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REPORT NO. 5
Airtightness Performance of Twenty Detached Houses Over a Two-Year Period

Report of the Flair Homes
Enerdemo Canada/CHBA Mark XIV Project

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AIRTIGHTNESS PERFORMANCE OF
TWENTY DETACHED HOUSES OVER
A TWO YEAR PERIOD

PART OF THE
FLAIR HOMES ENERGY DEMO/CHBA FLAIR MARK XIV PROJECT
BY

G. PROSKIW, P.Eng.
UNIES Ltd.

SEPTEMBER, 1988

SUMMARY

Airtightness tests were performed on 20 new houses over a two year period as part of the Flair Homes Energy Demo/CHBA Flair Mark XIV project in Winnipeg. The houses were constructed with a variety of air/vapour barrier systems and three different types of main walls: 38x140 (2x6), framed walls with exterior insulated sheathing, and double wall construction. Polyethylene was used as the air/vapour barrier in six of the houses while the remaining 14 used the Airtight Drywall Approach (ADA). The houses had similar floor plans and were constructed by the same builder.

Both the polyethylene and ADA systems were found to be capable of meeting the airtightness requirements of the R-2000 Standard with the tightest structures being the double wall houses. No significant or permanent change in airtightness was observed for any of the houses over the two year monitoring period. Variations which did occur were judged to be due to normal house behaviour.

The application of stucco as an exterior wall finish was found to produce a noticeable improvement in airtightness for the ADA houses. Stucco was not observed to have a significant impact on airtightness of the double wall houses which used polyethylene as the air/vapour barrier.

Consistent sources of air leakage in the ADA houses were found to be the electrical outlets on exterior walls, despite the presence of commercially manufactured poly pans and cover plate foam gaskets. Window leakage was also noted in many houses and the frequency of this leakage increased over the monitoring period. A significant leakage source was also found to be an integrated mechanical system, which ducted large volumes of outdoor air into the house.

It was also concluded there is a need to re-examine the design pressure requirements for residential air barrier systems. Specifically, this should investigate how transient wind-induced pressure loads are resisted by air barrier systems and whether some portion of the load is taken by other envelope components such as the exterior finish, sheathing and the interior surface.

An air leakage detection system was proposed which would be suitable for use by builders to aid in the construction of low leakage houses. It would consist of a simple non-instrumented blower which would exhaust through a suitable opening such as a floor drain/sump pump or dryer vent to permit easy installation and use.

The airtightness testing program will continue until March, 1989.

RÉSUMÉ

Des mesures de l'étanchéité à l'air ont été effectuées sur une période de deux ans dans 20 maisons neuves construites à Winnipeg dans le cadre du projet Flair Mark XIV de Flair Homes Energy Demo et de l'ACCH. Différents systèmes pare-air-vapeur ont été incorporés à la construction de ces maisons. On a aussi fait appel à trois types de murs : à ossature de poteaux de 38 x 140 (2 x 6), à ossature de poteaux avec revêtement extérieur isolé et le double mur. Le polyéthylène a été utilisé dans six des maisons alors que la cloison sèche étanche à l'air a été incorporée aux 14 autres maisons. Les maisons avaient des plans d'étage semblables et ont été construites par le même entrepreneur.

Le polyéthylène et la cloison sèche étanche se sont tous deux avérés capables de satisfaire aux exigences d'étanchéité à l'air de la norme R-2000. Les maisons les plus étanches étaient celles à doubles murs. Aucun changement important ni permanent n'est survenu dans l'étanchéité à l'air des maisons au cours de la période de monitorage de deux ans. Les variations qui ont effectivement été mesurées sont attribuées au comportement normal d'une maison.

Les mesures indiquent que l'application de stucco comme revêtement extérieur de mur améliorait considérablement l'étanchéité à l'air des maisons à cloison sèche étanche. Le stucco n'avait pas d'effet significatif sur l'étanchéité à l'air des maisons à doubles murs dont le pare-air-vapeur est en polyéthylène.

Dans le cas des maisons à cloison sèche étanche à l'air, des fuites d'air importantes ont été localisées aux prises de courant sur des murs extérieurs malgré la présence de boîtiers de polystyrène commerciaux et de garnitures de mousse aux joints des plaques-couvercles. Des fuites par les fenêtres ont aussi été détectées dans de nombreuses maisons et la fréquence de ces fuites a augmenté au cours de la période de monitorage. D'importantes fuites d'air ont aussi été attribuées à un système mécanique intégré qui injectait d'importants volumes d'air extérieur dans la maison.

Les conclusions de l'étude indiquent la nécessité de réévaluer les pressions de calcul pour les systèmes pare-air. Plus précisément, il faudrait analyser de quelle façon les pare-air résistent aux pressions transitoires produites par le vent et déterminer si une partie de cette pression est

absorbée par les éléments de l'enveloppe comme le revêtement extérieur, le revêtement intermédiaire et la surface intérieure.

Un système de détection des fuites d'air a été proposé. Ce système pourrait être utilisé par les constructeurs afin de réaliser des maisons très étanches. Le système serait constitué d'une simple soufflante sans instruments qui évacuerait l'air par une ouverture appropriée comme un avaloir de sol, une pompe d'épuisement ou le tuyau d'une sécheuse, ce qui en faciliterait l'installation et l'utilisation.

Le programme de mesure de l'étanchéité à l'air continuera jusqu'en mars 1989.

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SECTION 1
INTRODUCTION

1.1 AIRTIGHTNESS

Airtightness is a measure of the resistance to air leakage provided by the building envelope. For leakage to occur, physical openings must be present in the envelope along with a pressure differential to drive the flow. In residential construction, pressure differentials are created by natural forces, specifically wind and stack action, and by mechanical systems such as ventilation equipment, furnaces and other household appliances.

From a building science perspective, air leakage has several negative effects. The most obvious is increased energy consumption for both the heating and cooling loads of the structure. This is most evident with "plug flow" leakage in which the air moves through discrete, relatively large holes in the envelope. If the leakage sites are dispersed over the envelope (such as in the dynamic wall approach), a portion of the heat moving through the insulated shell is recaptured as the infiltrating air moving through it is warmed. The second and perhaps most important effect is moisture movement into the envelope. It is generally recognized that the prime mechanism for moisture transport is air exfiltration. This process can deposit significant quantities of water in the envelope, usually in concentrated locations around the leakage sites. Moisture accumulations can lead to accelerated rotting of wood components, insulation wetting and staining/destruction of interior surfaces.

Leakage can reduce comfort levels in a home if infiltrating cold air is noticed by the occupants. Holes and cracks can also increase the transmission of outdoor noise to the interior since sound will travel through physical discontinuities in the envelope in a manner analogous to air flow.

Air infiltration can also degrade the quality of the indoor air if leakage occurs through an area where pollutants are present, such as through the surrounding soil (radon) or attached garages (various chemicals).

Thus, building science, comfort and air quality considerations all would suggest that it is desirable to maximize the airtightness of a house. In practice, of course, air leakage cannot be eliminated, but only controlled within prescribed limits. At present, the National Building Code of Canada does not contain any quantitative requirements for residential airtightness (Ref. 1). The R-2000 Home Program requires that all houses registered under the Program must have a measured leakage which does not exceed 1.5 air changes per hour at a pressure differential of 50 Pascals (ac/hr_{50}) or that the Normalized Leakage Area at 10 Pascals (NLA_{10}) does not exceed 0.7 cm^2/m^2 (Ref. 2). Compliance with the requirement must be verified by a blower door test performed in accordance with CAN/CGSB-149.10-M86 (Ref. 3).

1.2 OBJECTIVES

The objectives of the work described in this report were to monitor the airtightness of the 20 houses in the Flair Homes Energy Demo/CHBA Flair Mark XIV Project, to compare the performance of the different envelope systems used in the houses, and to identify opportunities for improving the design of airtightness systems in new construction.

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

The Flair Homes Energy Demo/CHBA Flair Mark XIV Project has three objectives:

1. To demonstrate and evaluate the performance of various low energy building envelope systems.
2. To demonstrate and evaluate the performance of various residential mechanical systems with particular emphasis on ventilation systems.
3. To transfer the knowledge gained in the project to the Canadian home building industry.

In addition, the project is structured to support the R-2000 Home Program funded by Energy, Mines and Resources Canada and administered by the Canadian Home Builders Association. The project acquired the Mark XIV designation when a substantial portion of the research priorities identified by the Technical Research Committee of the CHBA in 1983/84 were incorporated into the project.

Support for the project has been provided by Energy, Mines and Resources Canada under the Energy Demo Program and by Manitoba Energy & Mines under the Manitoba/Canada Conservation and Renewable Energy Demonstration Agreement (CREDA). Project management is the responsibility of Flair Homes (Manitoba) Ltd. Monitoring of the project houses is the responsibility of UNIES Ltd. and will continue until the spring of 1989.

To meet the project objectives, 20 houses employing various envelope and mechanical systems were constructed in 1985 and 1986 in the Genstar Development Co. Lakeside Meadows subdivision of Winnipeg. The houses were built by Flair Homes (Manitoba) Ltd. using two of their standard floor plans. The houses are divided into 10 pairs, with each pair having a different combination of envelope and mechanical systems. Conservation levels range from those of conventional Canadian houses to those which meet or exceed the R-2000 Standard. All of the houses were constructed with stucco as the exterior finish on three walls and wood, brick or stone was used on the fourth. A summary of the project houses is shown in Table 1 and more detailed descriptions are given in Ref. 4. A sample floor plan is shown in Figure 1.

TABLE 1
SUMMARY OF PROJECT HOUSES

HOUSE NO.	WALL CONSTRUCTION	BUILDING ENVELOPE AIR/VAPOUR BARRIER	BASEMENT INSULATION	ATTIC INSULATION	MECHANICAL SYSTEMS			
					SPACE HEATING	DHW HEATING	VENTILATION SYSTEM	VENT. DISTRIBUTION SYSTEM
1,2	38x140 (2x6), 38 mm (1½") Glasclad Insulated Sheathing c/w Tyvek Air Retarder (Reversed)	ADA, Paint Vapour Barrier	Interior Batts/Framing	Cellulose Fibre	Forced Air Electric Furnace	Electric Tank	HRV	Indirect Connection to Forced Air Heating System
3,4	38x140 (2x6), 38 mm (1½") Glasclad Insulated Sheathing c/w Tyvek Air Retarder (Reversed)	ADA, Paint Vapour Barrier	Interior Batts/Framing	Cellulose Fibre	Forced Air Electric Furnace	Electric Tank	HRV	Indirect Connection to Forced Air Heating System
5,6	38x140 (2x6), 38 mm (1½") Glasclad Insulated Sheathing c/w Tyvek Air Retarder (Reversed)	ADA, Paint Vapour Barrier	Interior Batts/Framing	Cellulose Fibre	Forced Air Electric Furnace	Electric Tank	HRV	Indirect Connection to Forced Air Heating System
7,8	38x140 (2x6)	ADA, Paint Vapour Barrier	Interior Batts/Framing	Cellulose Fibre	Forced Air Electric Furnace	Electric Tank	Central Exhaust	Fresh Air Intake to Return Air Plenum of Furnace
9,10	38x140 (2x6)	6 mil Poly	Interior Batts/Framing	Cellulose Fibre	Forced Air Naturally Aspirated, Gas Furnace	Gas Tank	Bathroom Exhaust Fan	None
11,12	38x140 (2x6), 51 mm (2") Glasclad Insulated Sheating c/w Tyvek Air Retarder (Taped)	ADA Limited Gaskets, Paint Vapour Barrier	76mm (3") Exterior Baseclad and 25mm (1") Glasclad Underslab	Blown Fiberglass	Electric Baseboards and Heat Pump	Heat Pump, Int. with Vent. System	Exhaust-only Heat Pump Int. with Space and DHW Systems	Envelope Leakage and Exhaust Vent. Heat Recovery
13,14	38x140 (2x6), 51 mm (2") Glasclad Insulated Sheating c/w Tyvek Air Retarder (Taped)	ADA Limited Gaskets, Paint Vapour Barrier	Interior Batts/Framing	Blown Fiberglass	Forced Air Electric Furnace	Electric Tank	HRV	Envelope Leakage and Unbalanced Heat Recovery Ventilator
15,16	Double Wall	6 mil Poly	Interior Batts/Framing	Cellulose Fibre	Air-to-Air Heat Pump Int. with Vent. and DHW Systems	2 Tank System Int. with Space Heating and Vent. Systems	A/A Heat Pump Int. with Forced Air Heating System	Combined Forced Air Heating and Ventilation System
17,18	Double Wall	6 mil Poly	Interior Batts/Framing	Cellulose Fibre	Electric Baseboards	Electric Tank	A/A Heat Pump HRV and Duct Heater	Dedicated Supply-only Ventilation System
19,20	38x89 (2x4), 51 mm (2") SM Insulated Sheathing	ADA, Paint Vapour Barrier	51mm (2") Exterior SM and Interior Batts/Framing	Cellulose Fibre	Electric Baseboards	Electric Tank	HRV	Dedicated Supply-only Ventilation System

LEGEND

Int. - Integrated
c/w - Complete With
ADA - Airtight Drywall Approach

Vent. - Ventilation
DHW - Domestic Hot Water
A/A - Air to Air

HRV - Heat Recovery Ventilator


DINING.
KITCHEN.
BATH
MR. BEDROOM
LIVING
ENTRY
BR#3
BR #2
8.0m (26'-3")
12.27m (40'-3")

FIGURE 1

SECTION 2
AIR BARRIERS

2.1 AIR BARRIER THEORY

The primary mechanism used to control air leakage through building envelopes is the air barrier which may consist of a single material or an assembly of materials. The main requirements for air barriers are generally defined as:

1. Low permeability to air flow
2. Structural strength to withstand the pressure loads
3. Continuity to reduce leakage
4. Durability to last the life of the building
5. Rigidity to provide pressure equalization behind exterior cladding

In new residential construction sheet polyethylene is the most commonly used material. Joints in the poly may be sealed with caulking or simply stapled in place. In most applications, it is also used as the vapour barrier.

