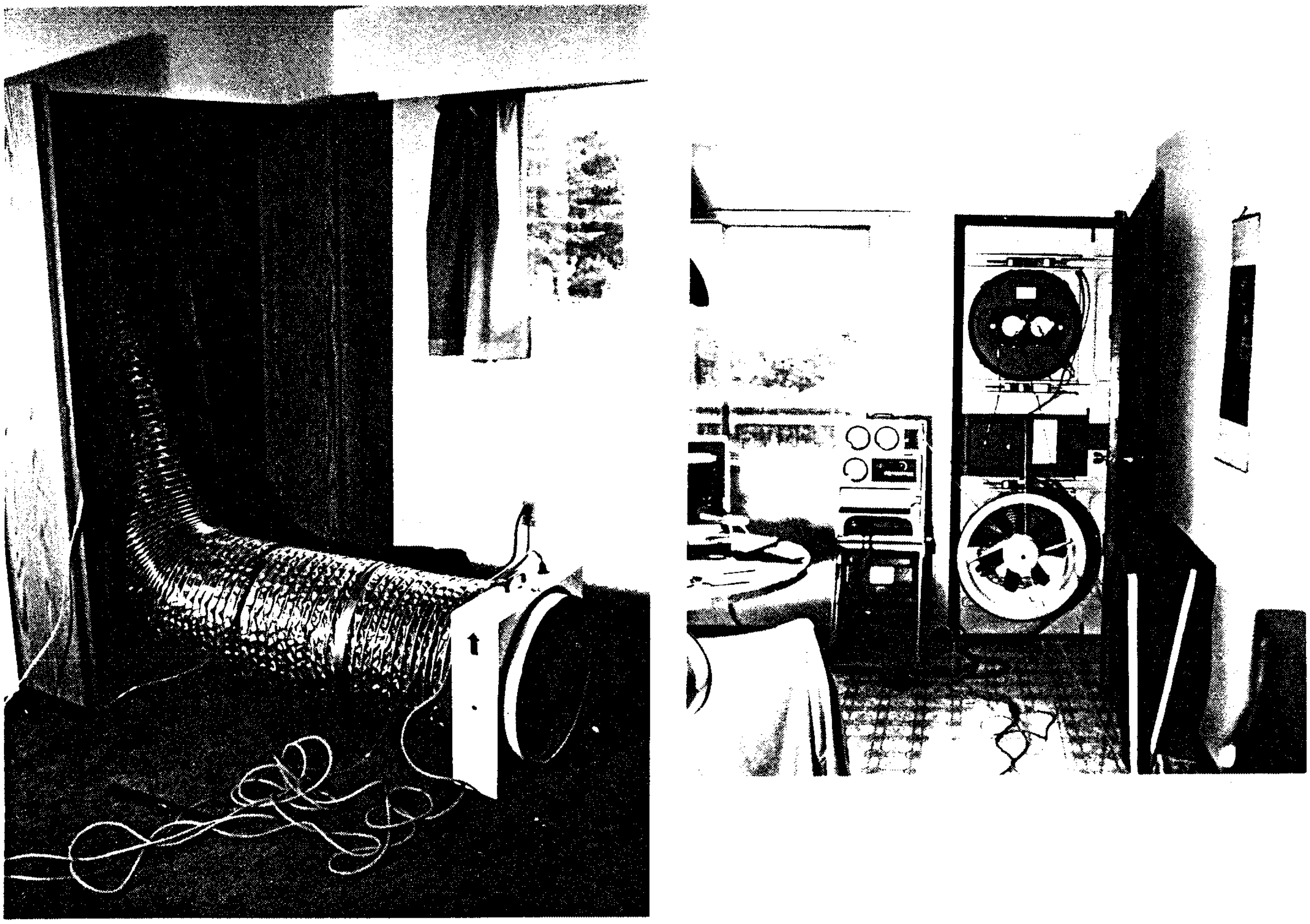


House No.2 - Attic Construction



House No.2 - Join Between Attic and Cathedral Ceiling

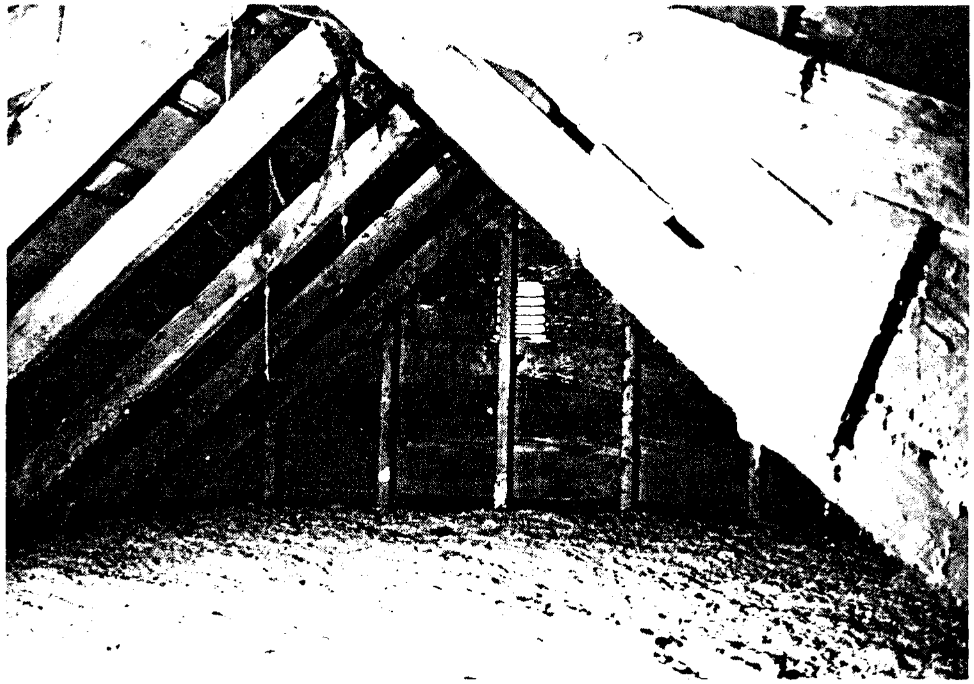
