AIR LEAKAGE CHARACTERISTICS OF VARIOUS ROUGH-OPENING SEALING METHODS FOR WINDOWS AND DOORS

PREPARED FOR:

The CANMET Energy Technology Centre (CETC)
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SUMMARY

The air leakage characteristics of eight alternative methods for sealing rough-openings (R/O) around windows and doors were measured under laboratory conditions using a typical wood frame window installed in a 38x140 (2x6) wall section. The eight methods were:

1. No treatment (empty)
2. Conventional (fibreglass)
3. High density fibreglass
4. Backer rod
5. Casing tape
6. Poly-return
7. Poly-wrap
8. Foamed-in-place urethane

Significant differences were found among the air leakage rates of the different methods. As expected, the maximum leakage occurred with the untreated R/O (Method 1) while the second largest occurred using the conventional practice of packing fibreglass into the R/O space (Method 2). In contrast, Methods 5, 6, 7 and 8 were each able to reduce R/O leakage to negligible levels.

A further analysis was carried out to determine the percentage of the total building leakage which would occur through the window and door R/O cracks using a typical 97 m² (1040 ft²) bungalow with a whole-house airtightness of 1.5 ac/hr_{50} as a reference structure. Using Method 1 (no treatment), the R/O leakage accounted for 39% of the total house leakage; with Method 2 (conventional), this figure dropped to 14%. However, with each of Methods 5 to 8, the contribution of R/O leakage to total house leakage was less than 1%. These results showed that substantial reductions in R/O leakage can be achieved using relatively simple sealing methods such as foamed-in-place urethane (Method 8).

Recommendations were also made to study the durability of the various sealing methods and to establish a testing program to evaluate the air leakage characteristics of other parts of the building envelope (such as wall/floor intersections, service penetrations, etc.) using alternative sealing methods.

This study was conducted as part of the Flair Homes Energy Demo/CHBA Flair Mark XIV Project.

RÉSUMÉ

Les caractéristiques d'infiltrations et d'exfiltrations de huit autres méthodes de scellement des ouvertures brutes autour des fenêtres et des portes ont été mesurées dans des conditions de laboratoire, à l'aide d'une fenêtre type à cadre en bois, installée dans une section de mur de 38 mm x 140 mm (2 po x 6 po). Ces huit méthodes sont les suivantes :

1. Aucun dispositif (vide)
2. Classique (fibre de verre)
3. Fibre de verre haute densité
4. Tige d'appui
5. Ruban contre-chambranle
6. Retour en polyéthylène
7. Enveloppe de polyéthylène
8. Uréthanne formé sur place

Des différences notables ont été relevées entre les taux d'infiltrations et d'exfiltrations des différentes méthodes. Comme il était à prévoir, le taux maximal d'infiltrations et d'exfiltrations s'est produit avec l'ouverture brute sans dispositif (1^re^ méthode) alors que le deuxième taux plus élevé a été obtenu avec la méthode qui consiste à bourrer de la fibre de verre dans l'espace de l'ouverture brute (2^e^ méthode). Par contre, les méthodes 5, 6, 7 et 8 ont toutes permis de réduire à des niveaux négligeables les infiltrations et exfiltrations à travers l'ouverture brute.

On a effectué une autre analyse afin de déterminer le pourcentage des infiltrations et exfiltrations totales du bâtiment qui se produiraient à travers les fissures des ouvertures brutes de fenêtres et de portes, à partir d'un bungalow type de 97 m^2 (1 040 pi^2), ayant une étanchéité à l'air globale de 1,5 renouvellement d'air par heure (ra/h) comme structure de référence. Avec la méthode n° 1 (aucun dispositif), les infiltrations et exfiltrations par les ouvertures brutes ont représenté 39 % des infiltrations et exfiltrations totales de la maison; avec la méthode n° 2 (classique), ce taux est tombé à 14 %. Toutefois, avec les méthodes 5 à 8, la contribution des infiltrations et exfiltrations par les ouvertures brutes a été inférieure à 1 % du total pour la maison. Ces résultats montrent qu'il est possible de réduire substantiellement les infiltrations et exfiltrations par les ouvertures brutes en employant des méthodes de scellement des ouvertures brutes relativement simples, comme l'uréthanne formé sur place (méthode 8).

Il a également été recommandé de mener une étude de la durabilité des diverses méthodes de scellement et d'établir un programme d'essai visant à évaluer les caractéristiques des infiltrations et exfiltrations à travers d'autres parties de l'enveloppe du bâtiment (comme les intersections mur-plancher, l'entrée des services publics, etc.), en utilisant d'autres méthodes de scellement.

Cette étude a été effectuée dans le cadre du Projet de démonstration de la maison à haut rendement énergétique/Mark XIV de l'ACCH, de Flair Homes.

TABLE OF CONTENTS

SECTION 1

INTRODUCTION

1.1 BACKGROUND

Since the introduction of the blower door in the 1970's and the establishment of a standardized testing procedure (CGSB 1986), the airtightness of thousands of Canadian houses has been evaluated. A detailed knowledge base now exists on house leakage which includes information on the influences of house type, construction style, age, etc. However, a limitation of the blower door test is its inability to identify the leakage contribution of individual components. Builders and designers can speculate on the relative performance of different sealing methods by "feeling" for leakage while the house is depressurized, but quantitative data on component air leakage is sparse. For example, the ASHRAE Handbook of Fundamentals (ASHRAE 1989) gives effective leakage areas of several residential building components based on tests of American houses. However, this data has limited applicability to Canadian housing due to the differences in construction practices, materials, etc.

A building envelope component of particular interest is the rough-opening (R/O) crack around windows and doors. Excessive air leakage can increase moisture damage, energy consumption and the transmission of outdoor noise into the house. R/O leakage is often very noticeable to homeowners although they generally assume it is attributable to the windows or doors. Historically, various methods have been used to seal R/Os, although evaluating their effectiveness has proven difficult and no quantitative information is known to exist on the performance of alternative methods. Since the costs and effectiveness vary widely, the need for comparative air leakage data is apparent.

1.2 OBJECTIVE

The objective of this study was to measure the air leakage characteristics of alternative methods of sealing the rough-opening cracks around windows and doors in wood frame residential construction.

1.3 THE FLAIR HOMES ENERGY DEMO/CHBA FLAIR MARK XIV PROJECT

The work described in this report was conducted as part of the Flair Homes Energy Demo/CHBA Flair Mark XIV Project. This project was created in 1985 to provide a demonstration of various energy conservation technologies, products and systems which might be suitable for the Canadian home building industry. The specific objectives of the project were:

1. To demonstrate and evaluate the performance of various low energy building envelope systems.

2. To demonstrate and evaluate the performance of various space heating, hot water heating and mechanical ventilation systems.

