REDUCTION OF AIR INFILTRATION DUE TO WINDOW AND DOOR RETROFITS IN AN OLDER HOME

By

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Report PU/CEES 85

May 1979

the
center for
energy and
environmental
studies

princeton university

Acknowledgements

The authors wish to express their appreciation to the Fels family for their assistance in this study even to the point of collecting infiltration data at inconvenient periods. In addition, the authors wish to thank the French firm of Superhermit and particularly Max Mayer of that organization, for providing and arranging for installation of the retrofitting material. The efforts of Kenneth Gadsby and Roy Crosby in the conduction of the tests is greatly appreciated. We wish to acknowledge the support of the U.S. Department of Energy to undertake this study under Contract No. EE-77-S-02-4288 and the initiatives provided by Howard Ross, Program Technical Monitor.

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Abstract:

Window and door retrofitting using stainless steel weatherstripping was field evaluated in a 30-year old home. Three methods were used in the evaluation: tracer gas-dilution, depressurization of the entire house and pressurization/depressurization of individual windows. The windows were of the wooden double hung design. The doors included a pair of French doors in addition to front and rear doors. Storm windows were also applied to a high percentage of the windows. The savings in air infiltration from adding weather stripping was shown to be 10-14.7% for the windows/doors weatherstripped and dependent on the test method. For the complete retrofit, 15.5% leakage reduction is predicted which results in an estimated 4-6% energy savings. Weather stripping and storm windows in combination resulted in 20.6-23.2% savings in air infiltration losses for the retrofit measures that were taken. An entire house retrofit was predicted to reduce air infiltration 27.5% and achieve 7-11% energy savings.

A. House Description

In order to test the improvements that might be expected in a window and door seal retrofit of an older home the following criteria were set.

1. The home would be at least 20 years old.
2. The windows would be of the double-hung design, the most prevalent design.
3. The framing and window/door material would be of wood construction, the most common material.
4. The preinspection should indicate that air leakiness of at least average levels did exist so that benefits should be readily observed.

The plan of the house chosen for the window retrofit study is shown in Fig. 1. Floor area is moderate,[7] 152 m^2 (1635 ft^2). The house was built in the late 1940s and an addition (see cross hatched section) was added in the mid 1960s. The house has a basement extending under the original structure, a first floor which contains a living room with fireplace, dining room, study, kitchen-pantry with ceiling vent and small bathroom. Upstairs are three small bedrooms, hall, main bathroom, and master bedroom with attached bathroom. The main bathroom is without windows but does have a powered vent.

An attic (used for storage) extends over the entire upper floor. Access is through a 0.4m^2 (4 ft^2) hatch cover in the hall. Other points of communication with the lower floors include the previously mentioned bathroom fan which was shown to have minimum leakage. The chimney is on the outside of the house and does not communicate with the attic.

The house has three exterior doors, which consist of a 91 cm (36 inch) front door, 81 cm (32 inch) rear door, plus 152 cm (60 inch) wide French doors between the living room and back porch. All of the doors were constructed of wood and were weather stripped in the retrofit procedure.

The window details are described in Table 1. The window area represents 15% of the floor area (a value common in architectural design). In the older section of the house 13 of 17 windows were retrofitted. This represented 78 percent of the seal length of all the older windows.* The windows in the newer section were left untouched since tests on individual windows indicated that they represented a small fraction of the leakage (see section D).

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*Neglecting the basement windows

Tests on the house prior to retrofitting revealed infiltration rates of just less than one air exchange per hour. This value is close to the amount that would be calculated from standard ASHRAE procedures.[1]

B. Retrofitting Technique

In order to insure long term benefits from the retrofit procedure, a durable material was selected. The seals used were of a flexible stainless steel design. As shown in Figure 2, the seals were fitted to the window frame following a general rule of sealing along a line passing vertically through the double hung window. Only at the juncture between upper and lower sash was it necessary to add the seal to a moving portion of the window. For the lower sash seal an additional wood strip and seal was added across the sill so that when the window closed it would depress this "lip seal", eliminating air flow.

The details of the retrofitting procedure on both windows and doors began with a thorough inspection, noting problems of a dimensional nature. The window sashes were removed from their frames and wood strips were added or sashes were shaved until the proper sliding fit was obtained. After the proper fit was obtained, the procedure was continued and the seals were added. The stainless steel lip seals were cut from long rolls of the seal material and nailed into place. Nails were placed 40 per meter (1 per inch) in the way a cobbler nails shoes. After the weather stripping was entirely in place on a given window, a special tool was moved along the full length of the seal to provide a precise angle to the stainless steel lip. In the process of attaching the weather strip, special care was taken in the area around the window latch in that the seal was contoured. At the corners small squares of foal plastic were glued into place so that no leakage would occur at those locations where there was a break in the metal seal.

C. Test Methods

Three independent measurements of air infiltration levels before and after window/door retrofitting were conducted. These measurements were based on the tracer gas - dilution method and the pressurization-depressurization technique. In the later procedure both the overall house and individual windows were tested separately.

a) Tracer gas-dilution

The tracer gas dilution method and the associated automated air infiltration unit (AAIU) have been used many times in the past.[2-5] The equipment is shown in Fig. 4. The method is based upon the use of a tracer gas, in this case sulphur hexafluoride (SF_6), which is injected into the warm air duct system. The amount of gas and the method of injection are carefully controlled to provide rapid mixing and to achieve concentration levels of approximately 40 parts per billion (ppb) within the house. With the particular AAIU deployed for these tests, measurements of concentration were made every five minutes using the electron capture detector and gas chromatograph which are part of the AAIU. The data were stored on magnetic tape cassettes. Each cassette could hold up to one week of data but was normally changed on a four or five day schedule.

Each AAIU has a slightly different calibration factor and the units are recalibrated periodically. The general form of the governing relationship is based upon Beers law

$$-\ln \frac{I}{I_o} = kC^B$$

where I is the current reading for the SF_6 concentration present

I_o is the standing current (i.e. steady-state reading prior to sampling)

k is a constant

C is the concentration

and B is the concentration exponent which is the item checked in the calibration procedure.

In determining air exchange rates one measures concentrations at two times, C_t and $C_{t + \Delta t}$, where Δt is the time between tests. In this calculation the air infiltration rate is simply

$$A = \frac{1}{\Delta t} \ln \frac{C_t}{C_{t + \Delta t}}$$

and the k factor cancels out.

Throughout the pre-retrofit testing and the post-retrofit testing the AAIU was placed next to the furnace in the basement, monitoring the duct air. Because winter weather was so consistently cold in the immediate post retrofit period, additional data were gathered late in the winter season so that a range of outside temperatures and the resultant air infiltration levels could be used in the comparisons. In these tests the data were collected for a range of wind conditions. However, for comparison with the other testing techniques, emphasis was placed on infiltration rates for winds less than 4.5 m/s (10 mph).

This was because the pressurization/depressurization testing cannot tolerate high wind conditions and maintain accurate measurements.

(b) Pressurization/depressurization for the whole house.