House No.2 - Cathedral Ceiling



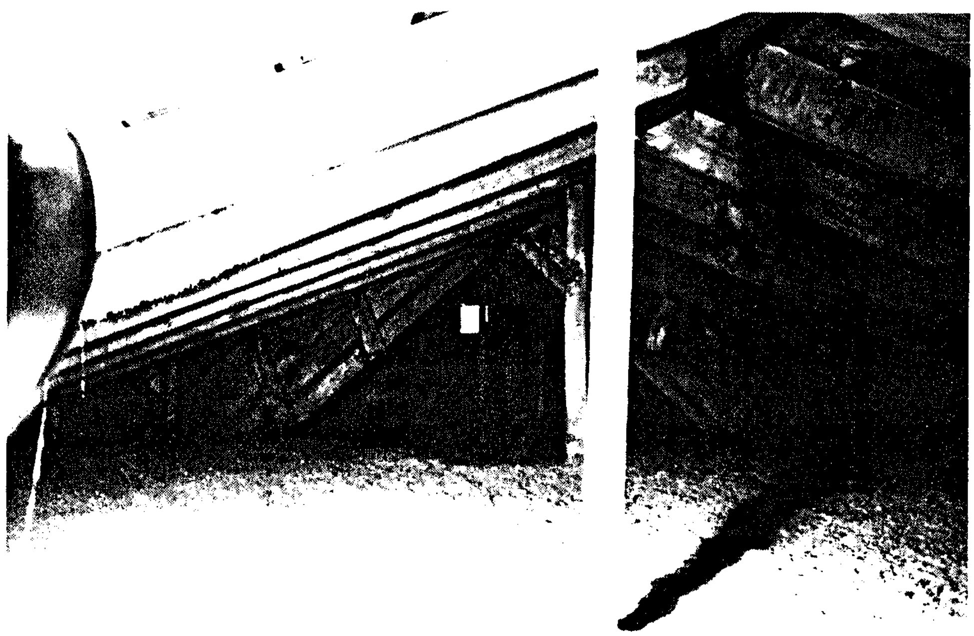
House No.2 - Equipment Set-up


House No.3 - Front View with Gable Vent