3. To transfer the knowledge gained in the project to the Canadian home building industry.

Support for the project was provided by Energy, Mines and Resources Canada under the Energy Demo Program and by Manitoba Energy and Mines under the Manitoba/Canada Conservation and Renewable Energy Demonstration Agreement (CREDA). Project management was the responsibility of Flair Homes (Manitoba) Ltd. Project monitoring and reporting were performed by UNIES Ltd., consulting engineers, of Winnipeg.

The project was also designed to provide technical support to the R-2000 Home Program, which is funded by Energy, Mines and Resources Canada and administered by the Canadian Home Builders Association (CHBA). The CHBA's "Mark XIV" designation was acquired when a major portion of the research priorities identified by the CHBA's Technical Research Committee was incorporated into the work plan.

To meet the project's objectives, 24 houses were constructed in Winnipeg by Flair Homes Ltd. and independently monitored for periods of up to three years. Energy conservation levels ranged from those of conventional houses to those which met or exceeded the R-2000 Standard.

SECTION 2

TEST PROGRAM

2.1 METHODOLOGY

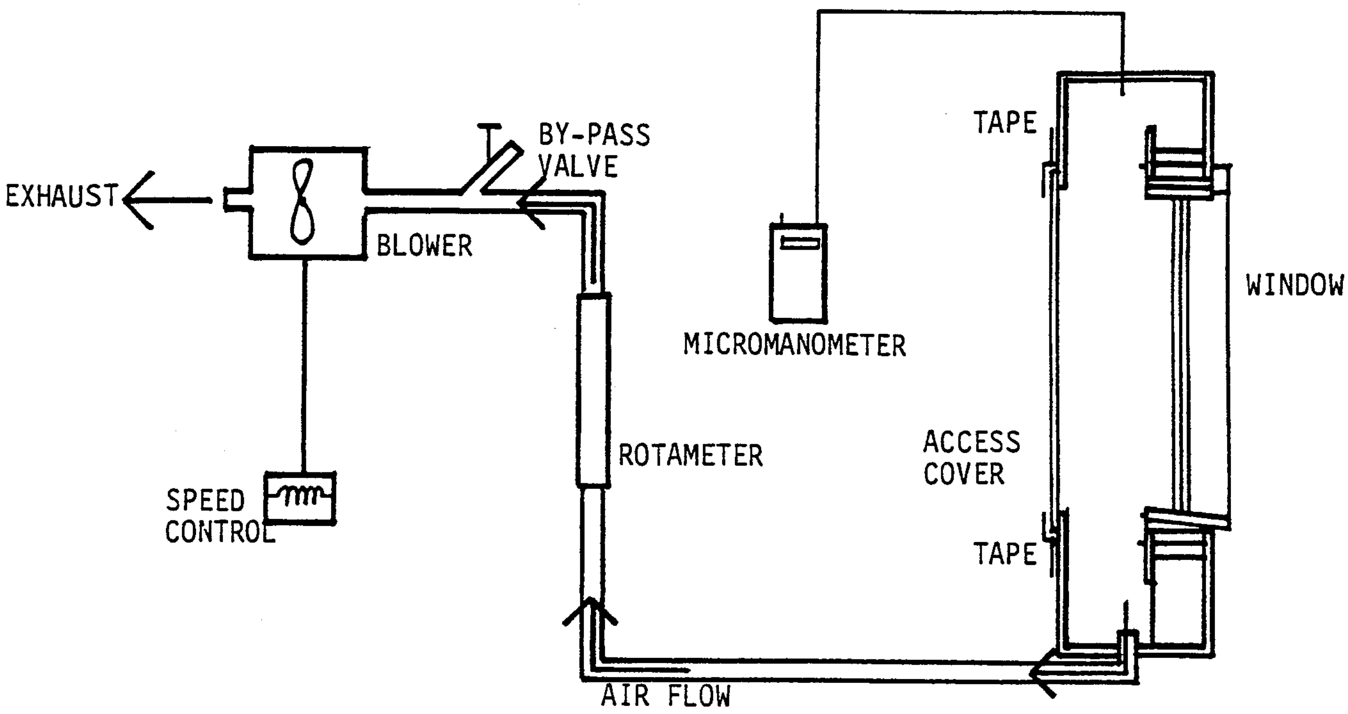
A test program was established to measure, under controlled conditions, the air leakage characteristics of eight commonly-used, or proposed, methods of sealing rough-opening cracks around windows and doors. An experimental apparatus, shown in Fig. 1, was constructed consisting of a well-sealed chamber with one side built to simulate a typical 38x140 (2x6) frame wall into which was installed a standard, non-operating 0.97 m x 0.67 m (38" x 26½") wood window. The frame wall was constructed with plywood sheathing, building paper and horizontal lap wood siding on the exterior and drywall on the interior. The window was secured into the R/O using screws through the brick mould. A plexiglass access panel was installed on the opposite side of the chamber to permit viewing.

Rough-opening leakage was defined as the air movement which occurred along the shaded pathway shown in Fig. 2, i.e. between the brick mould and sheathing, into the space between the framing and window and then around the casing into the living space. The sides of the framing/window passageway were sealed to minimize by-pass flow into the wall cavity.

For testing purposes, the R/O's were sealed using a level of care which was considered typical of normal residential construction, no attempt was made to produce an "ideal" seal. In most cases, two different installers were used for the replicate tests (discussed below). To maintain equivalent crack geometries, the R/O dimensions were controlled by installing the window against wooden spacer blocks to give uniform crack widths around the frame (approximately 13 mm or ½" on the sides and top, and 32 mm or 1¼" on the bottom). The interior drywall was cut flush with the framing members to provide uniform conditions.