Using a blower door device,[6] the whole test house could be pressurized and depressurized according to well-established methods.[7-8] The blower door is shown in Fig. 5 and is designed to tightly fit into a wide variety of door frames. The procedure is then to provide a differential pressure between inside and outside the house under test. This pressure difference is completely adjustable using a variable-speed axial fan motor (d.c. motor and solid-state control). In the step-by-step changes in differential pressure the fan speed is read simultaneously. Within a matter of minutes a pressure-flow rate profile is established for the house. The flow is determined from previous laboratory calibrations of the fan speed and flow rate. The technique used in this house also allowed internal door closure to provide an additional plot of pressure versus flow rate and isolation of leakage sties.

c) Depressurization of individual windows

In the case of individual windows the depressurization technique was used together with a plastic cover tightly taped to the window frame (see Fig. 6). Depressurization was accomplished with a vacuum cleaner (suction side) and the flow was measured with a sensitive gas flow meter over a timed period. The differential pressure was measured as in the whole house tests using a sensitive pressure gauge (2 Pa, .01 in. H_2O). In order to minimize the chance for any leakage, other than through the window under test, the pressure in the house was lowered to the window pressure level using the blower door. In this procedure no differential pressure existed between window and house interior, hence even if a small opening developed along the taped plastic at the window frame edge or hoses, the leakage would be negligible.[9]

D. Results from Testing

1. Individual windows:

The first results to be described are those involving the tests on the individual windows. These results are in Figure 7. The data in group I is for six windows prior to retrofit. Group II includes tests on two windows after weatherstripping. The improvement in leakage rate is quite evident with an approximate reduction of 75% with retrofitting when measuring the air leakage rates within the window frame. This plot is normalized for crack length.

Also of interest in such window comparisons is that the 1960s windows in the newer portion of the house exhibited approximately the same leakage characteristics as the retrofitted windows with positive pressure. (See window sizes as listed in Table 1). The 1960s windows had seals between sashes and where the sash met the sill.

Comparing the results with the data listed in the NBS Window Study,[10] shows that the tested windows are slightly leakier than the "typical window" cited. Our after retrofit value of 2.0 m^3/mh (21 ft^3/fth) should be compared with 1.8 m^3/mh (19 ft^3/fth) at a pressure difference of 12.5 Pa (0.05 inches of water).[10] The same comparison made before retrofit gives 7.5 m^3/mh (80ft^3/fth) for our tested windows and 6.5 m^3/mh (69 ft^3/fth) for the "NBS typical window."[10] The "typical window" shows a 70% reduction, while the tested windows show a 75% reduction starting from a 14% higher value. The problem, however, with these windows is that an important part of the leakage goes through the openings for the counterweight cables. For a retrofitted window this leakage is approximately 35% of the total leakage at 12.5 Pa (0.05 inches of water) (see Fig. 8). Without this leakage the post retrofit value would be 1.3 m^3/mh (14 ft^3/fth), which is better than the "typical case window", and represents an 81% reduction based on seal length.

2. Entire house depressurization

Using the techniques previously described the entire house depressurization tests are described in Figure 9. This figure includes data from three test conditions from which comparisons can be made. Table 2 should be referred to in order to aid comparisons between test condition A (no weather stripping and original doors and windows), test condition B (where weather stripping was added) and test condition C (where both weather stripping and storm windows have been added). Over the range of pressure difference from 17.5 - 50 Pa (.075 to .200 inches of water) one observes that there is an average 14.7% decrease in whole house air exchange rate for the addition of the weather stripping and 20.6% for weather stripping and storm windows.

3. Tracer gas results

The levels of air infiltration as recorded by the automated Air Infiltration Unit using the tracer gas method are plotted as points in Fig. 10. The data have resulted from testing immediately before and after the period of retrofitting (second week of January 1978) and additional data taken later in the winter of 1978 so that the same range of weather parameters (low wind speed <4.5 meters/sec [10 mph] and temperature differences from 15 - 20°C [27 - 36°F]) could be documented. Weather data were supplied from the U.S. National Weather

Service in Trenton, N.J.

All data sets are based on a compilation of five minute data. The first data set was prior to retrofitting without the storm windows. The second data sets occurred after retrofitting without storm windows. The final data set included retrofitting and storm windows.

Results are as follows: the average air infiltration rate prior to retrofitting was .82 ± .05* air changes per hour, after retrofitting with weather stripping the infiltration rate dropped to .74 ± .06 air changes per hour, a ∿ 10% improvement, and finally the addition of storm windows to the retrofitted windows drops the air infiltration rate to .63 ± .05 air exchanges per hour or a 23.2% improvement over the preretrofit condition. It should be remembered from Table 1 that only 60% of the total seal area in the house was retrofitted and storm windows covered approximately the same proportion of window/door cracks.

Typical of data gathered on natural air infiltration there is a spread in the values of data points. However, the standard deviation is small enough so that the average values of the three are significantly different. Unfortunately the preretrofit case with storm windows in place was lost because of a tape recording problem.

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*Value of air exchange rate per hour with standard deviation.

Conclusions:

The use of high quality stainless steel weather stripping to reduce air infiltration in an older home was shown to lower air exchange rates by 10 to 14.7%. The reduction in leakage through a typical window that was retrofitted was of the order of 75%, bringing these older wooden, double hung windows to approximately the same leakage levels as the 1960s vintage windows located on the newer addition to the house. Approximately 60% of the total lineal leakage paths were retrofitted using the stainless steel weather stripping.

Of interest in the study is that the pressurization technique measured a 14.7% reduction due to weatherstripping while the tracer gas technique measured 10%. When storm windows are added the total reduction becomes 20.6% and 23.2% respectively. Thus the pressurization approach points to a 71% contribution in total reduction from the weatherstripping, whereas the tracer gas technique shows a 43% contribution from this source. Although these numbers differ, they lie within the statistical spread of the measured quantities. The detailed mechanisms of how air flow takes place through window openings and the contribution of possible dynamic pressure effects may hold the answer. More research is needed on this subject.

The problems of older window retrofitting are clearly evident in this study. The double hung design presents problems in sealing which result in time consuming and hence costly retrofitting procedures. When these procedures are skillfully applied, sizeable reductions in air infiltration are achieved. Also, one achieves full use of the windows for important ventilation and safety functions since sashes freely move in the newly weather stripped channels. The stainless steel seals should pose no problems in durability.

Looking at the economics of retrofitting one must always keep in mind that home energy losses are made up of many components. For the house in question, depending upon the outside weather, we would expect the air infiltration component to fall in the 25-40% category. (The remaining energy losses would be of the conductive type, through windows, doors, walls, ceiling and floors). Using the data for all old window retrofits as outlined in Appendix A we find that for the weather stripping retrofit 4-6% savings would be expected. For weather stripping and storm windows 7-11% savings would be expected. In addition to such savings, however, the elimination of window and door drafts should allow overall house temperatures to be lowered. Drafts from windows and doors make the inside climate less comfortable causing thermostats to be set at higher levels to compensate for these local comfort problems. With drafts eliminated, reduced thermostat settings are possible with no loss in comfort, indeed the more uniform temperatures should provide more satisfactory living conditions. A 1°C (1.8°F) reduction of thermostat setting results in $\sim$9% energy savings which is a very important additional factor to consider when weighing the economics of payback of such weather strip retrofitting.