A second system which has gained acceptance is the Airtight Drywall Approach (ADA) which relies upon the drywall to function as the air barrier with paint or poly as the vapour barrier. Leakage at joints between major envelope components is controlled through the use of strategically located gaskets.

In the last few years, sheet materials such as spun-bonded polyolefin (SBPO), which function as air retarders but not vapour barriers, have also come into wider use. This system has the advantage that it can be placed at any location within the envelope assembly whereas poly must be located close to the warm side of the assembly to prevent condensation. If an SBPO layer is used as an exterior air barrier, it has the further advantage of protecting the insulation from "wind-washing".

At present, there is considerable debate about which system is the most appropriate for Canadian conditions. The so-called "poly approach" is usually viewed as a more traditional and hence better-understood technique for new construction while the ADA approach is argued to be better able to withstand the pressure forces to which the air barrier will be exposed. The sheet SBPO approach meanwhile, is finding application in combination with both systems.

One reason for the debate over residential air barrier design is the requirement for structural strength, specifically the maximum load the air barrier must be designed to resist. These loads, as previously noted, are due to wind action, stack effect and the operation of mechanical systems. In residential construction, pressure loads due to stack effect seldom exceed 10 to 20 Pascals while loads due to the mechanical systems may be slightly larger. Wind action however, can generate pressures on an exposed building surface of over 1000 Pascals. If the air barrier is intended to withstand the entire pressure differential experienced by the envelope assembly, then its structural design will be dictated by the wind loading.

2.2 BUILDING CODE REQUIREMENTS

Part 9 of the 1985 Building Code of Canada requires conformance of structural members and connections with Part 4 which deals with structural design (see Subsection 9.4.1). Subsection 4.1.8.1 describes how live loads due to wind are to be calculated:

$$P = q \, Ce \, Cg \, Cp \qquad (1)$$

where:

P = the specified external pressure

q = the reference velocity pressure

Ce = the exposure factor

Cg = the gust factor

Cp = the external pressure coefficient averaged over the area under consideration

The velocity pressure, q, used for the design of structural members is based on the wind speed which has 1 chance in 30 of being exceeded in any one year. Values for q are found in the Supplement to the National Building Code (Ref. 5) which tabulates appropriate values for over 600 locations in Canada. These values are typically based on measurements taken at a height of 10 m (30 ft.) above the ground in an area clear of significant obstructions. No credit is given to structures built in locations, such as in urban environments, where shading from the wind may occur. Some typical as well as extreme values of q are:

Location	Hourly Wind Pressures (1/30), Pascals
Winnipeg	420
Vancouver	550
Edmonton	400
Toronto	480
Halifax	520
Minimum (several locations)	240
Maximum (Coral Harbour, N.W.T.)	1200

The exposure factor, Ce, accounts for the increase in wind speed with increasing height above the ground. For heights up to 6 m (20 ft.), it is equal to 0.9 and for building heights between 6 and 12 m (20 to 39 ft.), its value is 1.0.

The gust factor, Cg, accounts for the gusting action of wind and is typically equal to 2.0 for entire buildings.

The pressure coefficient, Cp, accounts for the non-uniformity of wind loads on exposed surfaces and the fact that the entire velocity pressure is not converted into an applied load because of the aerodynamic effects of wind blowing over an immersed body. Appropriate values are usually determined empirically based on wind tunnel data and field measurements.

In practice, the major uncertainty lies in defining values for Cp and, to a lesser degree, Cg. Values for the product CpCg have been determined and are documented in Chapter 4 of the Supplement. Using this source, the maximum value of CpCg likely to be encountered by a typical house wall would be approximately -2.1 (the minus sign indicating a suction force).

Using the above information, one can determine the design pressures which the envelope will be structurally required to withstand:

Location	Design Pressure, Pascals
Winnipeg	880
Vancouver	1160
Edmonton	840
Toronto	1010
Halifax	1090
Minimum (several locations)	500
Maximum (Coral Harbour, N.W.T.)	2520

2.3 VARIATIONS IN AIRTIGHTNESS

Airtightness is not a fixed performance characteristic of a structure but can increase, decrease or fluctuate over time. Persily (Ref. 6) observed seasonal variations of 25% in a single, unoccupied wood frame structure located in New Jersey using ac/hr$_{50}$ as the measurement parameter. He postulated that the changing moisture content of framing members was responsible for these variations since it might vary the crack dimensions along leakage routes. Kim and Shaw (Ref. 7) explored this issue in more detail in two unoccupied structures in Ottawa and reported seasonal variations of approximately 20% with the maximum ac/hr$_{50}$ values occurring in late winter and minimum values in late summer and early fall. They also found a strong relationship between the level of airtightness and the humidity ratio of the indoor air which further supports the swelling/shrinking of wood frame members theory.

Howell and Mayhew (Ref. 8) tested six houses in Edmonton over a period of 1.5 to 2 years. They found that the four houses constructed with the ADA system were tighter than the two built using conventional practice (although "conventional" was different from that of the "conventional" houses in this project). At the end of the test period, the ADA houses were observed to have become leakier while the conventional houses were unchanged. The change was attributed to degradation of the caulked joints between the basement drywall and the floor joists (this technique was not used on the Flair houses).

European experiences seem to be slightly different. The Air Infiltration Centre publication TN 16 (Ref. 9) observed that changes usually occur in the first year after construction. They report examples of five Swedish houses which averaged a 70% increase in ac/hr_{50} values in the first year and then remained constant. Three British houses were reported to have experienced an average 83% increase in the first year. Carlsson and Kronvall (Ref. 10) described measurements on 15 Swedish "timber-framed" houses tested at the time of completion and then after a period of from 1.5 to 4.5 years. They found that airtightness levels generally remained constant. It is unknown how applicable these results are to North American construction.

SECTION 3
MONITORING

3.1 DESCRIPTION OF THE AIRTIGHTNESS MONITORING PROGRAM

Airtightness testing has been conducted on the 20 houses in the Flair project since March, 1986 and will continue until March, 1989. Tests are conducted two to four times per year and are performed in accordance with CAN/CGSB-149.10-M86 "Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method".

At the time of the initial tests in March, 1986, Houses #1 to #10 were complete while #11 to #20 were complete except for the stucco which was applied shortly afterwards.

Houses #1 to #10 were framed by a single crew while Houses #11 to #20 were framed by a second crew. Both were very experienced with energy-efficient construction.

During the testing period, regular monthly contact has been maintained with the houses and their occupants to identify changes which may have affected the structures. Those changes which have occurred are considered typical for new houses, such as degradation of door and window weatherstripping, cracking of the basement floor slab and general movement of the structure. Some development of the basement has taken place in eight of the houses (#1, #9, #10, #13, #14, #15, #17 and #20), but this is not considered to have had a major impact on the airtightness.

SECTION 4
RESULTS

4.1 INTRODUCTION

Summaries of the airtightness test results are shown in Tables 2 and 3 which give measured values of the air change rates at 50 Pascals (ac/hr$_{50}$) and the Normalized Leakage Areas (NLA$_{10}$). Table 4 gives the absolute and percentage changes in airtightness between the initial test (defined as the test conducted with the house complete and the stucco in place) and the most recent test. A negative percentage change in airtightness is defined as that produced by the house becoming more airtight.

Maximum monthly wind speeds and the corresponding velocity pressures recorded during the monitoring period are shown in Figs. 2 and 3. These were measured at 10 m above ground level at Winnipeg International Airport, located approximately 15 km from the project site. It should be noted that 19 of the 20 project houses were located on the extreme northern edge of urban development with little protection against winds from that direction.

4.2 HOUSES #1 TO #6

The ADA system was used for the main walls and ceilings with paint serving as the vapour barrier on these houses. An interstitial air retarder was incorporated using an untaped SBPO layer attached to the warm side of the rigid insulated sheathing (reversed Glasclad). The basements used interior framing and insulation with poly as the vapour barrier and concrete as the air barrier.

The airtightness results are plotted in Fig. 4. As shown, the initial airtightness performance of the houses was at or slightly below the R-2000 requirement. Airtightness levels then fluctuated over the monitoring period and while some noticeable variations did occur, particularly in the NLA$_{10}$, no permanent, systematic change was observed.

4.3 HOUSES #7 AND #8

These two houses also used the ADA system for the main walls and

TABLE 2
AIRTIGHTNESS TEST RESULTS
Air Changes Per Hour @ 50 Pascals (ac/hr$_{50}$)

HOUSE #	DATE OF TEST					
1	Mar.25/86 1.669		Nov.21/86 1.475	Feb.14/87 1.568			Feb.29/88 1.479
2		Jul.16/86 1.053	Nov.24/86 1.171	Feb.18/87 1.119	Jul.6/87 0.977	Nov.18/87 1.047	Mar.8/88 1.169
3	Mar.15/86 1.509		Nov.25/86 1.539	Feb.15/87 1.852	Jul.8/87 1.486		Mar.4/88 1.689
4	Mar.25/86 1.455		Nov.26/86 1.311	Feb.17/87 1.299	Jul.13/87 1.115		Mar.3/88 1.415
5	Mar.24/86 1.118		Nov.26/86 1.264	Feb.20/87 1.104	Jul.9/87 1.144		Mar.2/88 1.049
6	Mar.15/86 1.205		Nov.24/86 1.255	Feb.14/87 1.306	Jul.10/87 1.187		Feb.29/88 1.417
7	Mar.25/86 1.166		Nov.26/86 1.522	Feb.16/87 2.196			
8	Mar.14/86 1.588		Dec.1/86 1.392	Feb.20/87 1.740	Jul.20/87 1.342		Mar.2/88 1.444
9	Mar.24/86 1.622	Jul.16/86 1.655	Nov.24/86 1.741	Feb.15/87 1.838	Jul.23/87 1.484	Nov.25/87 1.684	Mar.2/88 1.781
10	Mar.26/86 1.281	Jul.14/86 1.152	Nov.21/86 1.429	Feb.21/87 1.386	Jul.14/87 1.167	Nov.30/87 1.038	Mar.8/88 1.032
11	Mar.22/86 1.694*	Jun.11/86 0.892	Nov.26/86 0.962	Feb.16/87 0.881	Jul.9/87 0.879		Mar.2/88 1.007
12	Mar.23/86 1.593*	May 28/86 1.120	Nov.20/86 0.960	Feb.16/87 0.979	Jul.8/87 0.878		Mar.9/88 0.980
13	Apr.25/86 1.268*	Jul.18/86 0.836	Dec.8/86 0.830	Feb.18/87 0.761	Jul.8/87 1.043		Mar.9/88 0.938
14	Mar.22/86 1.319*	Jun.10/86 1.136		Feb.19/87 0.955	Jul.15/87 0.989		Mar.3/88 1.155
15	Mar.15/86 1.473*	May 7/86 1.328	Nov.20/86 1.257	Feb.20/87 1.152			Mar.3/88 1.104
16	Mar.26/86 1.258*	Jul.14/86 1.292	Nov.21/86 1.382	Feb.17/87 1.405			Mar.9/88 1.519
17	Mar.24/86 0.549*	Jul.29/86 0.363	Nov.20/86 0.713	Feb.13/87 0.437	Aug.25/87 0.570	Dec.1/87 0.384	Mar.24/88 0.564
18	Mar.16/86 0.486*	Jul.28/86 0.416	Nov.29/86 0.478	Feb.19/87 0.480	Jul.22/87 0.385	Nov.24/87 0.418	Mar.2/88 0.434
19	Mar.23/86 1.049*	Jul.14/86 0.807	Dec.8/86 0.842	Feb.17/87 0.908	Jul.16/87 0.715		Feb.29/88 1.038
20	Mar.23/86 1.126*	Jul.25/86 0.708	Nov.25/86 0.815	Feb.13/87 0.731	Jul.17/87 1.008		Mar.8/88 0.797

NOTES

1. * Indicates no stucco.