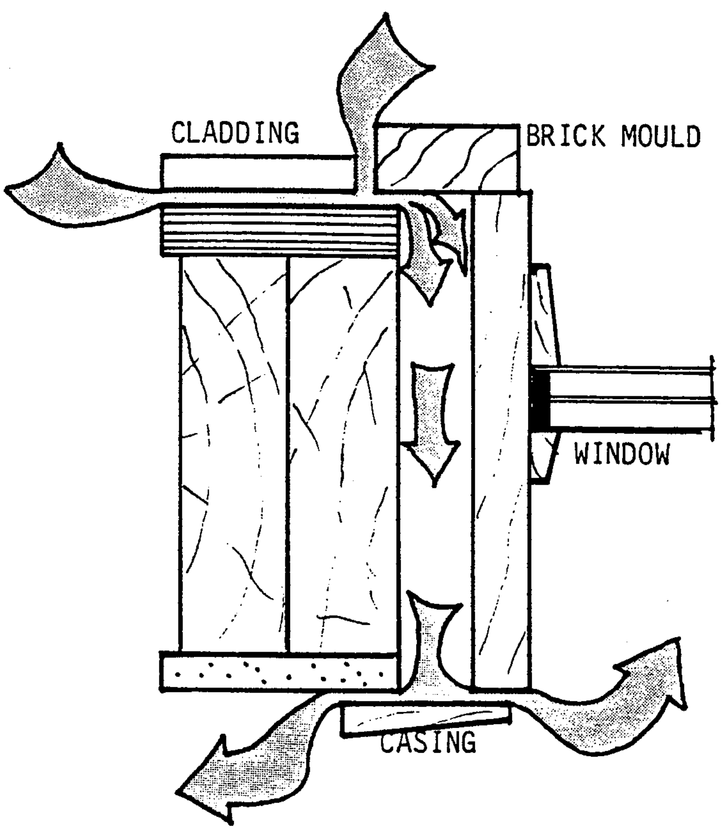
Extraneous chamber leakage (i.e. leakage other than that through the window rough-opening) was determined by first measuring the total chamber leakage (i.e. R/O plus extraneous). The window casing was then taped to eliminate R/O leakage and the test repeated. By subtracting the taped leakage value from the total leakage rate, the extraneous leakage could be determined. This process was repeated for each test.

Five separate air leakage tests were conducted with each of the eight sealing methods. For each test, the R/O was sealed using the method under consideration, the interior casing installed and the chamber sealed. Once the test was completed, the casing and R/O seal were removed and the process repeated for the next test. In some instances, the window was also removed and re-installed for each test.



EXPERIMENTAL ARRANGEMENT

FIGURE 1



ROUGH OPENING LEAKAGE

FIGURE 2

Air flow rates were measured using Dwyer rotameters with ranges of 0.04 l/s to 0.39 l/s and 0.47 l/s to 4.7 l/s. Pressure differentials in the test chamber were measured using an Air Instruments Resources Ltd. MP6KD digital micromanometer. All hose connections were sealed, tested and checked.

Air leakage rates were measured at 10 to 15 Pascal (Pa) increments between 10 Pa and 90 Pa. The test data was analyzed using a procedure similar to that described in CAN/CGSB 149.10-M "Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method" in which a regression curve, of the form shown below, was generated to describe the leakage:

$$Q = C \cdot \Delta p^n \qquad (1)$$

where:
Q = air flow rate (l/s)
C = flow coefficient ($l/s \cdot Pa^n$)
Δp = pressure differential (Pa)
n = flow coefficient.

Once C and n were determined, leakage rates (Q) could be calculated for any value of Δp. Air leakage rates were corrected to the reference conditions specified in the standard (20 °C and 101.325 kPa).

2.2 ROUGH-OPENING SEALING METHODS

Eight commonly-used or proposed methods of sealing rough-openings were evaluated (see Fig. 3).

1. No Treatment - Although not an advocated method, this represents the worst case scenario which might occur due to faulty workmanship or in retrofits of older houses. The only significant restrictions to air flow are those provided by the interior casing and the exterior brick mould.

2. Conventional - This method, which consists of packing pieces of fibreglass batt insulation into the R/O space, is the most common in residential construction. It is inexpensive and easy to apply but is often criticized as being ineffective since fibreglass insulation is not intended to serve as a barrier to air leakage.

3. High Density Fibreglass - This technique consists of packing extra insulation into the R/O to further reduce air leakage and has been suggested as a low cost improvement over conventional practice. For the tests, the insulation density was arbitrarily set at double that employed with the conventional method. Density was established by using twice the number of fixed-sized insulation pieces. Care is needed with this technique to prevent inward bowing of window and door frames if excessive insulation is forced into the R/O space.

4. Backer Rod - The backer rod technique was first suggested as a component of the Airtight Drywall Approach (ADA) and uses a suitably sized, round polyethylene gasket squeezed into the R/O space. However, it is now recognized that this material is susceptible to creep under compressive loads and may not have the necessary life for such applications and for this reason, is no longer recommended. However, it was included in the test program to provide an example of what could be achieved, from an air leakage perspective, with a suitable product.

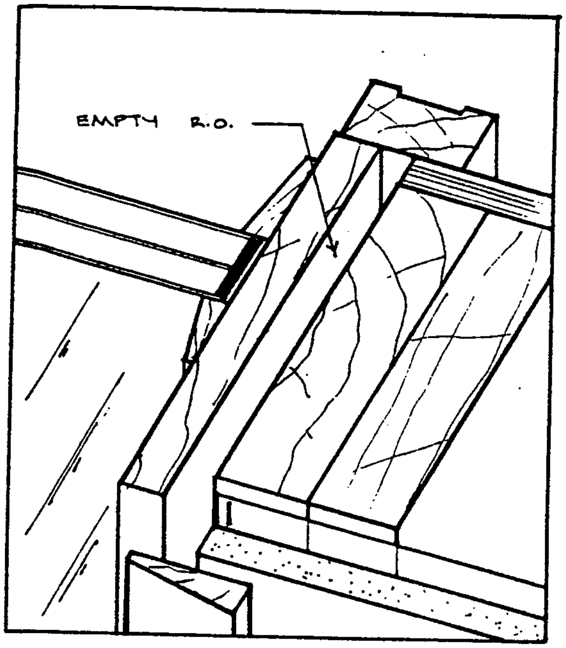
5. Casing Tape - This novel method has been suggested as a low cost alternative to conventional practice. After the fibreglass has been packed into the R/O space and the drywall installed, a strip of contractor's sheathing tape is applied across the R/O gap from the drywall to the window frame. This product is normally used for taping joints in exterior insulated sheathing. The casing is then applied over the tape.

6. Poly-Return - Although not commonly used, this method has been suggested for use with polyethylene air barrier systems. After the fibreglass has been installed, the polyethylene air/vapour barrier (from the wall) is returned to the window or door frame, caulked and stapled in place.

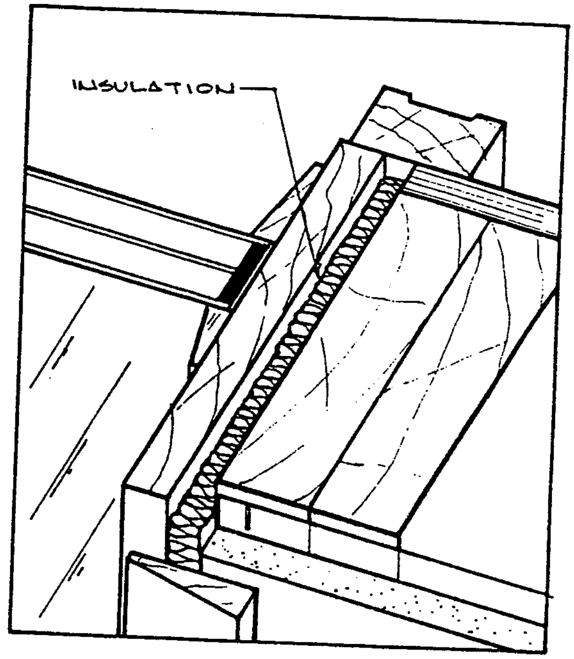
7. Poly-Wrap - The poly-wrap technique is commonly used in airtight construction and was developed more than a decade ago for double wall houses. A polyethylene apron is caulked and stapled around the window frame; after the window and fibreglass have been installed, the apron is folded back and sealed to the wall polyethylene.