Table 1 - Window Data

Window No. (See Figure 1)	Size, Cm (inches)	Seal length, Cm (inches)
3, 6, 29	127x91 (50x36)	527 (208)
1, 2, 4, 5	127x79 (50x31	491 (193)
7,**8,**23,**24**	127x81 (50x32	497 (196)
9,* 10*	97x61 (38x24)	376 (148)
11,* 12*	92x61 (36x24)	366 (144)
13,14,15,16,17,18*	114x79 (45x31)	465 (183)
19, 20, 21**	114x91 (45x36)	503 (198)
25*	127x76 (50x30)	483 (190)
26,* 27,* 28*	81x41 (32x16) basement	244 (96)
Doors		
A Front	200x90 (78.5x35.5)	578 (228)
B Rear	200x76 (78.5x30)	550 (217)
C French	203x152 (80x60)	915 (360)
	Total	14,112 (5556)
	Retrofitted	8,456 (3329)

* Not retrofitted, used in total crack length determination

** Newer windows, not retrofitted, used in total crack length determination, 1960's installation.

TABLE 2 - Whole house leakage, With and Without Retrofitting Using Depressurization Method.

Pressure Difference		Air Flow Rate, m^3/h						
Pa	inches of water	A	B	C	A-B	%	A-E	% ← Condition
18.8	.075	4500	3850	3550	650	14.5	950	21.1
25	.100	5400	4550	4150	950	17.6	1250	23.2
31.8	.125	6100	5150	4750	950	15.6	1350	22.2
37.5	.150	6750	5700	5350	1050	15.6	1400	20.8
43.8	.175	7300	6300	5900	1000	13.7	1400	19.2
50	.200	7750	6900	6450	850	11.0	1300	16.8
					Ave.	14.7 ± 2.2		20.6 ± 2.3

A. Pre retrofit - no storm windows

B. Post retrofit - no storm windows

C. Post retrofit with storm windows

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8. Kronvall, Johnny, "Testing of Houses for Air Leakage Using a Pressure Method," ASHRAE TRANSACTIONS 1978, Vol. 84, part 1.

9. Andberger, Mats and Wånggren, Bengt, "Weather Stripping for Windows and Doors," Royal Institute of Technology, Division of Building Technology, Stockholm, Sweden, Draft, May 1978.

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Appendix A

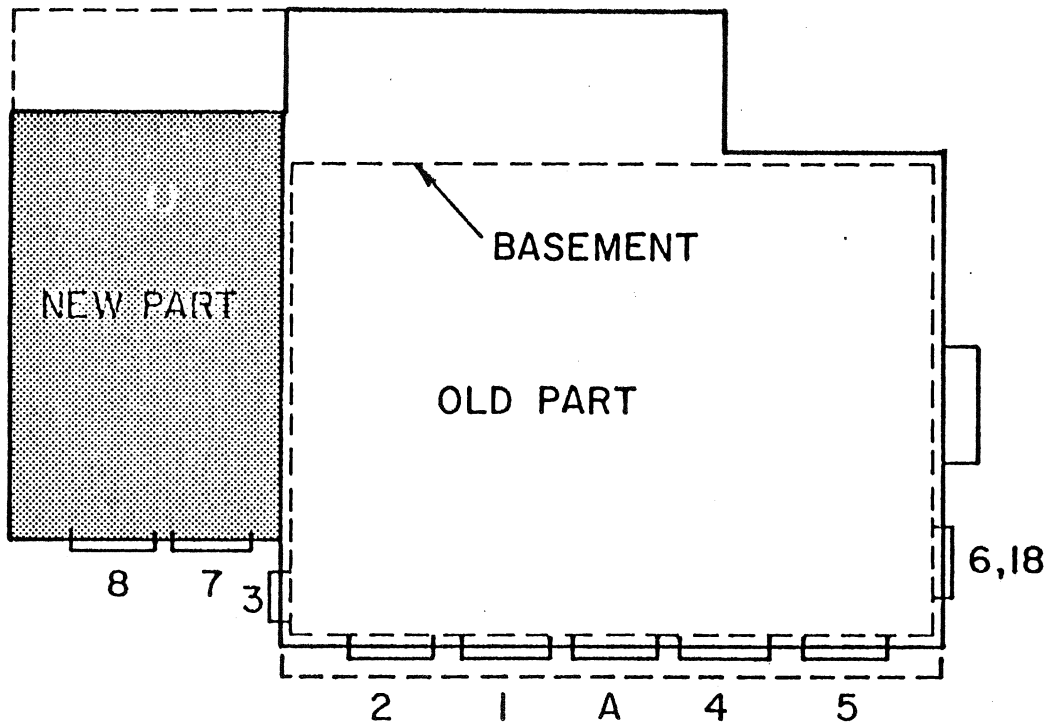
Since only a portion of the windows were retrofitted, a calculation will be made here to adjust for the remaining windows. Data from Table 1 indicate that of the 14,112 cm (5556 in) of seal surface, 8,456 cm (3329 in) were retrofitted. The remainder consists of (a) 1933 cm (767 in) of older windows, (b) 731 cm (288 in) of basement windows and (c) 2992 cm (1178 in) of newer windows (1960s addition).

For the weather stripping retrofit, with the two test methods, leakage reductions were 10% and 14.7% or 12.35% average reduction. For the case of group (a) old windows, this should scale proportionately and result in an additional 2.8%. For the (b) group, even though these basement windows are not in the living space there is a high degree of communication between the two areas (in many pressurization tests no differences could be seen when the basement door was closed) and hence full benefit of retrofit will be assigned, or .4%. Since the newer windows based on Figure 7 and Appendix A show minimal differences in leakage from the retrofitted windows we will assign no additional contribution in this case. Note, if these had been older, more leaky windows, then our original infiltration rates would have been above the norm and questions about the choice of house could have been raised.

In total, the anticipated reduction in air infiltration rate from retrofitting taking into account a complete window retrofit would be $\sim$ 15.5%. In the conclusions section this number is used in the determination of economic benefit.

In a similar way we can scale the benefits of the storm window plus weather stripping. The revised value would be a 27.5% reduction in air infiltration.

1" = 8'   SCALE 1:96
DOTTED LINE INDICATES 2nd FLOOR



note: numbers and letters refer to windows/doors of table I (window no. 18 is on second floor) and were individually tested.