TABLE 3
AIRTIGHTNESS TEST RESULTS
Normalized Leakage Area @ 10 Pascals (NLA_{10})

HOUSE #	DATE OF TEST					
1	Mar.25/86 0.577		Nov.21/86 0.467	Feb.14/87 0.380			Feb.29/88 0.477
2		Jul.16/86 0.410	Nov.24/86 0.603	Feb.18/87 0.451	Jul.6/87 0.400	Nov.18/87 0.425	Mar.8/88 0.503
3	Mar.15/86 0.513		Nov.25/86 0.517	Feb.15/87 0.762	Jul.8/87 0.564		Mar.4/88 0.656
4	Mar.25/86 0.585		Nov.26/86 0.482	Feb.17/87 0.551	Jul.13/87 0.437		Mar.3/88 0.643
5	Mar.24/86 0.444		Nov.26/86 0.450	Feb.20/87 0.432	Jul.9/87 0.334		Mar.2/88 0.341
6	Mar.15/86 0.473		Nov.24/86 0.488	Feb.14/87 0.613	Jul.10/87 0.366		Feb.29/88 0.581
7	Mar.25/86 0.433		Nov.26/86 0.637	Feb.16/87 0.981			
8	Mar.14/86 0.857		Dec.1/86 0.636	Feb.20/87 0.745	Jul.20/87 0.620		Mar.2/88 0.664
9	Mar.24/86 0.560	Jul.16/86 0.587	Nov.24/86 0.566	Feb.15/87 0.623	Jul.23/87 0.596	Nov.25/87 0.641	Mar.2/88 0.659
10	Mar.26/86 0.588	Jul.14/86 0.418	Nov.21/86 0.642	Feb.21/87 0.805	Jul.14/87 0.404	Nov.30/87 0.441	Mar.8/88 0.392
11	Mar.22/86 0.753*	Jun.11/86 0.345	Nov.26/86 0.396	Feb.16/87 0.317	Jul.9/87 0.282		Mar.2/88 0.370
12	Mar.23/86 0.835*	May 28/86 0.468	Nov.20/86 0.417	Feb.16/87 0.329	Jul.8/87 0.318		Mar.9/88 0.405
13	Apr.25/86 0.569*	Jul.18/86 0.360	Dec.8/86 0.314	Feb.18/87 0.401	Jul.8/87 0.437		Mar.9/88 0.403
14	Mar.22/86 0.754*	Jun.10/86 0.490		Feb.19/87 0.516	Jul.15/87 0.393		Mar.3/88 0.467
15	Mar.15/86 0.774*	May 7/86 0.655	Nov.20/86 0.597	Feb.20/87 0.547			Mar.3/88 0.539
16	Mar.26/86 0.677*	Jul.14/86 0.675	Nov.21/86 0.714	Feb.17/87 0.711			Mar.9/88 0.777
17	Mar.24/86 0.278*	Jul.29/86 0.154	Nov.20/86 0.340	Feb.13/87 0.166	Aug.25/87 0.250	Dec.1/87 0.132	Mar.24/88 0.307
18	Mar.16/86 0.259*	Jul.28/86 0.227	Nov.29/86 0.190	Feb.19/87 0.192	Jul.22/87 0.155	Nov.24/87 0.138	Mar.2/88 0.171
19	Mar.23/86 0.444*	Jul.14/86 0.232	Dec.8/86 0.320	Feb.17/87 0.347	Jul.16/87 0.279		Feb.29/88 0.402
20	Mar.23/86 0.560*	Jul.25/86 0.298	Nov.25/86 0.287	Feb.13/87 0.208	Jul.17/87 0.444		Mar.8/88 0.299

<u>NOTES</u>

1. * Indicates no stucco.

TABLE 4

CHANGE IN AIRTIGHTNESS BETWEEN INITIAL AND MOST RECENT TESTS

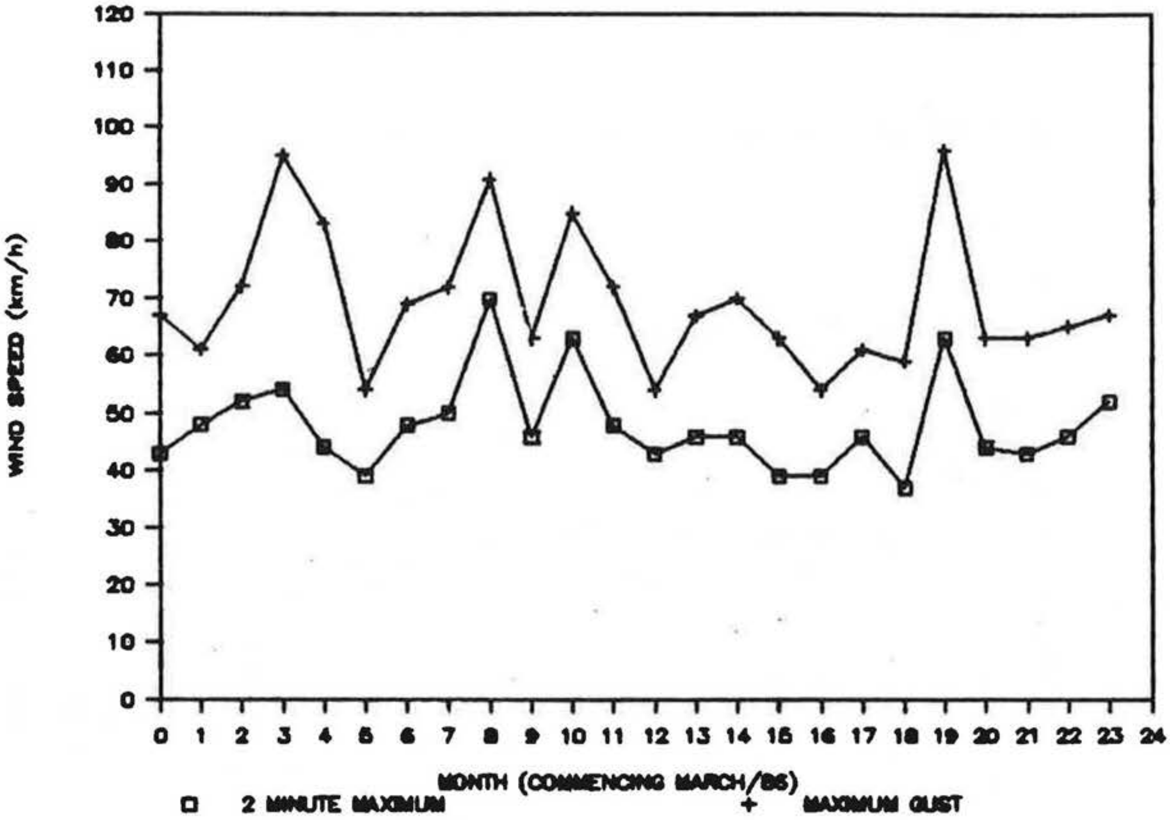
HOUSE #	AC/HR_{50}				NLA_{10}				MONTHS BETWEEN INITIAL AND MOST RECENT TEST
	INITIAL	FINAL	ABS. CHG.	%	INITIAL	FINAL	ABS. CHG.	%	
1	1.669	1.479	-0.189	-11.4	0.577	0.477	-0.101	- 17.5	23
2	1.053	1.169	0.117	11.1	0.410	0.503	0.093	22.7	20
3	1.509	1.689	0.180	11.0	0.513	0.656	0.143	27.9	24
4	1.455	1.415	-0.040	- 2.8	0.585	0.643	0.058	9.9	23
5	1.118	1.049	-0.069	- 6.2	0.444	0.341	-0.103	- 23.2	23
6	1.205	1.417	0.212	17.6	0.473	0.581	0.108	22.9	23
7	1.166	2.196	1.029	88.3	0.433	0.981	0.548	126.4	11
8	1.588	1.444	-0.145	- 9.1	0.857	0.664	-0.193	- 22.5	24
9	1.622	1.781	0.160	9.9	0.559	0.659	0.100	17.0	23
10	1.281	1.032	-0.248	-19.4	0.588	0.392	-0.197	- 33.4	23
11	0.892	1.007	0.115	12.8	0.345	0.370	0.026	7.5	21
12	1.120	0.980	-0.140	-12.5	0.468	0.405	-0.063	- 13.4	21
13	0.836	0.938	0.101	12.1	0.360	0.403	0.043	12.1	20
14	1.136	1.155	0.019	1.7	0.490	0.467	-0.023	- 4.7	21
15	1.328	1.104	-0.225	-16.9	0.655	0.539	-0.115	- 17.6	22
16	1.292	1.519	0.227	17.6	0.675	0.777	0.102	15.1	20
17	0.363	0.564	0.200	55.2	0.154	0.307	0.153	99.9	20
18	0.416	0.434	0.018	4.3	0.227	0.171	-0.056	- 24.7	20
19	0.807	1.038	0.231	28.6	0.232	0.402	0.170	73.4	20
20	0.708	0.797	0.089	12.6	0.298	0.299	0.001	0.4	20

MEANS:	AC/HR_{50}		NLA_{10}	
	ABS. CHG.	%	ABS. CHG.	%
#1 - #6	0.035	3.4	0.033	7.1
#7 & #8	0.442	39.6	0.177	51.9
#9 & #10	-0.044	- 4.8	-0.048	- 7.7
#11 - #14	0.024	3.5	-0.004	0.3
#15 - #18	0.055	15.0	0.021	18.2
#19 & #20	0.160	20.6	0.086	36.9

NOTES

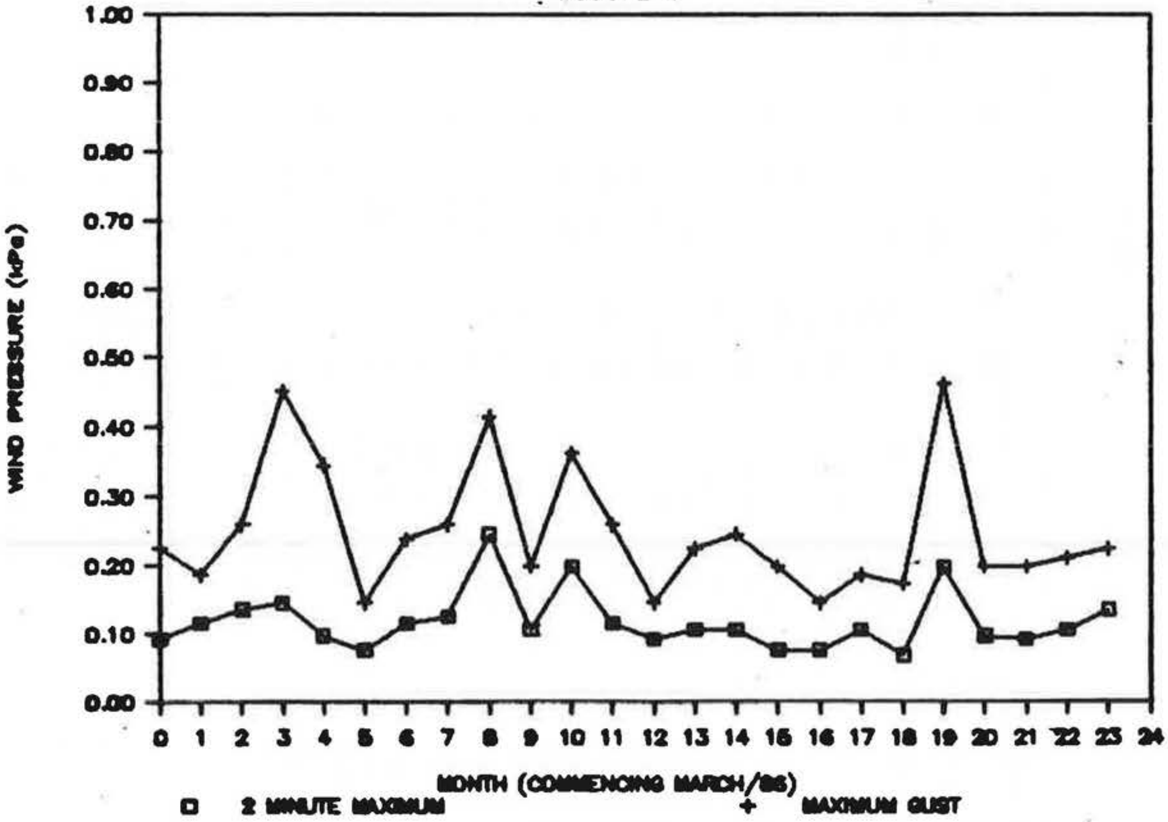
1. Nomenclature convention: a negative (-) change in airtightness indicates the structure became more airtight.