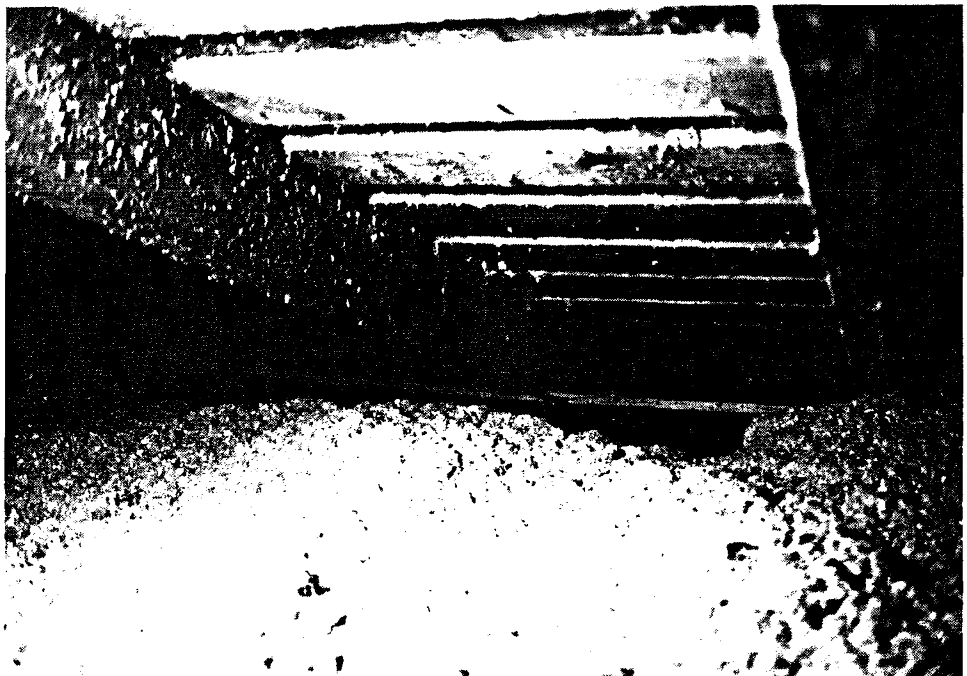
House No.3 - Rear View with Gable Vent and Dormer



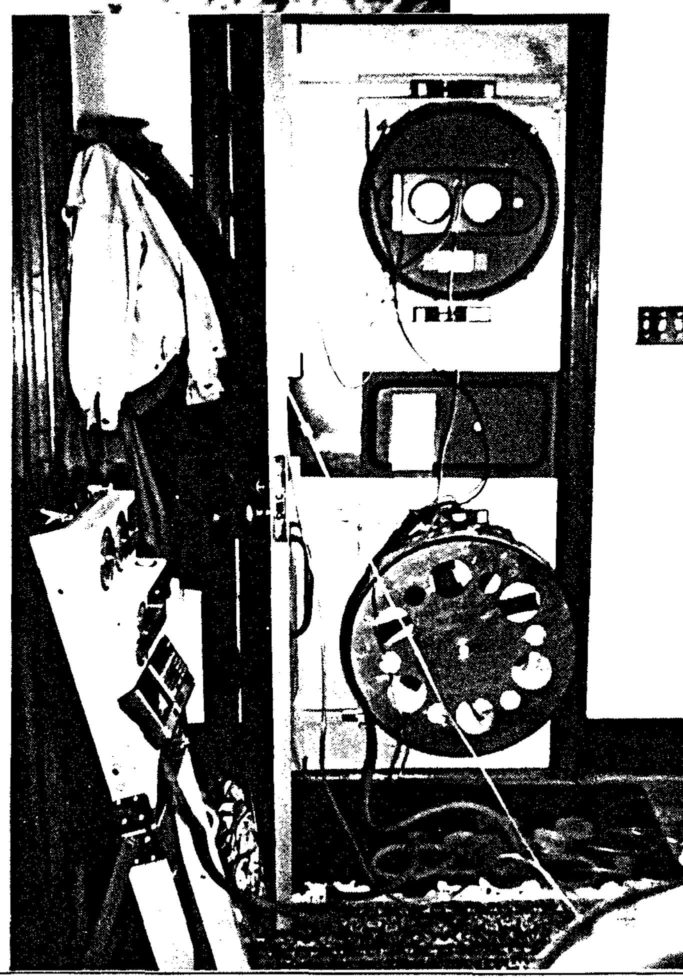
House No.3 - Front Interior of Attic with Cellulous