8. Foamed-in-Place Urethane - With this method, the R/O space is partially filled with foamed-in-place urethane. For the tests, two rows of foam were used. One and two-component foams are available, as are both expanding and non-expanding types. Several application methods can be used ranging from simple spray cans to spray guns which permit accurate control of the foam injection rate. The latter method was used for the tests described in this report.

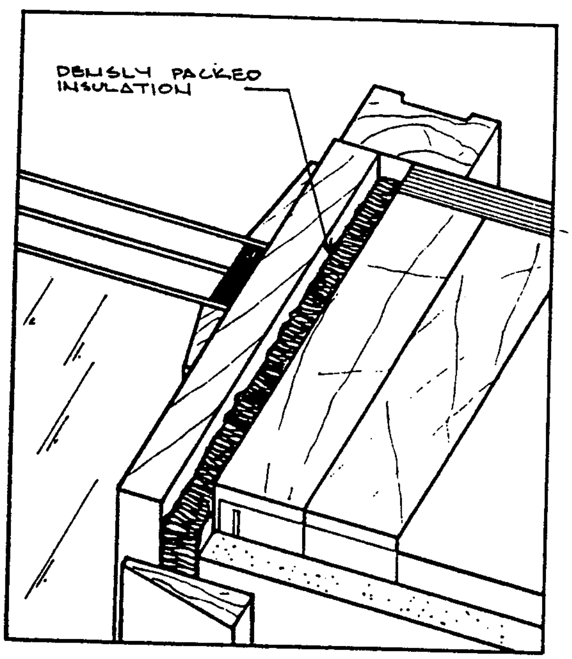
All eight R/O sealing methods can be used with conventional 38x89 (2x4) or 38x140 (2x6) framed walls and for frame walls with exterior insulated sheathing. However, the casing tape and poly-return methods (5 and 6) can only be used with double wall construction if the windows are mounted on the inside of the rough-opening. Likewise, interior strapped walls should only use the backer rod, casing tape, poly-return and urethane methods (4, 5, 6 and 8) if the joints in the R/O spaces, created where the strapping meets the wall framing, are first sealed.