FIGURE 2



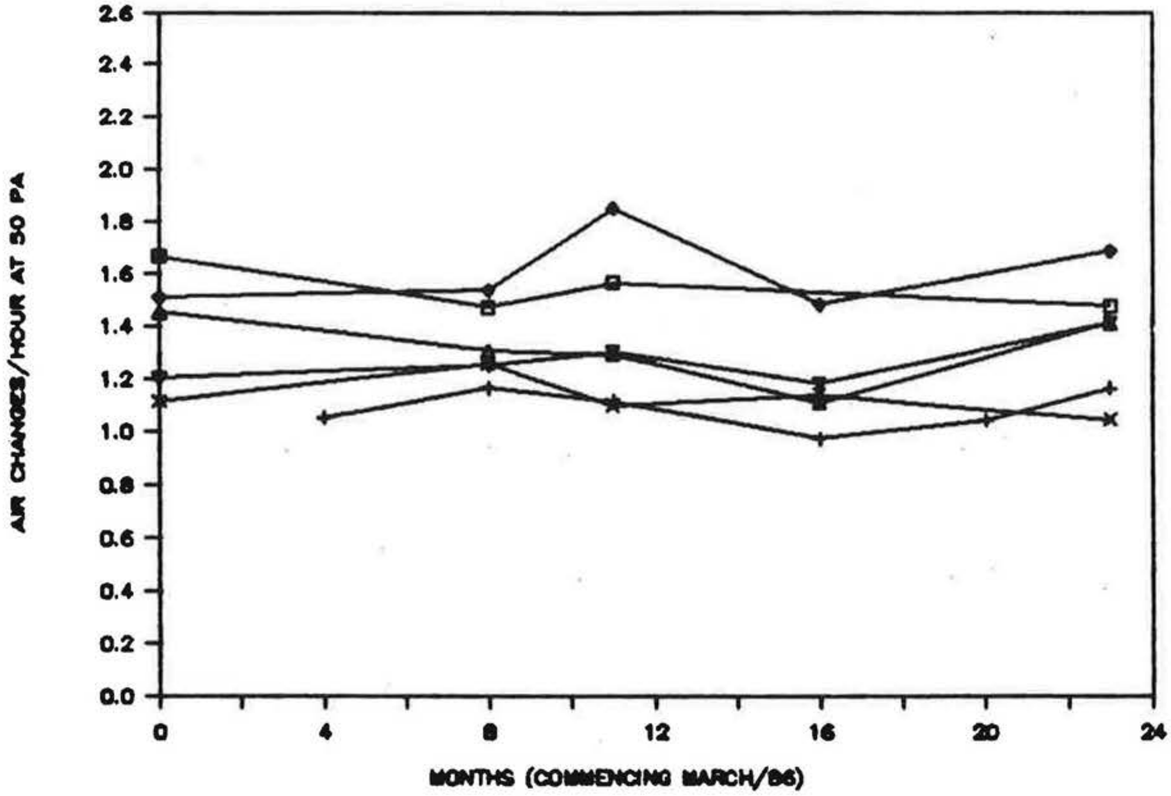
MAXIMUM MONTHLY WIND SPEEDS (AIRPORT DATA)

FIGURE 3

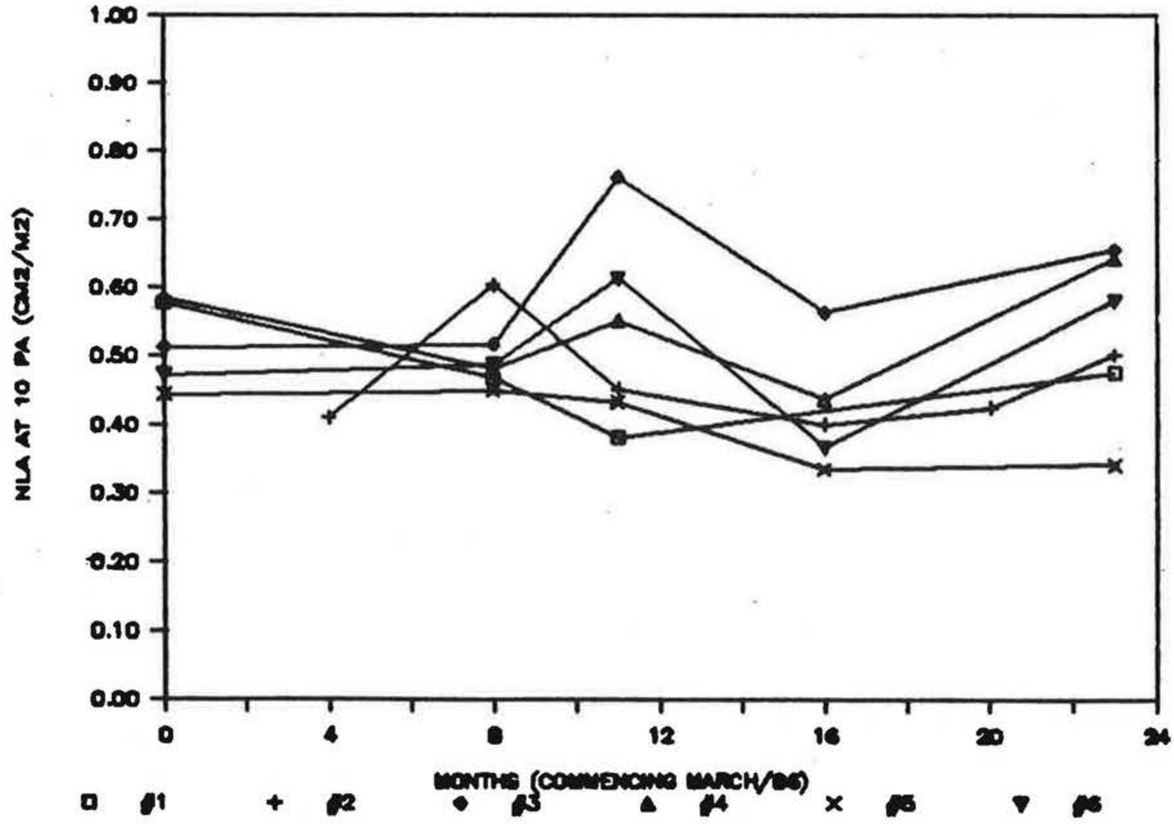


MAXIMUM MONTHLY WIND PRESSURES (AIRPORT DATA)

FIGURE 4



a) AIR CHANGES PER HOUR AT 50 PASCALS



b) NORMALIZED LEAKAGE AREA AT 10 PASCALS

HOUSES #1 TO #6 (MARCH/86 TO FEBRUARY/88)

ceilings but differed from the previous ones by using a standard 38x140 (2x6) wall without any insulated sheathing or an SBPO air retarder. The basement configurations were the same as Houses #1 to #6. The houses were not designed to the R-2000 Standard.

The airtightness results, plotted in Fig. 5 were less consistent, with House #7 displaying slightly erratic behaviour although the last test was performed in February, 1987. Results for House #8 were more stable over the monitoring period.

4.4 HOUSES #9 AND #10

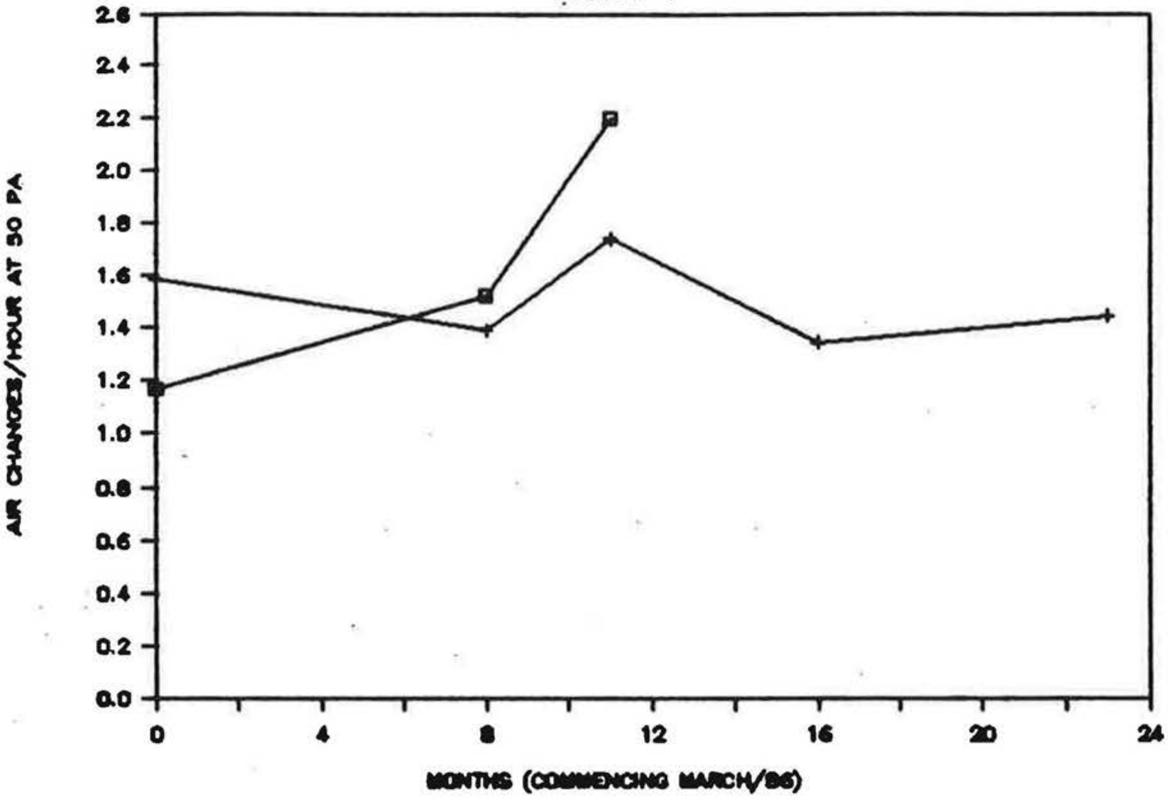
These two houses were conventional structures typical of current Manitoba construction. A 6 mil poly vapour barrier was used throughout but no extra effort was made to seal joints or otherwise make the structure airtight. Joints were overlapped and stapled but no caulking was used. Basement details were the same as those on Houses #1 to #8.

As expected, these were the leakiest structures in the project, as Fig. 6 indicates. Although not designed to the R-2000 Standard, both initially met the airtightness requirement using the NLA_{10} parameter. This can likely be attributed to the builder's previous experience with energy-efficient construction and the use of stucco and the cast-in-place floor system which minimizes leakage at the critical wall/floor/foundation intersection.