Figure 1. Plan of House

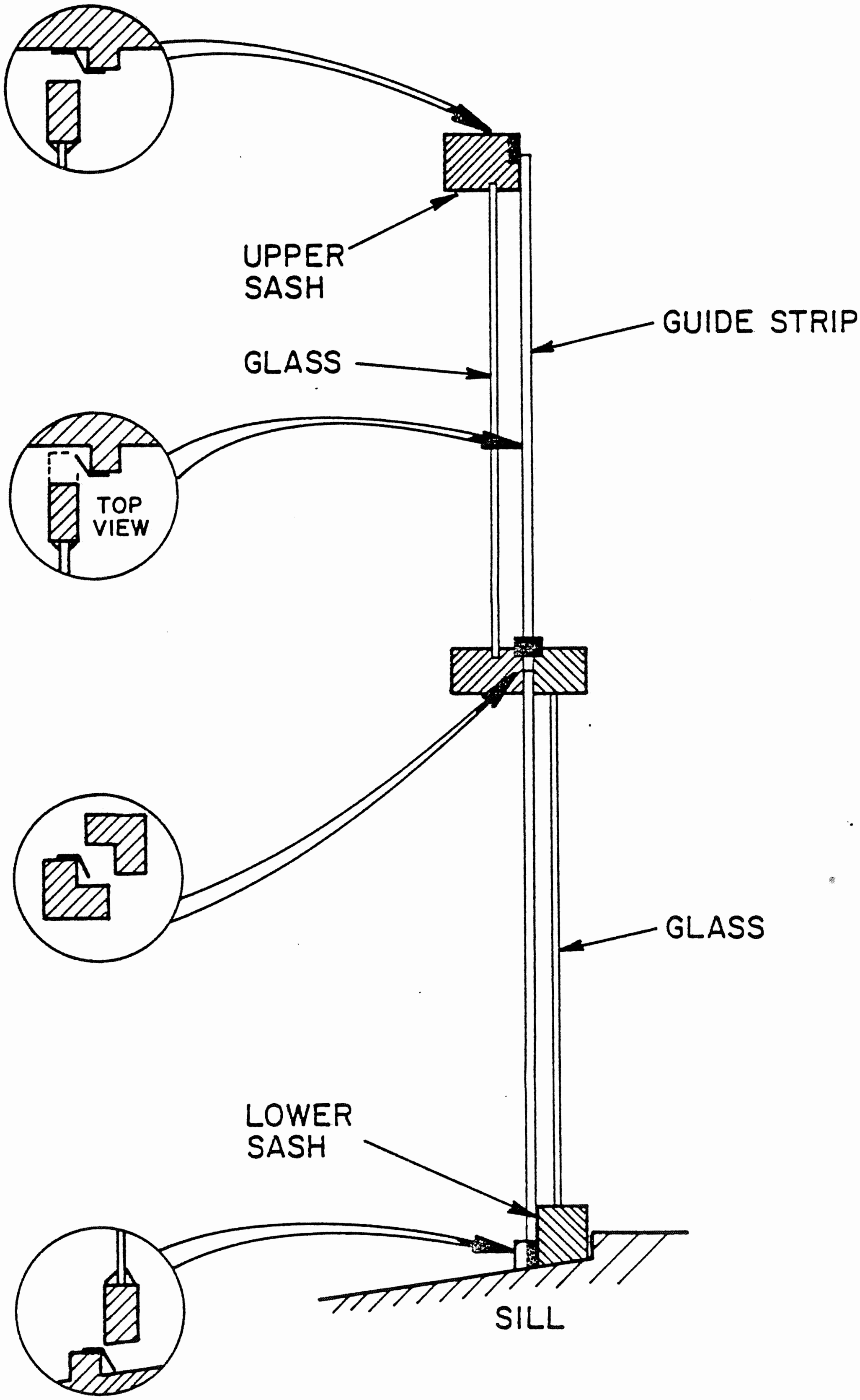
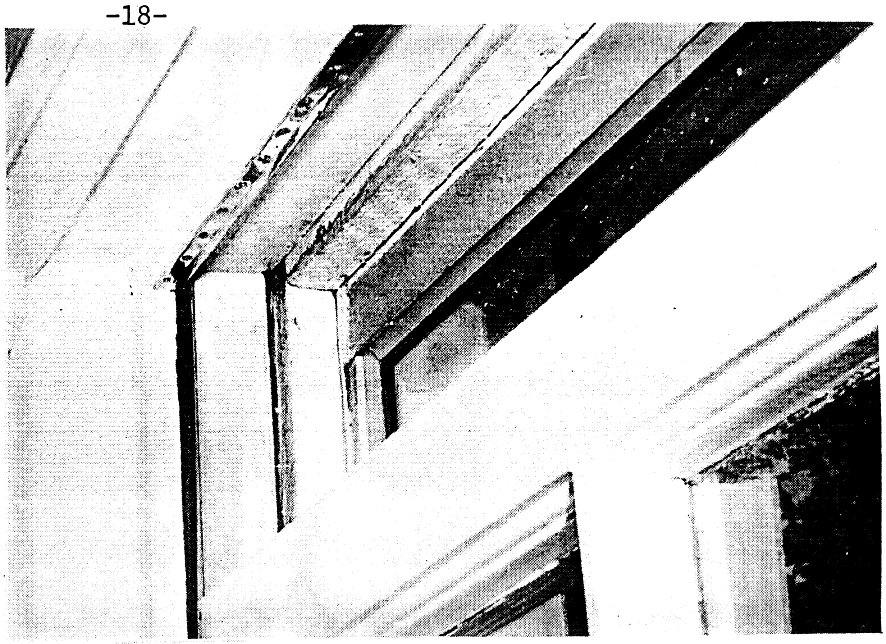
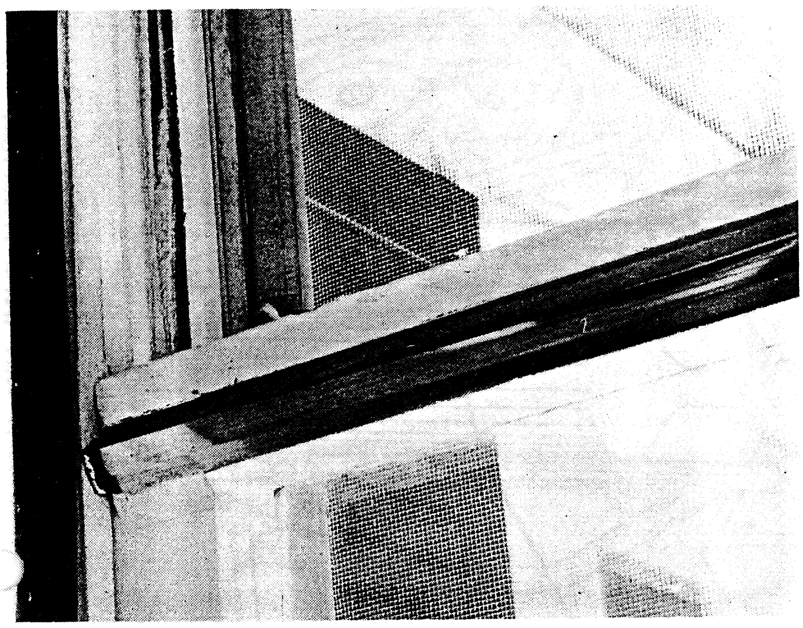