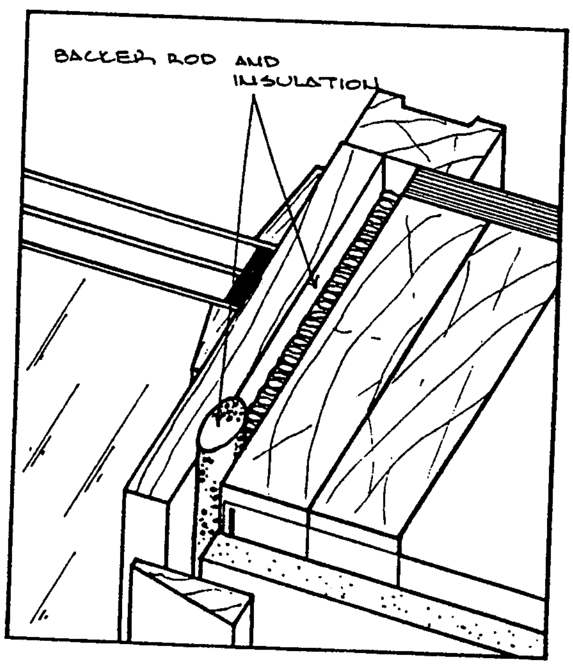
1. NO TREATMENT



2. CONVENTIONAL (FIBREGLASS)

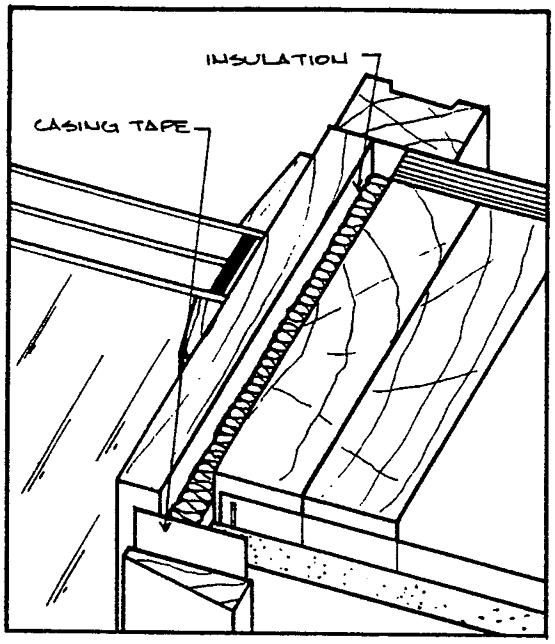


3. HIGH DENSITY FIBREGLASS

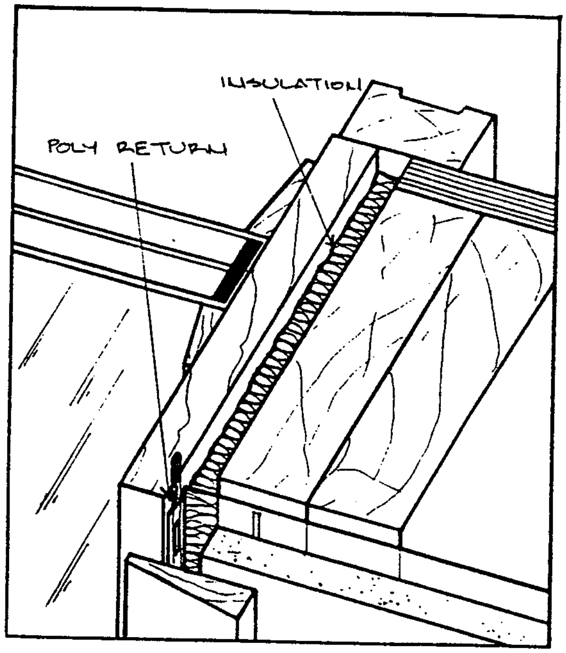


4. BACKER ROD

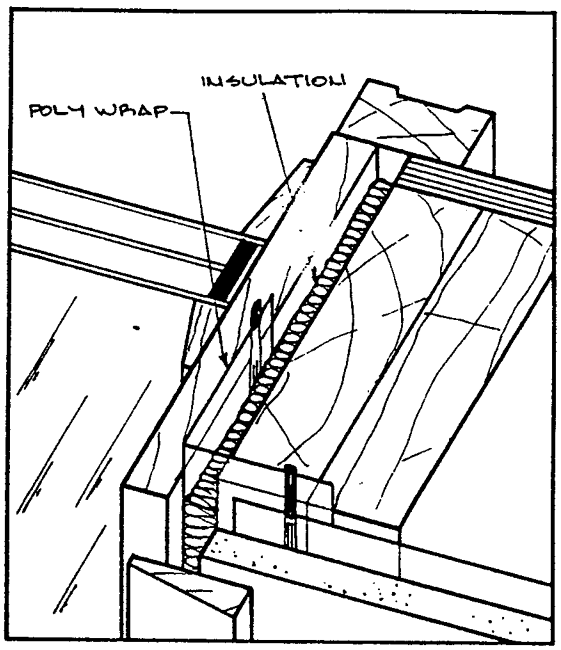
FIGURE 3



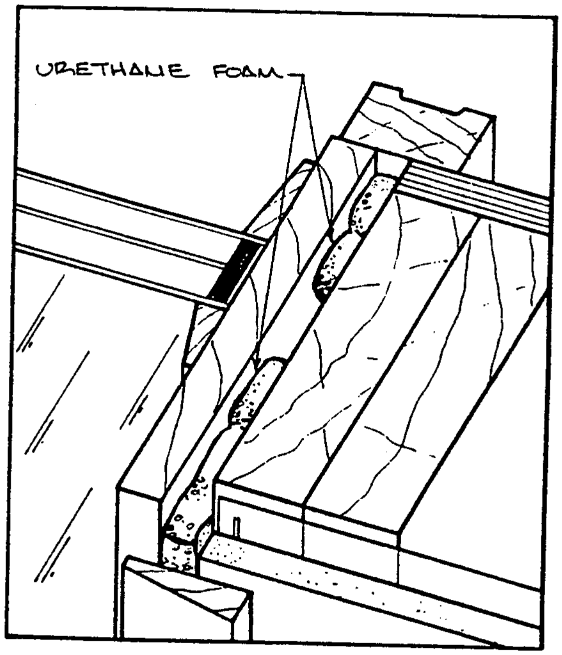
5. CASING TAPE



6. POLY-RETURN



7. POLY-WRAP



8. FOAMED-IN-PLACE URETHANE

FIGURE 3 (continued)

SECTION 3

RESULTS

3.1 ROUGH-OPENING AIR LEAKAGE

The measured air leakage rates, expressed in "litres per second per metre of rough-opening crack length" at pressure differentials of 50 Pa and 75 Pa are summarized in Table 1 and Figs. 4 and 5. The former pressure differential is referenced in CAN/CGSB 149.10-M while 75 Pa is used by ASTM E 283 "Rate of Air Leakage Through Exterior Windows, Curtain Walls and Doors" (1984) and ASTM E 783 "Field Measurement of Air Leakage Through Installed Exterior Windows and Doors" (1984). Group averages, calculated as the mean of the five replicate tests, are shown in Figs. 6 and 7 for each of the eight methods.

3.2 MEAN AIR LEAKAGE RATES

The mean air leakage rates were found to vary significantly among the eight sealing methods. Method 1 (no treatment) displayed the greatest leakage, 1.3793 l/s•m @ 50 Pa, while Method 2 (conventional) had a leakage rate about one-third this value, i.e. 0.5083 l/s•m @ 50 Pa. High density fibreglass (Method 3) produced a slight reduction relative to the conventional method while the backer rod approach (Method 4) showed a pronounced improvement. Methods 5 to 8 (casing tape, poly-return, poly-wrap and urethane foam) all displayed leakage rates which were negligible relative to conventional practice.

Method 1 can, of course, be ignored on the grounds that it does not represent good building practice (although it might be encountered in retrofits on some older houses). However, even if the conventional practice (Method 2) is considered the norm, the performance of some of the alternative sealing methods is still quite surprising. Note, for example, that the average leakage rate for the conventional method was over 100 times that of Methods 5, 6, 7 or 8.

3.3 VARIATION IN LEAKAGE AMONG REPLICATE TESTS

The variation in leakage among the replicate tests describes the reproducibility of the results - an important factor from a quality control perspective. Table 1 contains the standard deviation and coefficient of variation for the eight sets of tests. (The coefficient of variation is the standard deviation divided by the mean and is expressed as a percentage.)

In general, the measured air leakage rates were reasonably consistent. The largest standard deviation occurred with Method 3 (high density fibreglass). This may have been caused by problems with installing the material in a consistent fashion. Method 8 (foamed-in-place urethane) displayed the largest coefficient of variation because the mean leakage rate (i.e. the denominator in the definition) was almost zero.

TABLE 1
ROUGH-OPENING AIR LEAKAGE TEST RESULTS

TEST	AIR LEAKAGE (l/s•m) 50 Pa	AIR LEAKAGE (l/s•m) 75 Pa
1-A	1.3519	1.8010
1-B	1.4378	1.9069
1-C	1.3155	1.7492
1-D	1.3774	1.8338
1-E	1.4138	1.8507
MEAN	1.3793	1.8283
S	0.0486	0.0585
S/X (%)	3.5	3.2
2-A	0.4422	0.6515
2-B	0.5335	0.7486
2-C	0.5548	0.7958
2-D	0.4972	0.7127
2-E	0.5140	0.7487
MEAN	0.5083	0.7315
S	0.0428	0.0536
S/X (%)	8.4	7.3
3-A	0.1473	0.2192
3-B	0.3751	0.5453
3-C	0.3052	0.4479
3-D	0.4523	0.6673
3-E	0.4412	0.6508
MEAN	0.3442	0.5061
S	0.1248	0.1831
S/X (%)	36.3	36.2
4-A	0.0246	0.0329
4-B	0.1168	0.1628
4-C	0.0685	0.0955
4-D	0.0258	0.0342
4-E	0.1164	0.1615
MEAN	0.0704	0.0974
S	0.0457	0.0643
S/X (%)	64.9	66.0
5-A	0.0043	0.0054
5-B	0.0059	0.0076
5-C	0.0033	0.0045
5-D	0.0009	0.0034
5-E	0.0033	0.0046
MEAN	0.0035	0.0051
S	0.0018	0.0016
S/X (%)	51.4	30.8
6-A	0.0117	0.0162
6-B	0.0243	0.0317
6-C	0.0182	0.0238
6-D	0.0658	0.0881
6-E	0.0140	0.0173
MEAN	0.0268	0.0354
S	0.0223	0.0301
S/X (%)	83.3	85.0
7-A	0.0022	0.0029
7-B	0.0006	0.0007
7-C	0.0076	0.0078
7-D	0.0046	0.0047
7-E	0.0061	0.0068
MEAN	0.0042	0.0046
S	0.0028	0.0029
S/X (%)	67.3	62.9
8-A	0.0000	0.0000
8-B	0.0000	0.0000
8-C	0.0000	0.0000
8-D	0.0000	0.0000
8-E	0.0431	0.0470
MEAN	0.0086	0.0094
S	0.0193	0.0210
S/X (%)	223.6	223.6