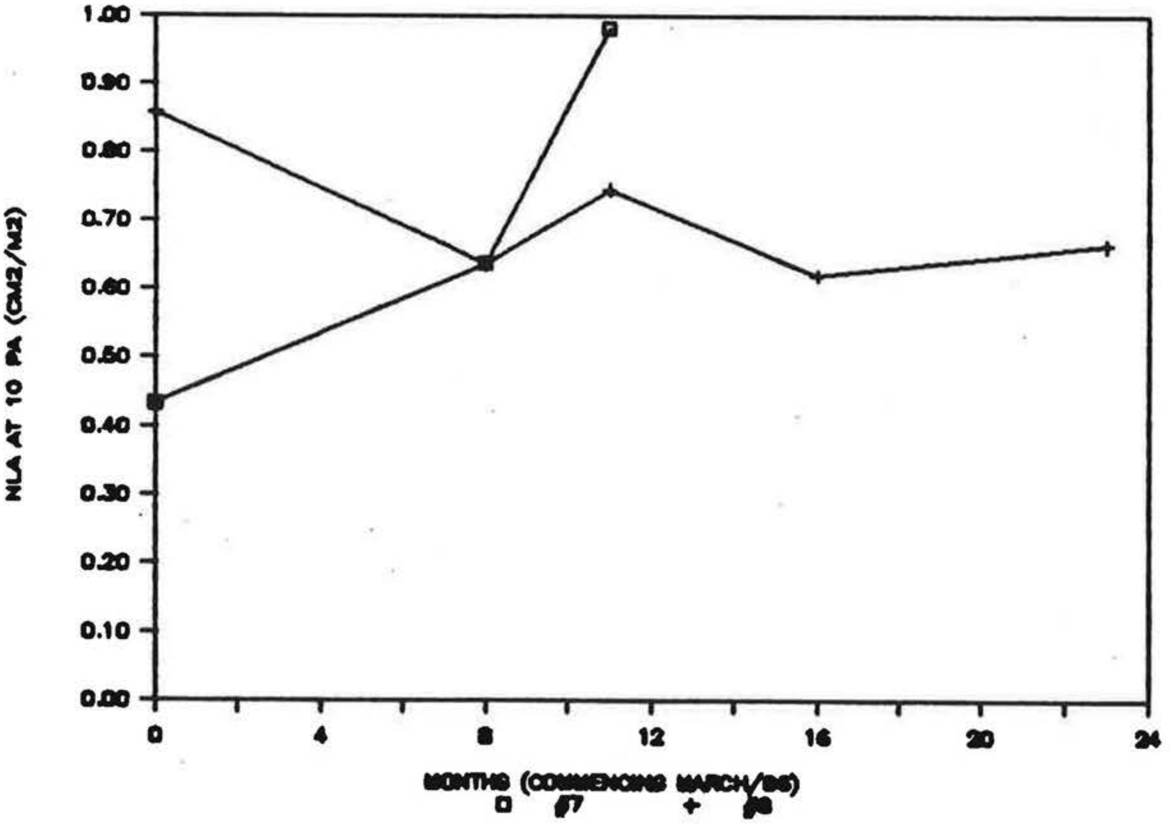
4.5 HOUSES #11 TO #14

These four houses were built using the Fiberglas Canada Inc. Low Energy House System (FCI LEHS). This can be broadly described as a modified ADA technique which relies upon a taped, SBPO exterior air retarder against a rigid board insulation. The system is not designed to form a tight air barrier but rather is intended to permit controlled amounts of leakage to occur such that infiltrating air is preheated by heat being conducted outwards through the building's envelope. Gaskets were used only around electrical fixtures on exterior walls and around windows and doors. Houses #11 and #12 used exterior rigid glass fibre insulation for the basement walls and floor slab while #13 and #14 used conventional

FIGURE 5



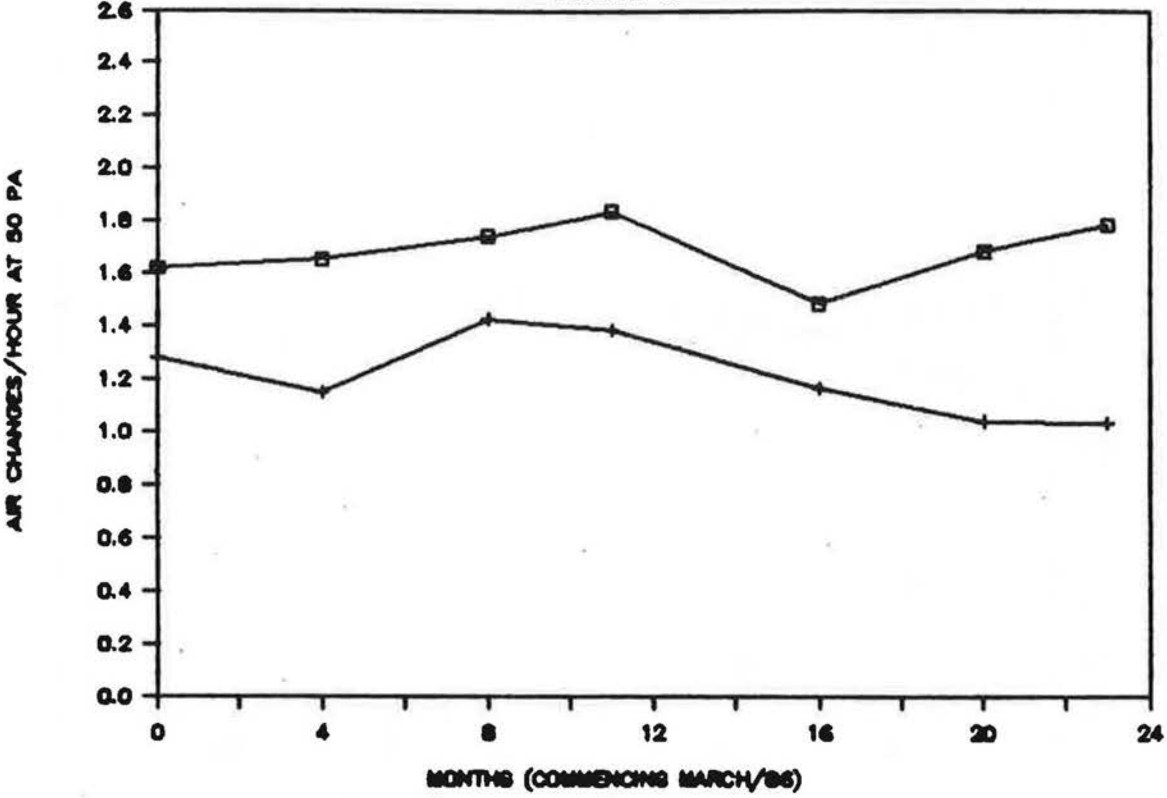
a) AIR CHANGES PER HOUR AT 50 PASCALS



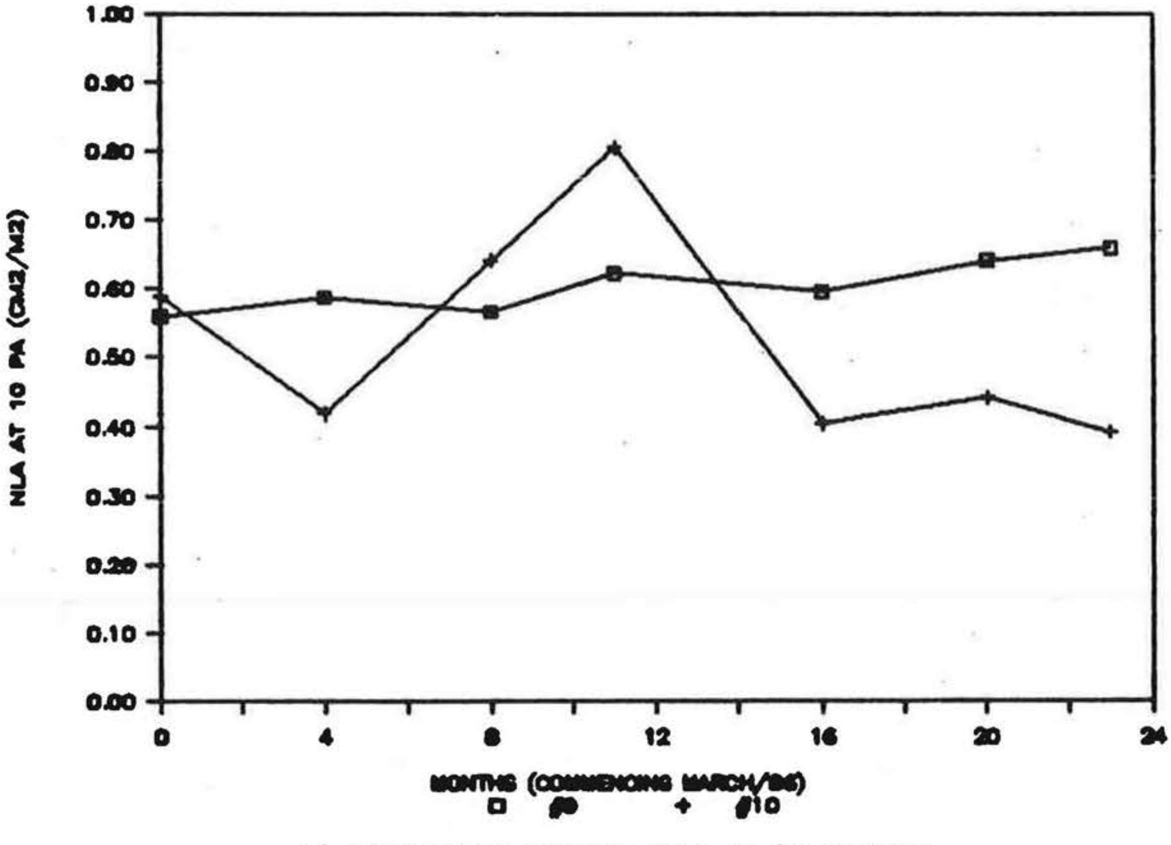
b) NORMALIZED LEAKAGE AREA AT 10 PASCALS

HOUSES #7 AND #8 (MARCH/86 TO FEBRUARY/88)

FIGURE 6



a) AIR CHANGES PER HOUR AT 50 PASCALS



b) NORMALIZED LEAKAGE AREA AT 10 PASCALS

HOUSES #9 AND #10 (MARCH/86 TO FEBRUARY/88)

interior framing and insulation for the walls and no sub-slab insulation. The stucco was applied between the first and second tests on all four houses. The airtightness results are plotted in Fig. 7.

Stucco was observed to have a significant impact on airtightness, producing an average reduction of 31% in ac/hr_{50} and 43% in NLA_{10}. Following application of the stucco, the airtightness remained constant with no indication of significant degradation or improvement. The two different methods of insulating the basement do not appear to have had a major impact on performance.

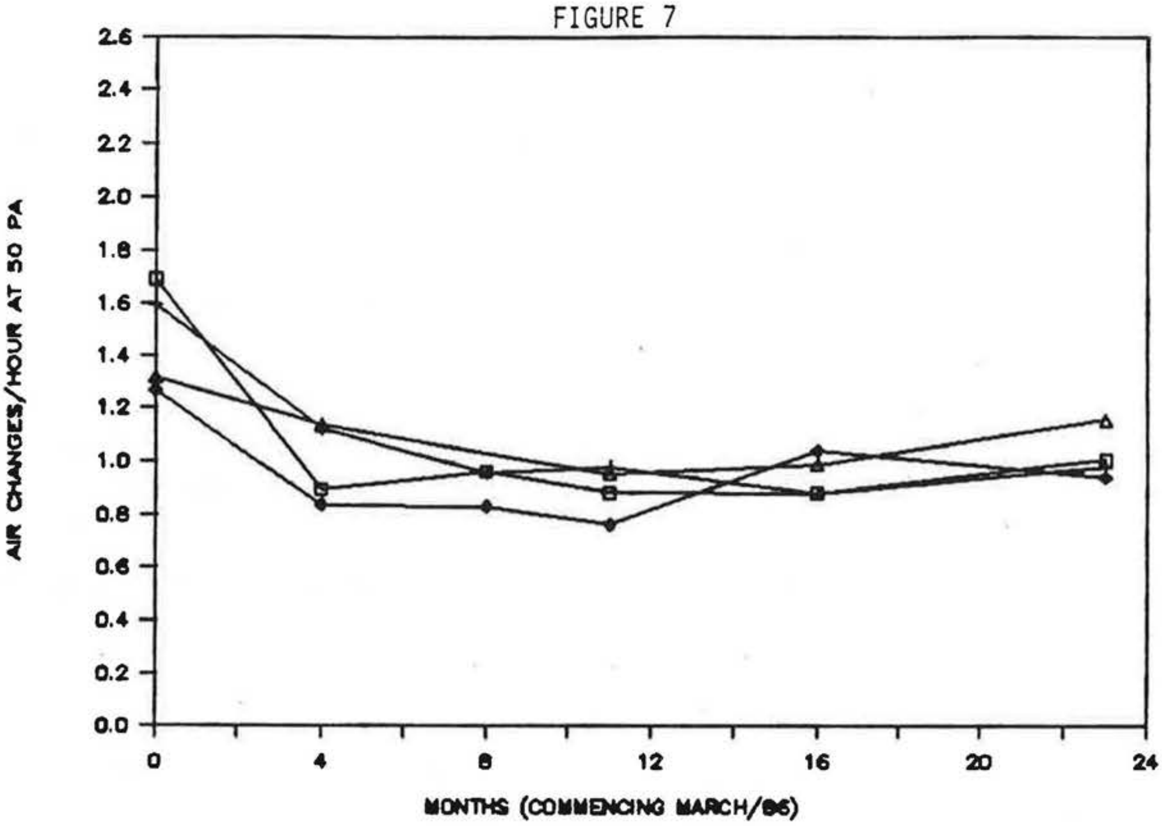
4.6 HOUSES #15 TO #18

These four houses were built using the double wall technique in which poly, sandwiched between the inner and outer walls, serves as both the air and vapour barrier. Poly was also used as the air/vapour barrier on the ceiling. All joints were carefully caulked to minimize leakage. Conventional framing and insulation were used in the basement with a poly vapour barrier. The stucco was applied between the first and second airtightness tests. Envelope construction was identical for the four houses, but two different types of mechanical systems were installed: in Houses #15 and #16, an integrated mechanical system which ducted large volumes of outdoor air through the house; while in Houses #17 and #18, conventional Heat Recovery Ventilators.