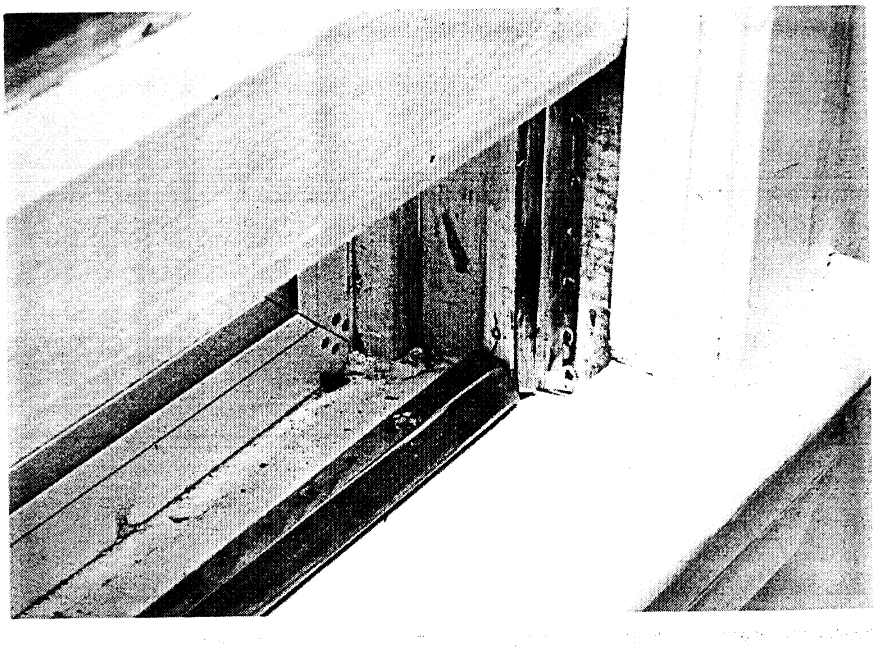
FIGURE 2 CROSS - SECTION OF A WINDOW WITH DETAILS ON THE RETROFITTED CEILING STRIPS



Seal placement
for upper window
sash



Seal arrangement between
sashs



Added trimstrip