NOTES:
1. S = Standard Deviation
2. S/X = Coefficient of Variation

FIGURE 4

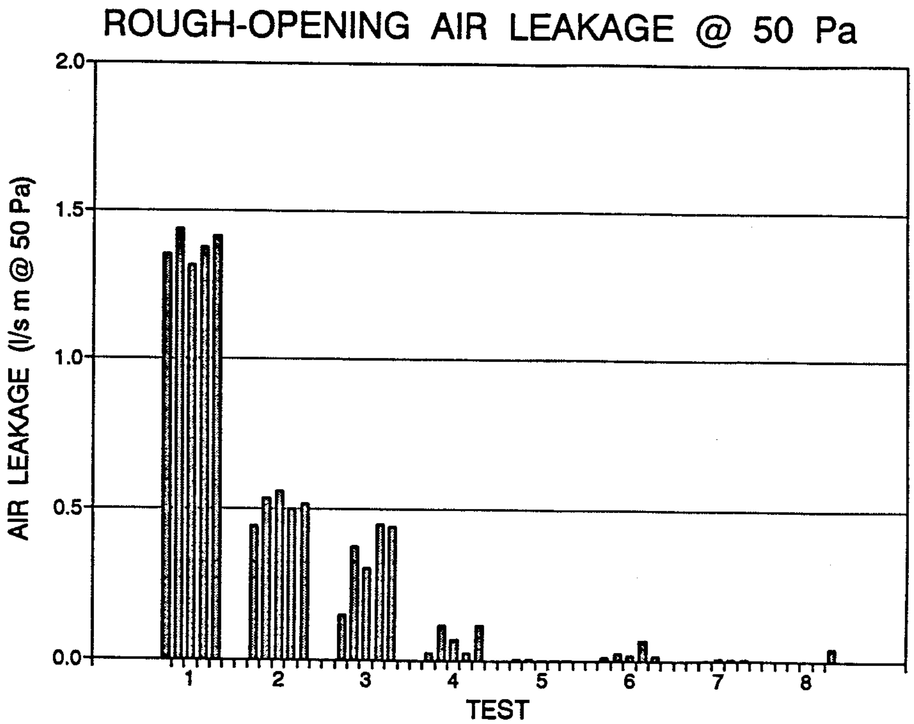


FIGURE 5

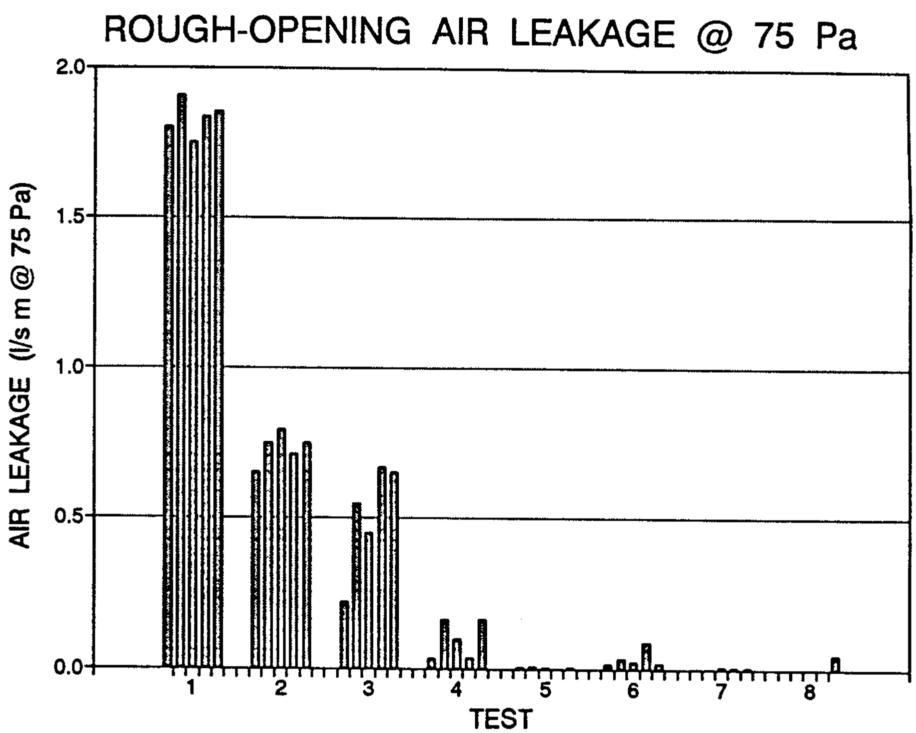


FIGURE 6

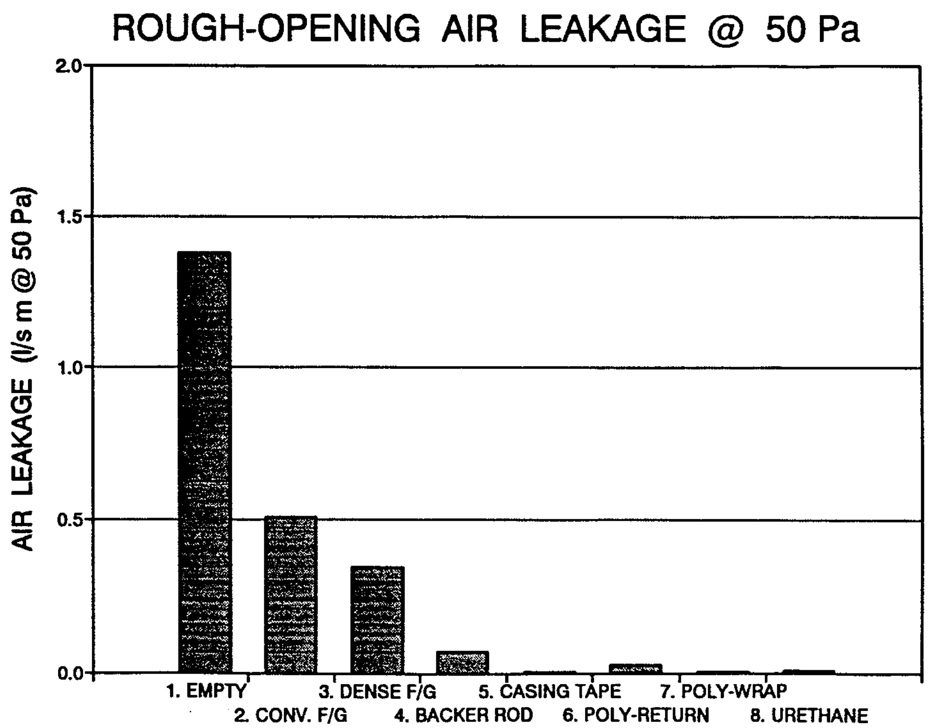
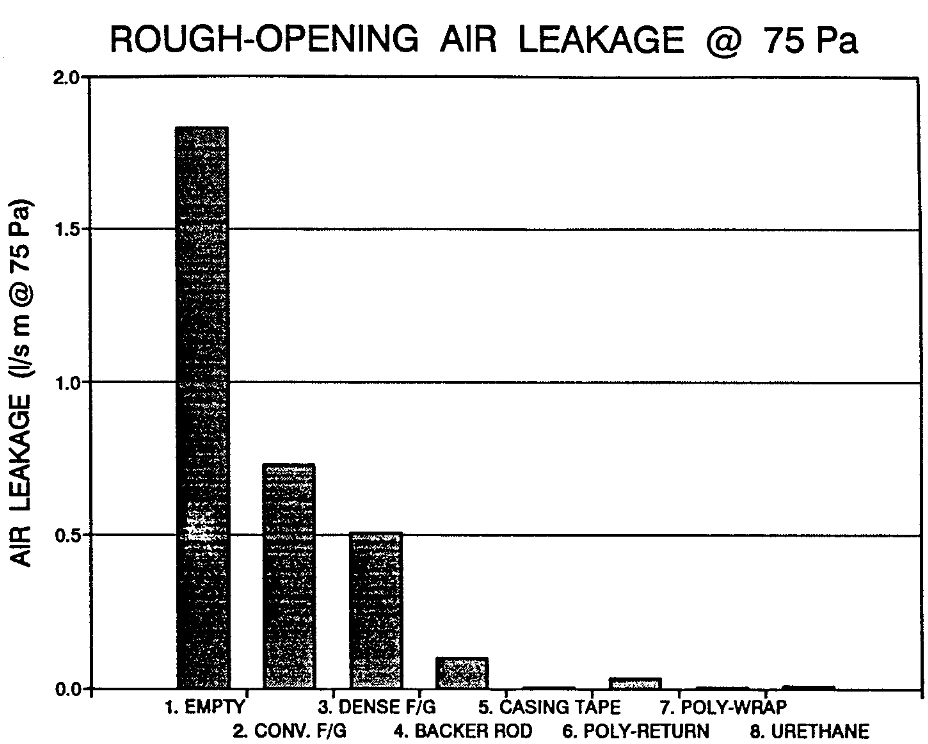


FIGURE 7



None of the individual tests showed dramatically higher leakage rates relative to others in the group, indicating that there were no "catastrophic failures" with individual tests. Since each method was applied with only normal care, the results suggest that consistent air leakage performance can be achieved for each sealing method.

3.4 ADDITIONAL COMMENTS

Frame Materials

Methods 6 and 7 (poly-return and poly-wrap) are best suited to wood windows and doors because of the need to staple into the frame, although tape could be used for vinyl, metal or fibreglass frames.

Ease of Installation

Method 6 (poly-return) was found to be difficult to use and somewhat vulnerable to damage during installation of the drywall. Methods 6 and 7 (poly-return and poly-wrap) required caulking which resulted in a significant clean-up time. Methods 5 and 8 (casing tape and urethane) were both judged easy to apply. Some care was required with Method 5 (casing tape) to insure none of the fibreglass was left protruding under the tape to form small leakage passageways.

The performance of Method 8 (urethane) depends heavily on the type of applicator used to apply the foam. For the test program, a professional-style gun was used with a one component, low expansion foam supplied in 1 kg. cans. The cost of the gun was approximately $150 and manufacturer's instructions were carefully followed. Learning time was minimal. Using the proper equipment and product, the foamed-in-place urethane approach was found to be particularly easy and quick to apply.

House Cladding System

The test apparatus was conducted with a air permeable wall cladding system (wood siding), therefore the results strictly only apply to windows and doors installed in walls with permeable cladding systems such as brick, wood, vinyl or metal siding. Air leakage rates for low permeability claddings, such as stucco, would likely be lower than the values measured.