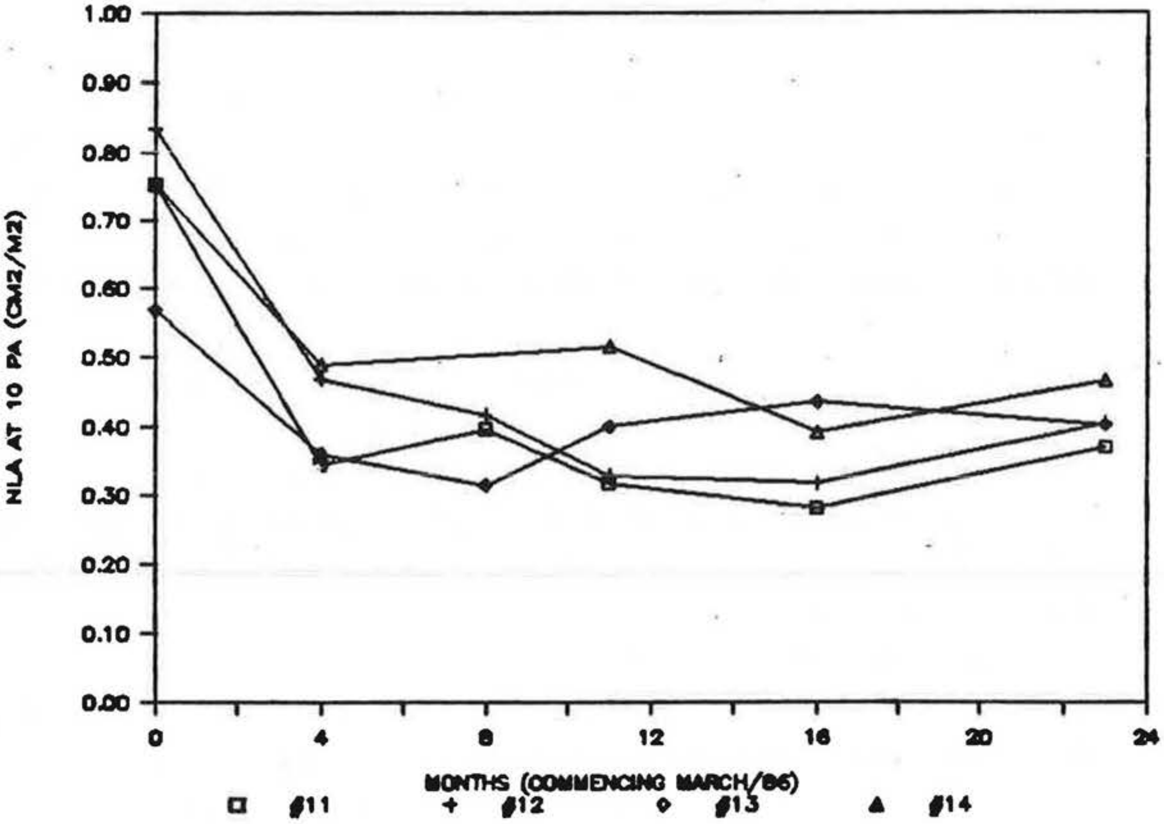
The airtightness results, plotted in Fig. 8 are quite interesting. Despite identical construction of the envelopes, Houses #15 and #16 were consistently leakier during all tests. Examination revealed significant air leakage through the (outdoor air) ductwork of the mechanical system as well as the unit itself. In particular, leakage was noted at the filter housings and vibration isolators.

Houses #17 and #18 were the tightest in the project, with measured airtightness values approximately one third of the maximum permitted by the R-2000 Standard. There was no evidence of significant change in airtightness during the monitoring period. The application of stucco had no apparent effect on the airtightness.

FIGURE 7

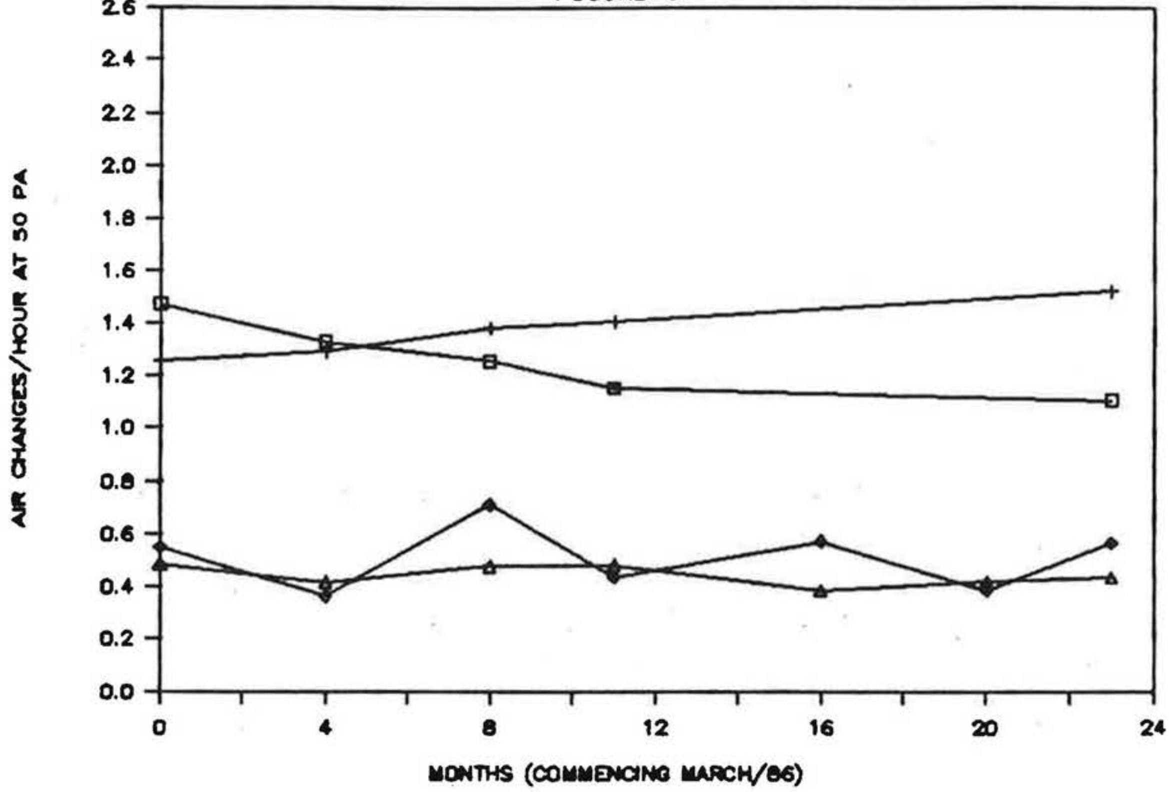


a) AIR CHANGES PER HOUR AT 50 PASCALS

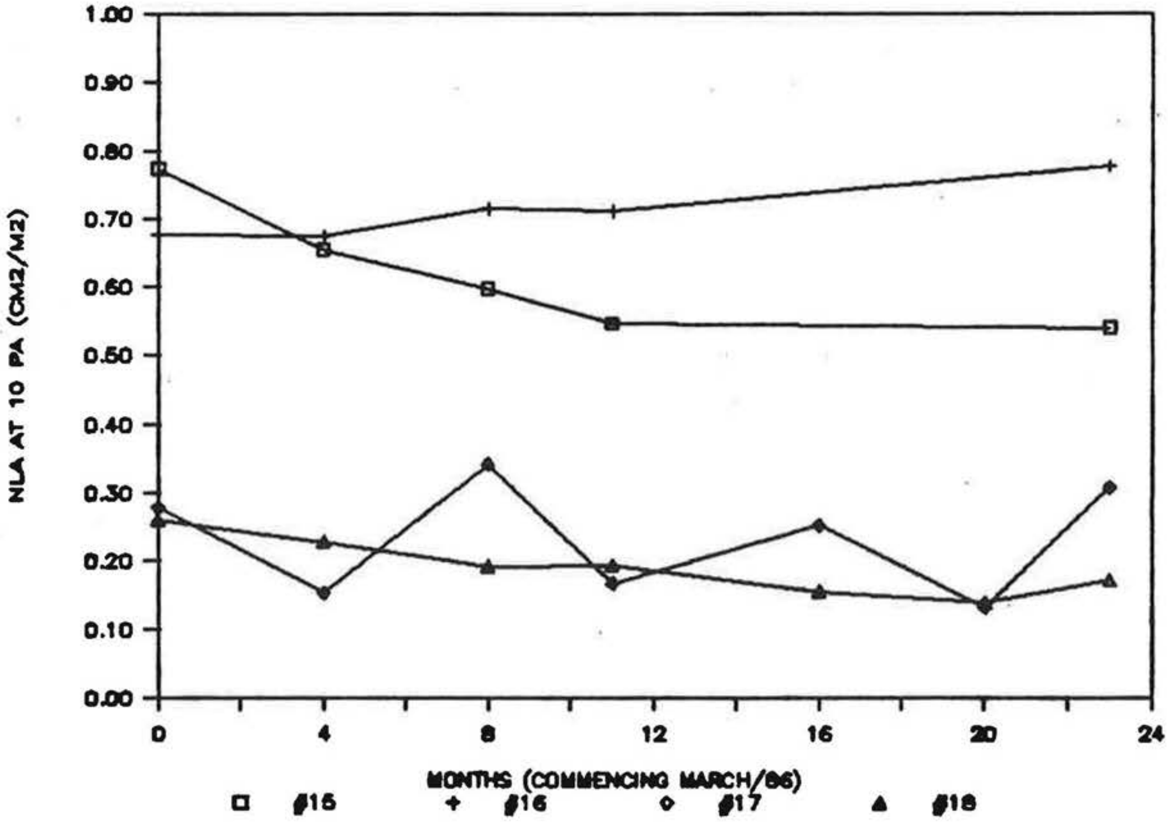


b) NORMALIZED LEAKAGE AREA AT 10 PASCALS
HOUSES #11 TO #14 (MARCH/86 TO FEBRUARY/88)

FIGURE 8



a) AIR CHANGES PER HOUR AT 50 PASCALS



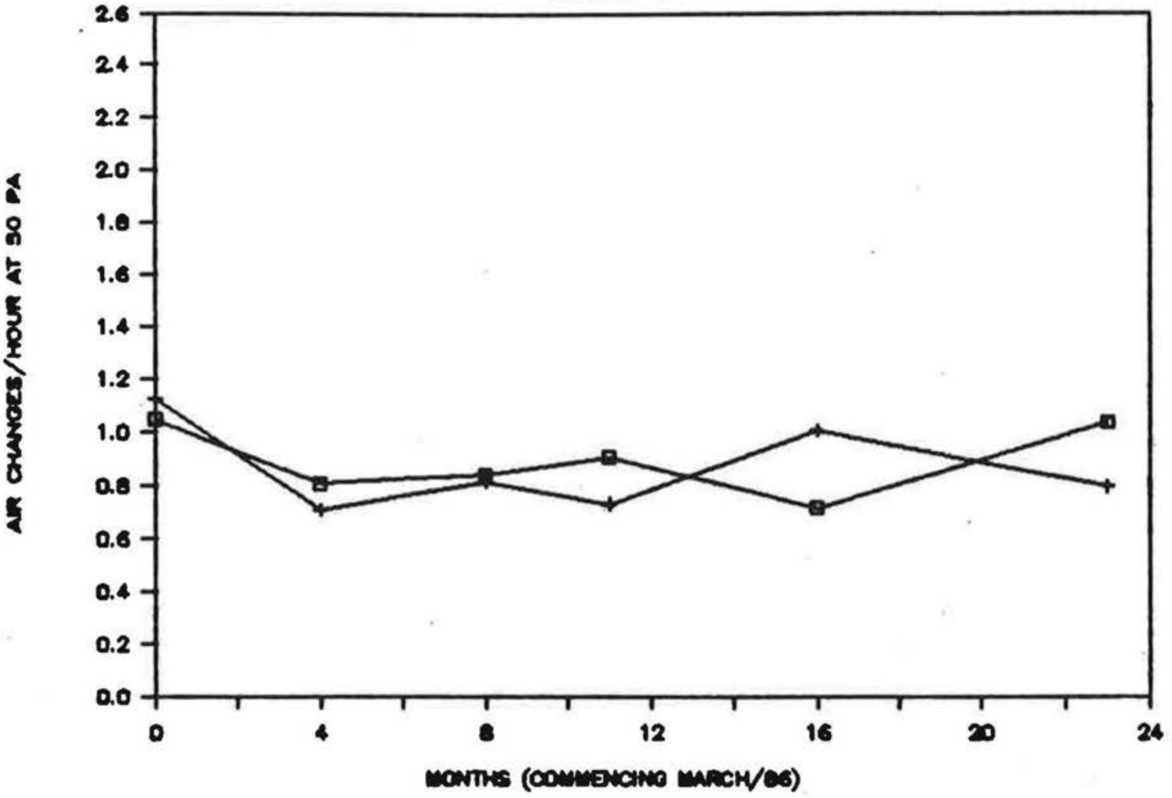
b) NORMALIZED LEAKAGE AREA AT 10 PASCALS
HOUSES #15 TO #18 (MARCH/86 TO FEBRUARY/88)