and seal on sill,
and view of side
seal

Figure 3, Details
of Seal Placement

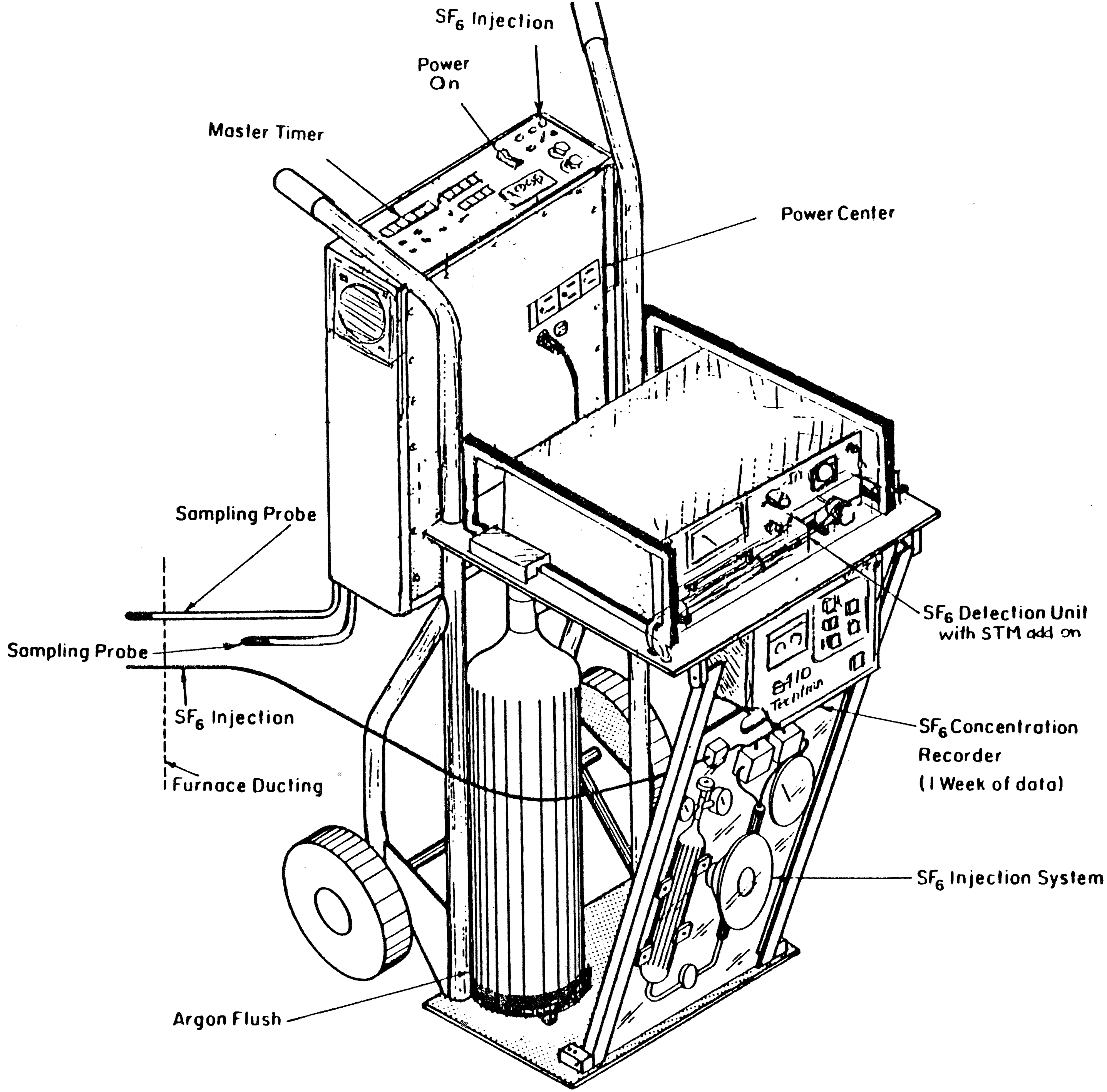
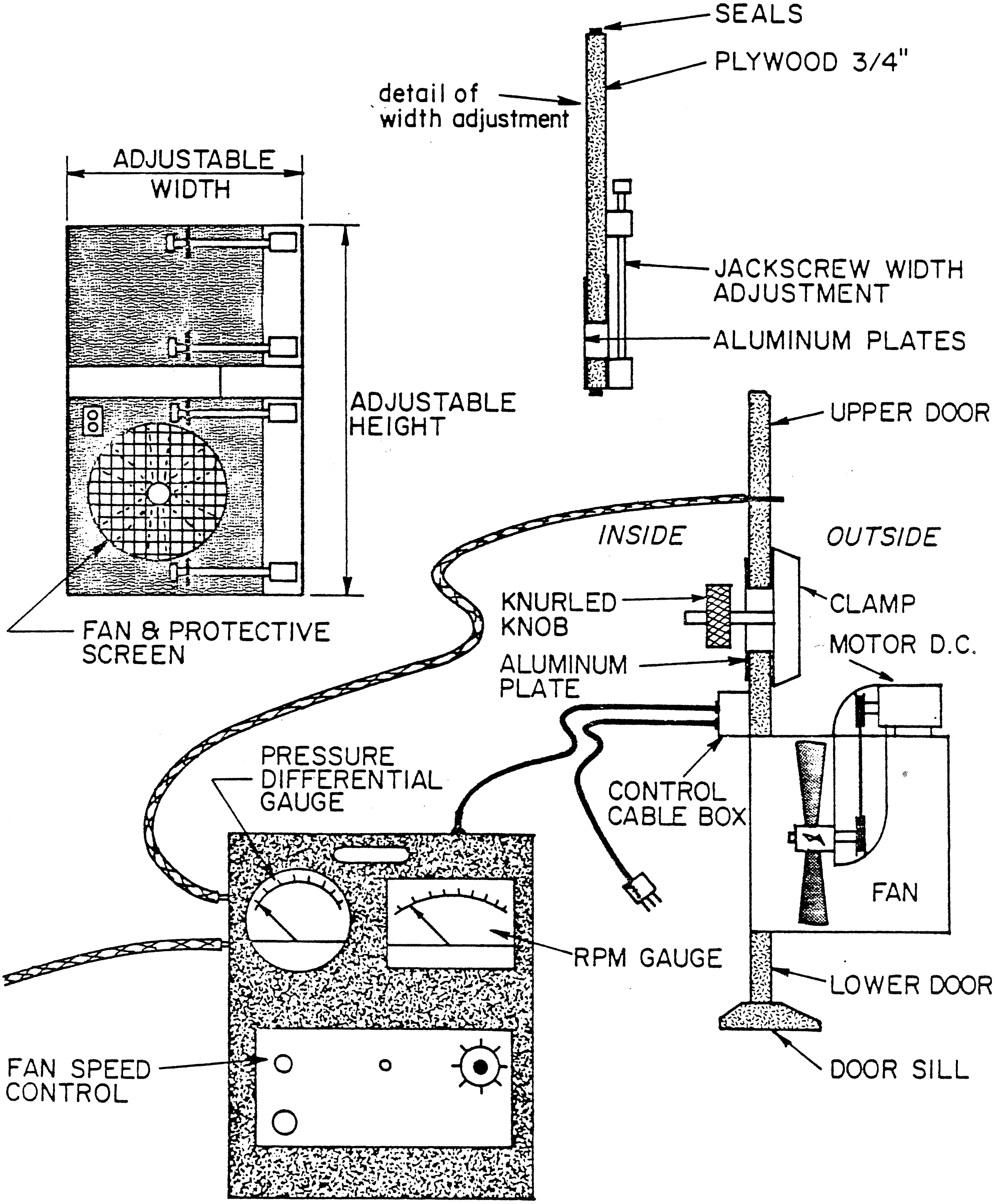
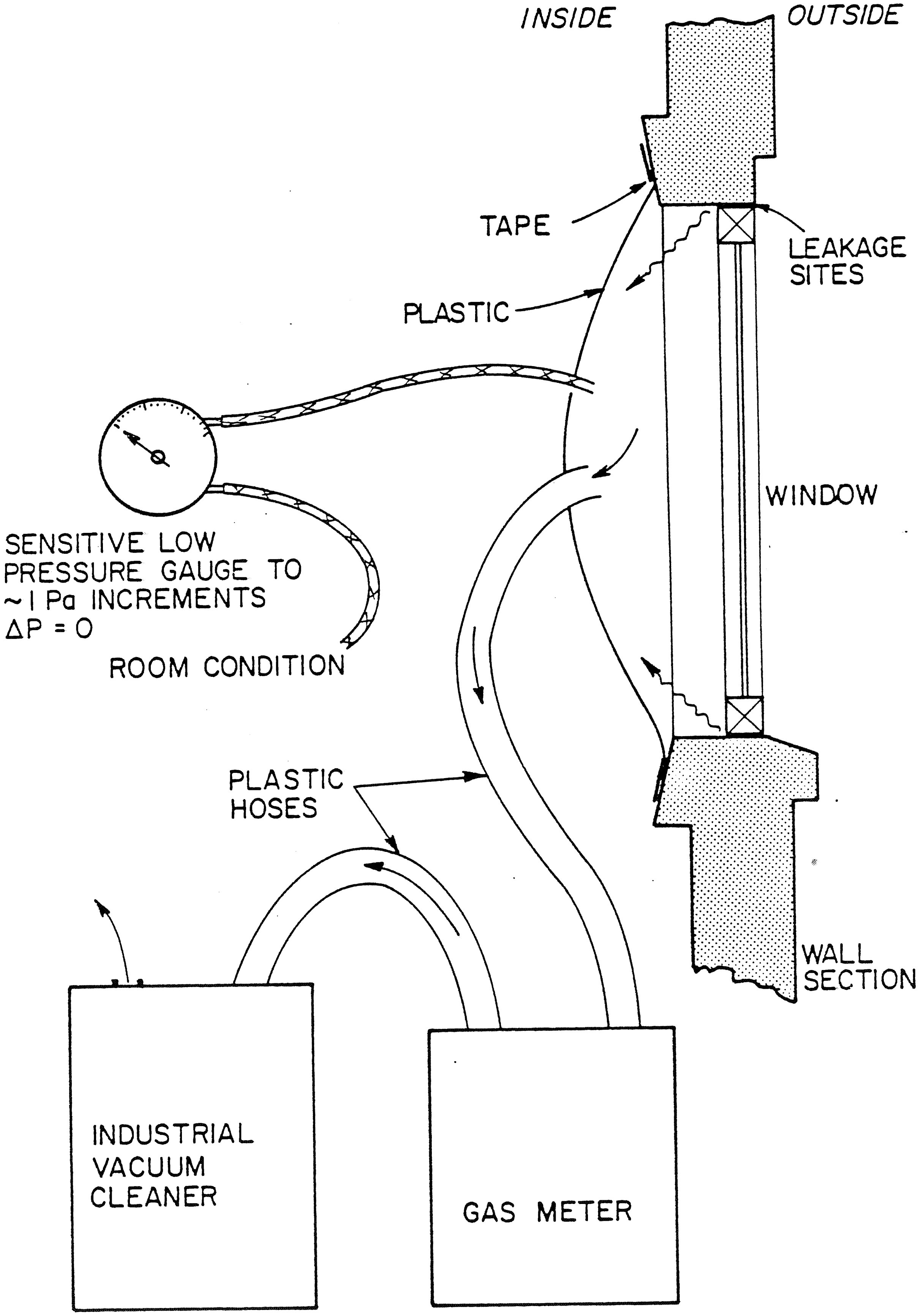