3.5 ROUGH-OPENING LEAKAGE AS A PERCENTAGE OF TOTAL HOUSE LEAKAGE

The significance of window and door rough-opening leakage can be placed in perspective by comparing it to the total house leakage. To illustrate this point, the measured R/O leakage rates were assumed to apply to a hypothetical 97 m^2 (1040 ft^2) bungalow with an airtightness of 1.5 ac/hr_{50} (air changes per hour at 50 Pa) - the maximum leakage permitted for R-2000 houses and the unofficial demarcation between "loose" and "tight" construction. The combined window and door R/O crack length for this example house was calculated as 53.7 m (176 ft).

The results of this analysis are summarized in Table 2 and Figs. 8 and 9. Figure 8 shows the calculated air change rate (at 50 Pa) due to R/O leakage for each sealing method while Fig. 9 presents the same data expressed as a percentage of the whole house leakage at 1.5 ac/hr.

For the methods normally used, or proposed, for residential construction (i.e. 2 to 8), the R/O leakage ranged between 0.1% and 14% of the total house leakage, whereas with Method 1 (no treatment), 39% of the house leakage occurred through the R/O.

These results show that rough-opening leakage can represent a significant portion of the total house leakage if conventional sealing methods are used. Further, the results clearly show that it is possible to reduce R/O leakage to negligible levels using relatively simple techniques, such as foamed-in-place urethane techniques (Method 8).

TABLE 2

IMPACT OF ROUGH-OPENING LEAKAGE FOR A TYPICAL 97 m^2 (1040 ft^2) HOUSE WITH AN AIRTIGHTNESS OF 1.5 AC/HR_{50}

ROUGH-OPENING SEALING METHOD	TOTAL HOUSE ROUGH-OPENING AIR LEAKAGE AC/HR_{50}	% OF 1.5 AC/HR_{50}
1. No treatment	0.59	39%
2. Conventional	0.22	14%
3. High density fibreglass	0.15	10%
4. Backer rod	0.030	2%
5. Casing Tape	0.002	0.1%
6. Poly-return	0.011	0.8%
7. Poly-wrap	0.002	0.1%
8. Foamed-in-place urethane	0.004	0.2%

3.6 RECOMMENDATION TO EVALUATE LIFE EXPECTANCY

Since this study did not address durability of the sealing systems, it is recommended that a program be established to evaluate the life expectancy of the various R/O sealing methods to determine what, if any, restrictions should be placed on their use.