4.7 HOUSES #19 AND #20

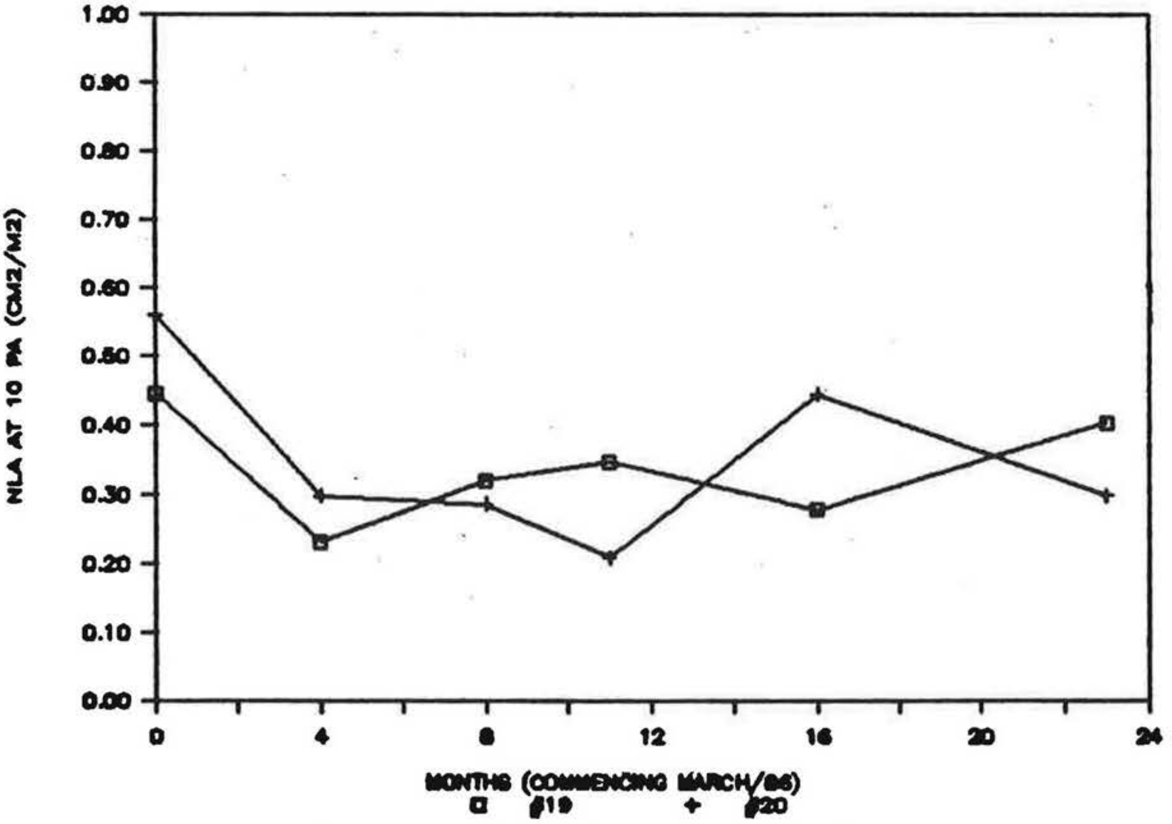
These houses were constructed using the ADA system with 51 mm (2") of rigid extruded polystyrene insulated sheathing on the main floor and basement walls. House #20 used a layer of fibreboard sheathing between the wall framing and insulated sheathing. The stucco was applied between the first and second airtightness tests.

As shown in Fig. 9, these houses performed in a manner similar to Houses #11 and #14 with initial (pre-stucco) airtightness levels below the R-2000 Standard and with a significant improvement attributable to the application of the stucco. Measured levels were relatively stable after this point. The fibreboard sheathing used on House #20 does not appear to have had an impact on the airtightness.

FIGURE 9



a) AIR CHANGES PER HOUR AT 50 PASCALS



b) NORMALIZED LEAKAGE AREA AT 10 PASCALS

HOUSES #19 AND #20 (MARCH/86 TO FEBRUARY/88)

SECTION 5
DISCUSSION OF TEST RESULTS

5.1 GENERAL OBSERVATIONS

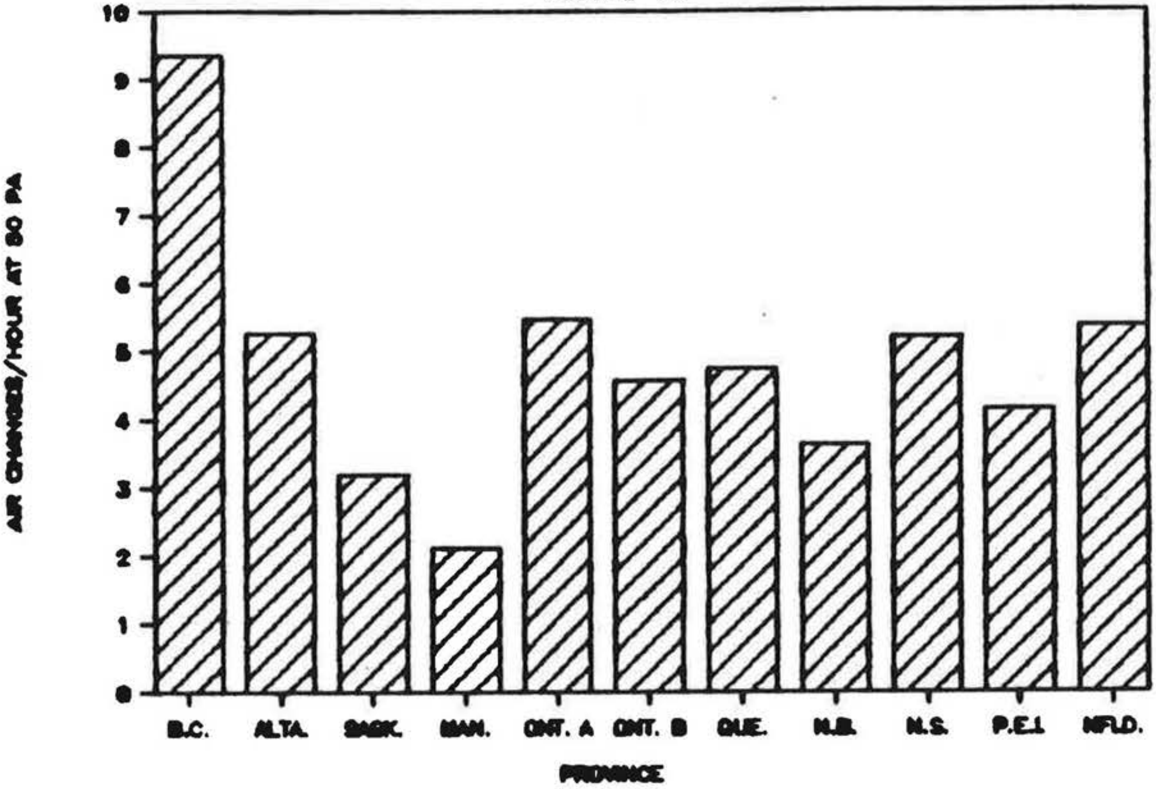
The monitoring results lead to some interesting observations concerning the air barrier systems demonstrated in the project. First, it is clear that both the poly and ADA systems (with or without the SBPO air retarder) are capable of meeting the airtightness requirements of the R-2000 Standard. All of the systems, with the exception of the FCI LEHS, met the Standard prior to the application of stucco which indicates they could also have met it if other, more permeable cladding systems had been used. The FCI LEHS, which is not designed to meet the airtightness requirement, was in fact very close and did reach this level once the stucco was applied.

The results, in general, are typical of R-2000 construction. Riley (Ref. 11) reported that average values for houses built to date under the program are about half the maximum permissible value of 1.50 ac/hr_{50} at the time of construction.

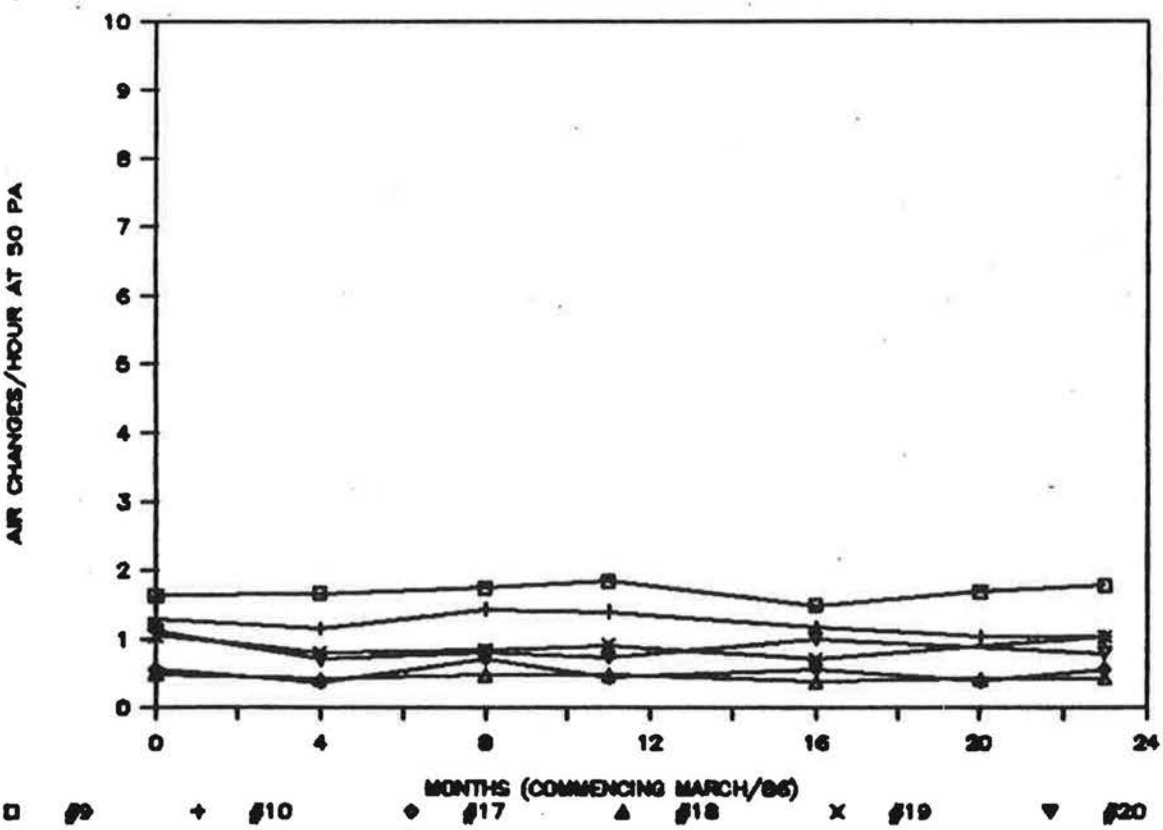
Also of note, each pair or group of houses with the same air barrier system behaved in a similar fashion suggesting a degree of reproducability which is significant from a codes and standards perspective. Although the project houses were conventional bungalows, the airtightness details could be extrapolated to more architecturally complicated structures.

None of the air barrier systems demonstrated any significant change in airtightness during the monitoring period once the stucco had been applied. Although the airtightness levels were observed to fluctuate, there was no systematic tendency to increase or decrease. Note that the observed variations in airtightness for the project houses were small compared to the range of airtightness levels measured for new, conventional Canadian construction. For example, Sulatisky (Ref. 12) reported typical ac/hr_{50} values ranging from 2.12 to 9.33 for 200 conventional new houses constructed in different parts of the country between 1980 and 1982. His results are summarized in Fig. 10 using a scale of 0 to 10 ac/hr_{50}. For comparison purposes, airtightness results for Houses #9, #10, #17, #18, #19

FIGURE 10



a) CONVENTIONAL NEW HOUSES, BUILT 1980 TO 1982
(FROM REF. 12)



b) SAMPLE OF PROJECT HOUSES
AIRTIGHTNESS VARIATIONS AMONG CONVENTIONAL NEW HOUSES
AND SAMPLE OF PROJECT HOUSES

and #20 are also shown using the same scale instead of the 0 to 2.6 ac/hr_{50} scale used in Figs. 4 to 9. When viewed in this manner, the variation in airtightness of the project houses appears very slight.