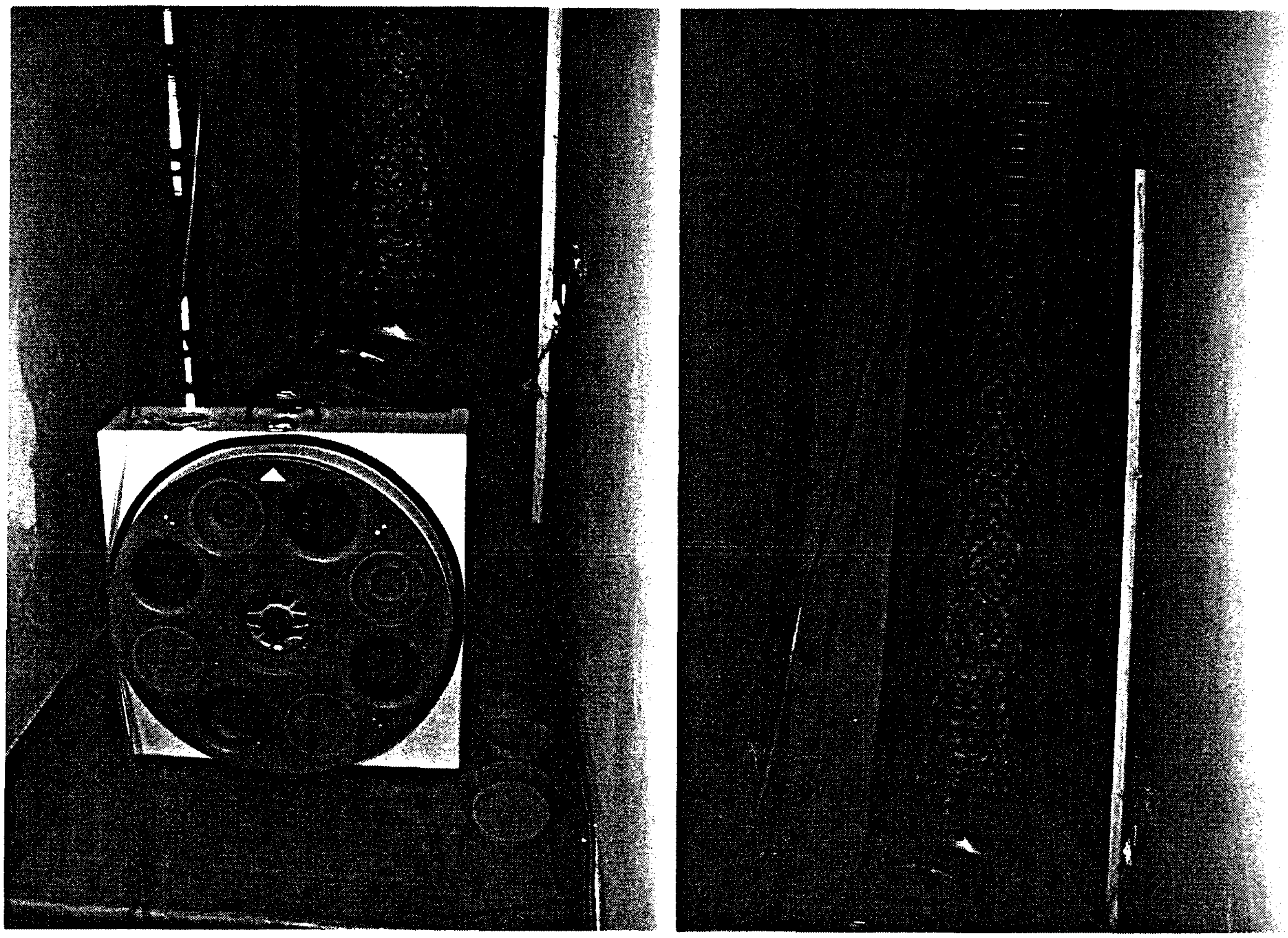
House No.3 - Near Interior of Attic



House No.3 -
Rafter Spaces
Connecting to
Know Well Attics



House No.3 -
Equipment
Set-up



House No.3 - Attic Blower

# A P P E N D I X 2

# RECALIBRATION DATA FOR BLOWER WITH FLEX DUCT ATTACHED, AND FLOW MEASUREMENTS AND ELA VALUES FOR TYPICAL ATTIC VENTS.

B. SIKORSKI

CALIBRATION OF FLOW ELEMENT
WITH FLEX DUCT & FLOW STRAIGHTENER

MAY, 15, 89

A) AN 800 SERIES FLOW ELEMENT WAS USED WITH 12.5 Feet OF FLEX DUCT (20" Ø) AND A FLOW STRAIGHTENER PLACED ≈ 1 DIAMETER FROM FAN INLET. USING A CURVE FIT PROGRAM (ON HP41 THE FOLLOWING EQUATIONS WERE FITTED TO THE FLOWS WITH/AND WITHOUT FLEX DUCT:

COEF OF DETERM (R)