FIGURE 8

CONTRIBUTION TO WHOLE HOUSE LEAKAGE

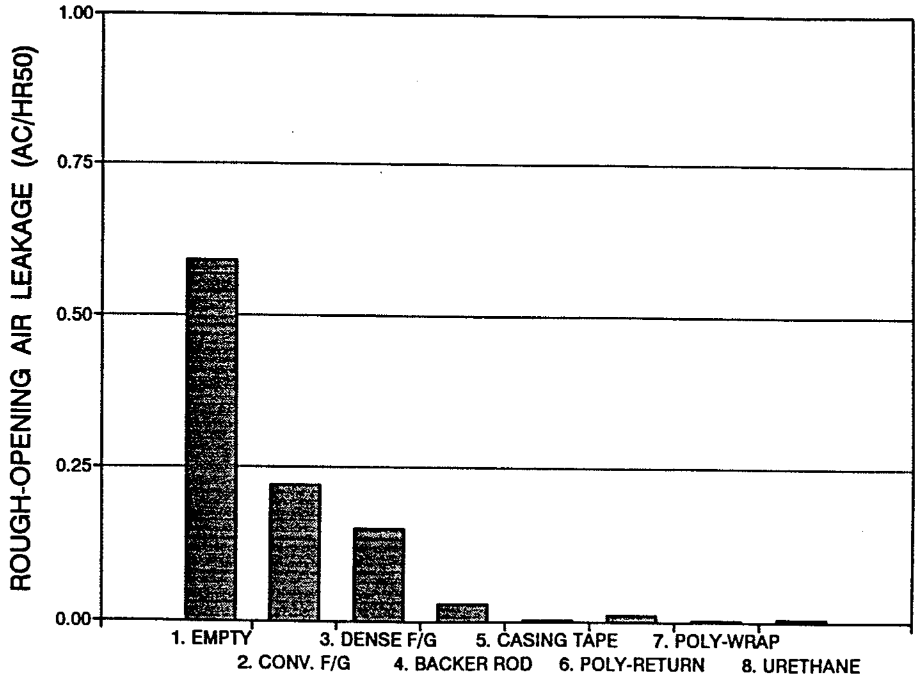
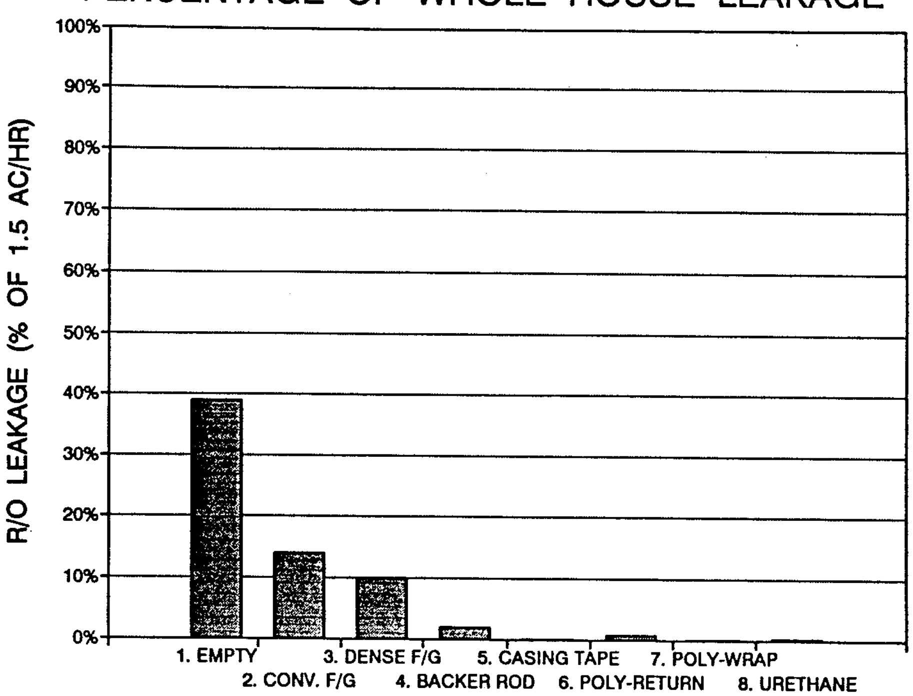


FIGURE 9

PERCENTAGE OF WHOLE HOUSE LEAKAGE



3.7 RECOMMENDATION TO STUDY THE LEAKAGE CHARACTERISTICS OF OTHER ENVELOPE COMPONENTS

The present study clearly highlighted the benefits of conducting controlled testing of alternative sealing methods on specific parts of the building envelope by identifying substantial improvements which could be achieved relative to conventional practice. While the study was only concerned with window and door rough-opening leakage, it is apparent that similar investigations, examining other envelope components, would also be useful. This would permit a better understanding of the relative significance of various envelope components relative to the total house leakage. Based on the experiences from the current study, it is recommended that such a testing program be established which considers all known or suspected leakage locations in a house including floor/wall intersections, foundation/floor intersections, interior partition wall/ceiling intersections, cantilevers, plumbing, heating and electrical penetrations, below grade service penetrations, etc.

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

- Significant differences were found in the air leakage characteristics of eight alternative methods of sealing the rough-opening cracks around windows and doors.

- The maximum air leakage occurred when the rough-opening was unsealed (Method 1) and the second largest using the conventional practice of packing fibreglass into the R/O space (Method 2). In contrast, leakage rates were found to be negligible for Methods 5 to 8 (casing tape, poly-return, poly-wrap and foamed-in-place urethane).

- The test results showed that substantial reductions in R/O leakage can be achieved using relatively simple sealing techniques such as foamed-in-place urethane (Method 8).

- A theoretical analysis was carried out to estimate the percentage of house leakage which would occur through the rough-openings in a typical 97 m^2 (1040 ft^2) bungalow with an assumed whole-house airtightness of 1.5 ac/hr_{50}. With unsealed R/Os (Method 1), 39% of the total house leakage would take place through the window and door rough-openings. Using the conventional sealing technique (Method 2), the R/O leakage would drop to 14%. However, if any of Methods 5, 6, 7 or 8 were used, the R/O leakage would be reduced to less than 1% of the total house leakage.

4.2 RECOMMENDATIONS

- The life expectancy of the various rough-opening sealing methods should be studied to verify their suitability for residential construction.

- A test program should be established to evaluate the air leakage characteristics of alternative methods for sealing other parts of the building envelope. This should include floor/wall intersections, foundation/floor intersections, interior partition wall/ceiling intersections, cantilevers, plumbing, heating and electrical penetrations, below grade penetrations, etc.

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