Fig. 4 AUTOMATED AIR INFILTRATION UNIT



BLOWER DOOR AND CONTROL PANEL

FIGURE 5



TEST ARRANGEMENT FOR WINDOW LEAKAGE MEASUREMENTS

FIGURE 6

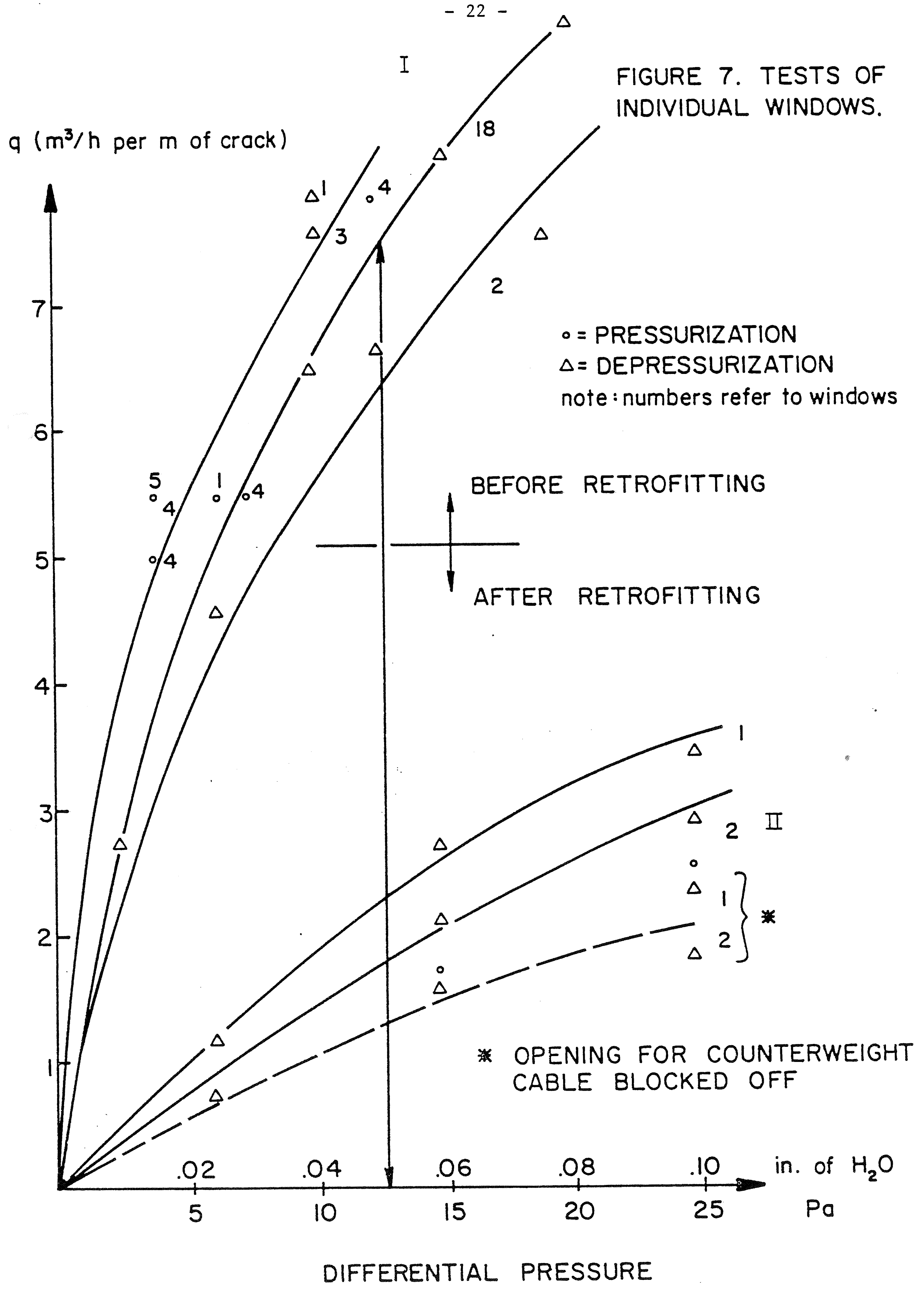


FIGURE 7. TESTS OF INDIVIDUAL WINDOWS.