1) NO FLEX DUCT & FREE INLET $Q_{CFM} = 295.8 \, \Delta P_{PA}^{.4831}$ 1.0004

2) WITH FLEX DUCT & STRTNR. $Q_{CFM} = 232.7 \, \Delta P_{PA}^{.5191}$ .9996

3) WITH NO FLEX & 9 HOLE PLATE $Q_{CFM} = 167.65 \, \Delta P_{PA}^{.4730}$ .996

4) WITH FLEX DUCT & STRTNR & 9 HOLE PLATE $Q_{CFM} = 137.29 \, \Delta P_{PA}^{.5055}$ .9999

B) COMPARISON OF THESE RESULTS GIVES THE CHANGE IN FLOW READING DUE TO DUCT:

| CONDITION | FLOW PRESSURE ($\Delta P$ Pa) | | PERCENT REDUCTION (%) OF FLOW | |
|---|---|---|---|---|
| 1) NO PLATE | 50 | 100 | -9.43 | -7.15 |
| 2) WITH 9 HOLE PLT | 50 | 100 | -7.01 | -4.9 |

463.63

NOZZLE WALL EQUATION (EVERYTHING 7,5,4,2

$Q_{cfm} = 1.720 \sqrt{\Delta P_{pa}} * A_{everything}$

$= 133.481 \sqrt{\Delta P_{pa}}$

| TEST #1 | STATIC | FLOW ΔP RDF | $Q_{RDF}$ | FLOW $\Delta P_{NOZ}$ $\Delta P_{pa}$ | $Q_{CFM}$ |
|---|---|---|---|---|---|
| NO FLEX DUCT | 0 | 62.5 | | 267 | 2181.1 |
| (18 R) | 0 | 74 | | 314 | 2365.3 |
| | 0 | 112 | | 469 | 2890.7 |
| TEST #2 | 0 | 36 | | 126 | 1498.3 |
| W FLEX DUCT | 0 | 66 | | 232 | 2033.1 |
| (18 F) | 0 | 88 | | 320 | 2387.8 |
| | 0 | 112 | | 411 | 2706.1 |
| | 0 | 130 | | (465+8) | 2903.0 |
| TEST #3 | 0 | 107 | | 132 | 1533.6 |
| NO FLEX W 9 HOLE | 0 | 155 | | 182 | 1800.8 |
| | 0 | 195 | | 234 | 2041.9 |
| ✓ TEST #2 | +20 | 68 | | 243 | 2080.8 |
| TEST #4 | 0 | 152 | | 170 | 1740.4 |
| W FLEXDUCT & | | 207 | | 232 | 2033.12 |
| 9 HOLE | | 242 | | 272 | 2201.4 |
| ANALYSIS | | 106 | | 118 | 1449.97 |

| | EQUATION OF LINE | COEF OF DETER. |
|---|---|---|
| TEST #1 | $Q_{cfm} = 295.8 \Delta P_{pa}^{.4831}$ | $R^2 = 1.000$ |
| TEST #2 | $Q = 232.7 \Delta P^{.5191}$ | $R^2 = .9998$ |
| #3 | $Q_{cfm} = 167.65 \Delta P^{.473}$ | $R^2 = .996$ |
| #4 | $Q_{cfm} = 137.23 \Delta P^{.5055}$ | $R^2 = .9999$ |

FLOW CHAMBER
TEST OF ROOF VENT | B.SIKORSKI | MAY, 16, 89

## ROOF VENT #1 ACTUAL OPEN AREA = $50\ in^2$

| STATIC | * $\Delta P_{NOZZLE}$ | $Q_{CFM}$ |
|---|---|---|
| -10 | 90 | 80.1 |
| -20 | 190 | 116.4 |
| -30 | 284 | 142.3 |
| -40 | 389 | 166.5 |

$Q_{10}$ = 80.3 CFM (37.89 L/s)

$A_{10Pa}$ = 23.64 $in^2$ (152.5 $cm^2$)

$Q_{CFM} = 23.94 * \Delta P^{.5256}$

USING 2.5 in NOZZLE $Q_{CFM} = 8.443\sqrt{\Delta P}$

## ROOF VENT #2 ACTUAL OPEN AREA = $50\ in^2$

| STATIC | $\Delta P$ NOZZLE | $Q$ CFM |
|---|---|---|
| -12 | 135 | 98.1 |
| -20 | 245 | 132.2 |
| -30 | 372+6 | 164.2 |
| -40 | 495 +12 | 190.12 |

$Q_{10}$ = 89.36 CFM (42.17 L/s)

$A_{10P}$ = 26.3 $in^2$ (169.8 $cm^2$)

$Q_{CFM} = 25.18 * \Delta P_{Pa}^{.5501}$

$R^2 = .9991$

$C = 25.182$

$n = .5501$