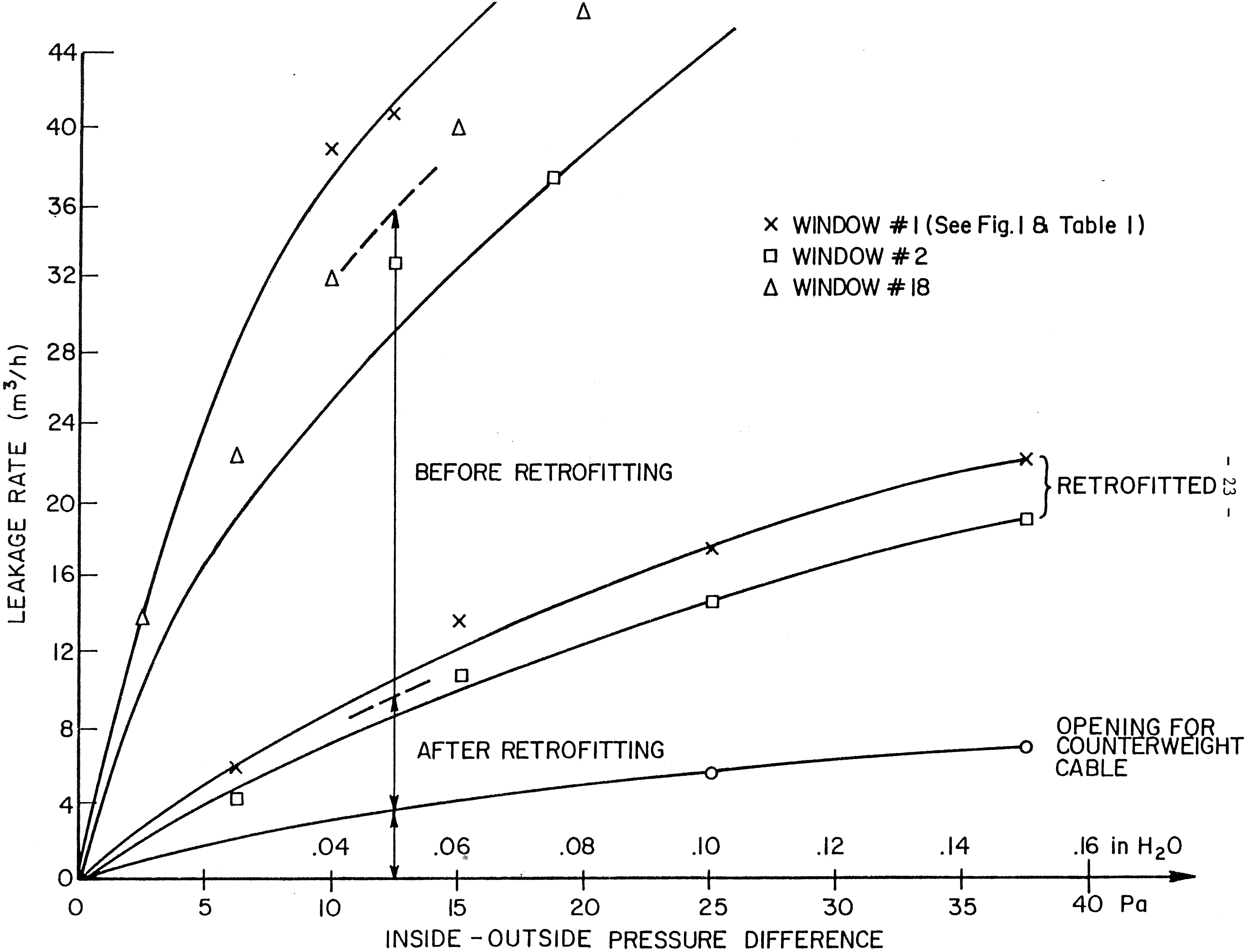
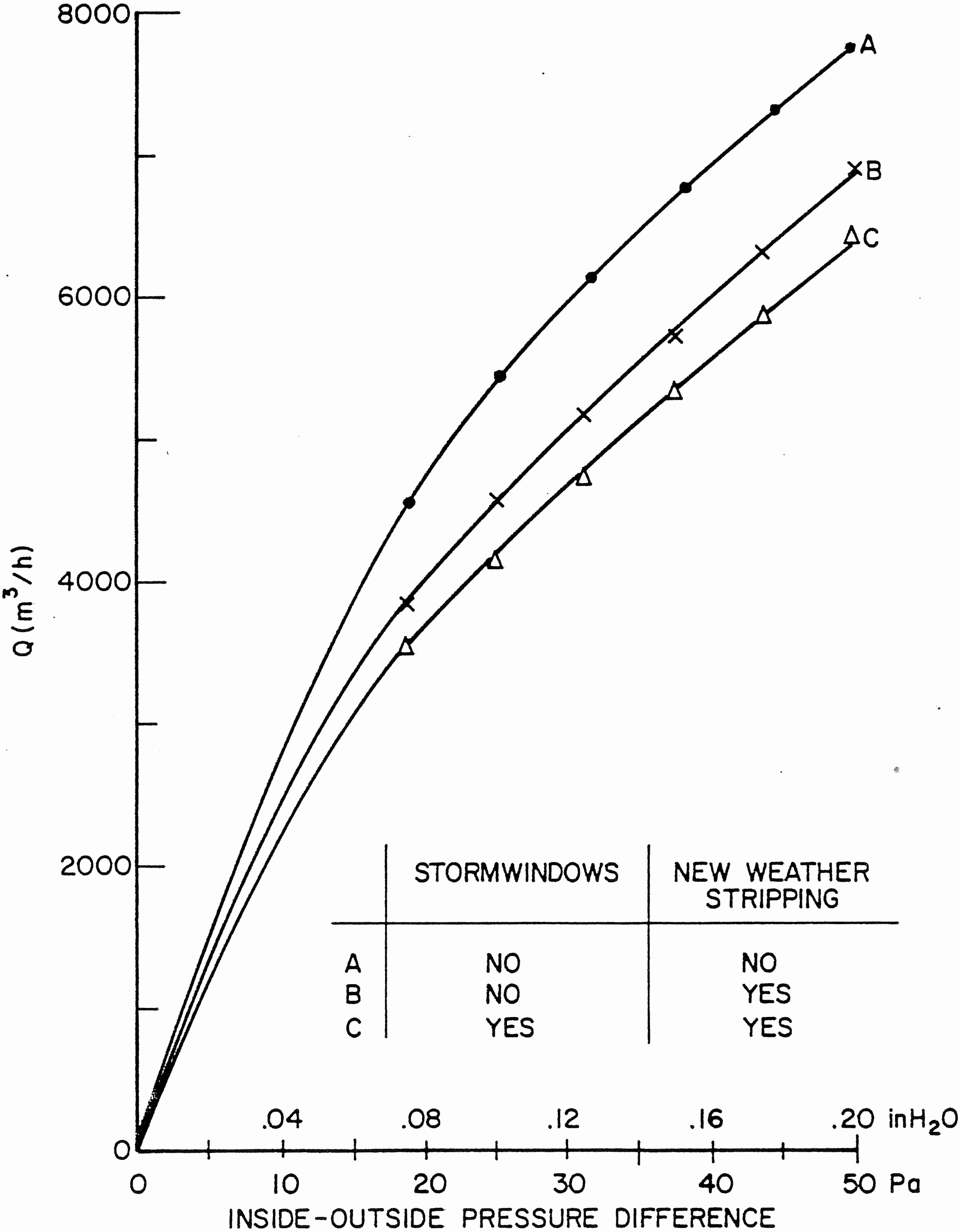
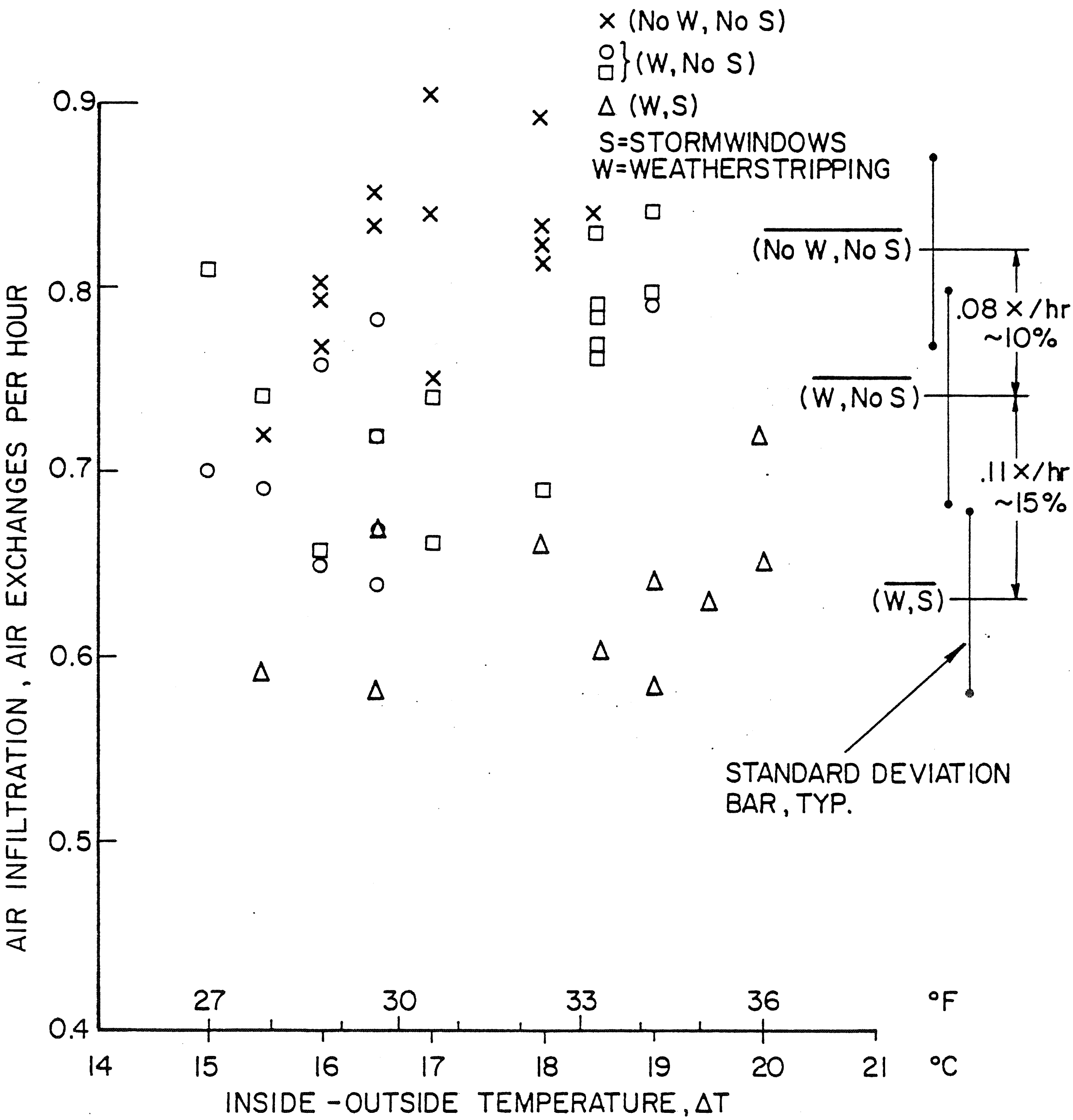


FIGURE DEPRESSURIZATION OF INDIVI[illegible]JAL WINDOWS



DEPRESSURIZATION OF THE ENTIRE HOUSE

FIGURE 9



WINDSPEED < 4.5 m/s (10 mph)

NATURAL VENTILATION

FIGURE 10