The observed variations in airtightness of the project houses could have resulted from several factors including: swelling and shrinking of wood framing members, degradation of weatherstripping, differential movement of the foundation, and measurement error. It should be noted that the poly used in Houses #9, #10 and #15 to #18 was manufactured prior to, and therefore did not meet the requirements of, the new Canadian standard CGSB CAN2-51.34-M86 "Vapour Barrier, Polyethylene Sheet, for Use in Building Construction" (Ref. 13).

Stucco, which was used on three of the four walls of each house, was observed to have a significant effect on the airtightness of all but the double wall houses. The ADA houses, with or without the SBPO air retarder, displayed significant reductions in their measured airtightness with the application of stucco while the double wall houses using poly did not exhibit equivalent reductions. This implies that leakage sites existed in the ADA envelopes which were sealable with the stucco while in the double wall houses, the same potential leakage sites had already been sealed with the poly. A similar effect is believed to have been demonstrated by Sulatisky (Ref. 12) during airtightness testing of conventional houses in 1982. Tests were conducted in each province and the most airtight structures were found in Manitoba and Saskatchewan, areas in which the use of stucco is more common.

5.2 POSSIBLE IMPLICATIONS ON AIR BARRIER THEORY

The purpose of the following discussion is to review the requirement that residential air barriers be required to withstand the full anticipated wind loading, i.e. their structural requirements.

The current debate on the structural requirements of air barriers has focused on the need to withstand the pressure loading created by gusting wind conditions such as those in Figs. 2 and 3. During the monitoring period, the maximum gust recorded at the airport weather station was 96 km/h from the north, equivalent to a pressure loading of 460 Pascals compared to the Winnipeg design value of 880 Pascals. The loading actually experienced by the houses is unknown but would have likely been less than that at the airport. However it should be noted that 19 of the 20 project houses were located on the extreme north edge of urban development with very little protection against winds from that direction.

The project houses have yet to be exposed to the structural design wind loads, hence it is not possible to predict their response to such an event. However, the loads which have been applied have not produced an identifiable degradation in airtightness for any of the houses including those with flexible air barriers such as the poly or SBPO (with rigid board backing) systems.

Shaw (Ref. 14) examined the behaviour of 4 and 6 mil poly membranes in wood frame wall sections using various techniques to fasten and secur the poly. Continuous pressure differentials were applied and the partial pressure differentials were measured across both the poly and the entire wall section to determine if the poly was functioning as a continuous air barrier. He found that while sheet poly without any joints exhibited considerable strength (resisting up to 781 Pascals), the staple fastening system used at joints could initiate tears in the material. Timusk and Seskus (Ref. 15) also explored the behaviour of built-up wall sections using poly and found that, under a negative pressure differential, the classic orifice-flow relationship was followed up to about 1000 Pa, after which the leakage rate increased. The pressure was ultimately taken to 2000 Pa. Thus, at least under laboratory conditions, poly can be expected to exhibit considerable strength provided its integrity is not compromised by the fastening system.

Ganguli (Ref. 16) described an experiment in which pressure differentials were measured across the wall assembly of a wood frame house. When a constant indoor-to-outdoor pressure differential was generated with a blower door, 50% of the total pressure drop was observed across the poly and 10% across the sheathing. However when the pressure differential was generated by gusting wind conditions, only 10% occurred across the poly with 50% across the siding. The test house used a strapped wall in which the poly was sandwiched between the vertical studs and the horizontal strapping. This system provides minimal structural support for the poly since it does not provide solid backing and leaves most of the stapled joints unprotected. His results suggest that the loads generated by transient wind gusts were not fully transferred to the flexible poly air barrier.

This raises an interesting point in our knowledge base on loadings of air barriers. Current practice, as dictated by the National Building Code is to design the air barrier to take the full anticipated gust load without any assistance from other components of the envelope assembly such as the exterior finish, sheathing or interior surface. In practice, a perfect air barrier is never attained since all components and assemblies demonstrate some degree of air leakiness. As a result, if a steady-state pressure differential is imposed across an assembly, each of these components will take some of the pressure drop. If a varying, dynamic pressure loading is applied, typical of gusting winds, then each of these components will again take some of the pressure drop. However, since the maximum load is of short duration, a steady-state condition may not be attained. As a result we need to consider the transient air leakage behaviour of the individual components, as well as the complete assembly, and to investigate component distribution of pressure differentials. Unfortunately, most of the available literature on envelope leakage deals with steady-state behaviour with little insight on transient characteristics.

Another issue which needs examination is the mechanics of air barrier failure. If the air barrier is exposed to a load which exceeds its structural capacity, then it will fail and its level of airtightness will be reduced. However, unlike the failure of conventional structural components, this failure may not be catastrophic. Once a failure occurs, for example a tear opens in a sheet of poly, a degree of pressure equalization will occur to reduce the forces to which the air barrier is exposed. This will have two effects. First, the airtightness of the air barrier will be degraded and second, further damage will be minimized by the reduced loading. The first result is of course undesirable but does have the advantage of controlling damage. Since design loads for residential air barriers are determined by short-duration wind loads, this initial failure may limit further failure to permit the peak loading to pass.

The previous discussion has been a largely theoretical consideration of the behaviour of residential air barrier systems. However, it was also noted that the airtightness monitoring program described in this report has not observed any significant change or degradation in measured airtightness in 20 relatively airtight houses over a two year period. Although testing is continuing, the results to date, coupled with the previous discussion, indicate that there is a need to examine the structural requirements for residential air barrier systems. Specifically, the response of actual envelope systems under transient pressure conditions typical of gusting winds needs to be studied. In addition, the ability of non-air barrier components to take a portion of transient pressure loadings should be investigated plus an examination of the effects of air barrier failure as it relates to load reduction and damage control.

SECTION 6
AIR LEAKAGE LOCATIONS

6.1 SOURCES OF AIR LEAKAGE

During the airtightness tests on the project houses, inspections were done to identify major sources of air leakage and to highlight any patterns in the distribution of sources around the envelope. Categorization of a leakage source as "major" was objectively determined by the testing technician. Results for the first and most recent inspections on each house are summarized in Appendix A.

It is evident that only a few areas were consistently noted as sources. The most obvious were electrical outlets on exterior and interior walls of the ADA houses. Commercially available semi-rigid "poly pans" with a foam gasket under the cover plate were used in these houses. Wire penetrations into the pan were caulked and reasonable care was taken to insure a tight fit between the pan and drywall. However, the flexibility of the pan material is believed to have permitted leakage between the flange face and the drywall (which was not controlled by the plate gasket). (Electrical outlet leakage has also been frequently noted during routine airtightness testing of R-2000 houses which use a poly air barrier underneath the drywall). Leakage at interior outlets was also noted despite the use of continuous ceiling drywall. It appears that an improved design or installation procedure is required for manufactured poly pans.

Window leakage was also frequently noted, particularly through joints in the frame, between the frame and casing and along the weatherstripping. The frequency of window source leakage has increased in the houses during the monitoring period indicating a gradual degradation of performance at this location.

Leakage was also noted along baseboards in the cantilevered bay windows in bedrooms in some houses. Similar leakage has been observed in other R-2000 houses due to problems with sealing the underside of the cantilever.

Other leakage areas less frequently noted were service penetrations for ventilation ducts and, on the two conventional houses, plumbing stacks and chimney penetrations. Also, as previously described, significant ductwork and case leakage was noted through the mechanical systems in Houses #15 and #16.

SECTION 7
OPPORTUNITIES FOR IMPROVING AIRTIGHTNESS

7.1 PROPOSED LEAK DETECTION SYSTEM

Research over the last 10 years has identified many techniques, systems and details by which desired levels of airtightness can be achieved. Design and construction experience from the R-2000 Program has refined many of these details to the point where they are routinely practiced by hundreds of builders. However, to produce such results on a consistent and reliable basis, an airtightness test is required both to verify compliance with the R-2000 requirements and to find leakage areas which may exist so that corrective action can be taken. The cost of the test varies but averages around $150 in urban areas and can be considerably more in rural and northern locations. In contrast, the incremental cost of constructing the house to this level of airtightness is around $100 to $200 for an experienced builder (Ref. 17). Thus the cost to construct the product is roughly the same as the cost to verify compliance. Within the R-2000 Program, this is acceptable but for large scale application of these techniques, it may not be.

Over the past eight years, UNIES Ltd. has performed approximately 1000 airtightness tests, complete with inspections to identify leakage areas. Some of these have been performed for builders constructing their first "airtight" house while others were for very experienced builders. In general, the performance of builders tends to follow a characteristic pattern or learning curve. In the first few houses significant leakage will be found at certain locations (depending on the envelope systems). Once these major leakage areas are identified, the builder is usually able to reach the R-2000 requirement for airtightness fairly consistently, only deviating when a new system or new subtrades are used or a "blunder" is made.

Houses which do not meet the R-2000 requirement usually fail because a few major "holes" have been left unsealed. One way for builders to reduce the cost of "airtight construction" may be through the use of a simple "leak detection system". Its purpose would be to identify significant leakage areas so they could be sealed. Compliance with an airtightness standard could, if necessary, be achieved through random airtightness testing. The proposed leak detector would not replace the conventional blower door because it would not have any measurement capability because the cost of measurement equipment is significant, the time required to perform a test and the necessary calculations (even if simplified) are considerable, and builders are not interested in performing airtightness tests. The industry traditionally uses subtrades wherever necessary and an airtightness tester is simply viewed as another subtrade.

The proposed leak detector would consist of a blower of sufficient capacity to depressurize the house by approximately 20 to 30 Pascals, sufficient for finding leaks. Since a major component of a blower door test, in terms of weight, bulk and time to set up, is the door itself, the leak detector would use a more accessible penetration through the envelope. Possible locations include the floor drain or sump with air being exhausted through the weeping tiles (provided the pressure drops were not excessive), or the dryer vent (which may require a quick-connect duct to the blower). To prevent excessive depressurization, a simple pressure relief valve would be incorporated into the device. The production cost of such a device has not been determined, but is estimated at under $500 (an important figure psychologically since builders routinely purchase tools around this cost).

SECTION 8

CONCLUSIONS

1. Airtightness tests were conducted on 20 houses constructed using polyethylene and Airtight Drywall Approach air barrier systems. The poly and ADA systems were both found to be capable of meeting the R-2000 Standard for airtightness. The tightest building envelopes were those constructed using the double wall technique.
2. Airtightness levels were measured over a two year period and while variations were noted, no significant or permanent change in airtightness was observed for any of the houses.
3. The application of stucco was observed to produce a noticeable improvement in airtightness for the ADA houses. This was noted for houses constructed with or without an exterior flexible SBPO air retarder. The airtightness of the double wall houses constructed with well-sealed poly air barriers was not significantly affected by the use of stucco.
4. Electrical outlets on exterior walls of ADA houses were consistently found to be sources of air leakage, despite the presence of poly pans and cover plate foam gaskets. Window leakage was also noted in many houses and the frequency of this leakage increased over the monitoring period. An integrated mechanical system which ducted large volumes of outdoor air through the houses was also found to be a major source of leakage.
5. It was concluded there is a need to re-examine the design pressure requirements for residential air barrier systems. Specifically, this should investigate how transient wind-induced pressure loads are resisted by an air barrier system and whether some portion of the load can be expected to be taken by other envelope components such as the exterior finish, sheathing and the interior surface.
6. An inexpensive air leakage detection system was proposed, suitable for use by builders. It would consist of a non-instrumented blower exhausting through a suitable opening such as a floor drain, sump pump hole, or dryer vent.

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APPENDIX A

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #1

LEAKAGE POINT	◥ = JAN '85 ◣ = FEB '88	Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING																			
	FRAMES	■		■						■	FRONT & BACK WINDOWS									
	LATCHES																			
	WEATHERSTRIPPING	■																		
EXTERIOR DOORS:	MOULDING																			
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING																			
EXTERIOR WALL ELECTRICAL:	OUTLETS	■		◥	◥	◥														
	SWITCHES																			
	WIRES THRU WALL																			
INTERIOR WALL ELECTRICAL:	OUTLETS																			
	SWITCHES																			
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING																			
	FRAME																			
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL		◥					◥												
	BASEBOARDS																			
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL																			
	CHIMNEY																			
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			
	HRV INTAKE & EXHAUST THRU. CONC. WALL									◥										

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #2

LEAKAGE POINT ◥ = DEC '84
◣ = FEB '88

		Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING																			
	FRAMES									◣										
	LATCHES																			
	WEATHERSTRIPPING					◣														
EXTERIOR DOORS:	MOULDING																			
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING	◥																		
EXTERIOR WALL ELECTRICAL:	OUTLETS	■			■	■														
	SWITCHES																			
	WIRES THRU WALL																			
INTERIOR WALL ELECTRICAL:	OUTLETS						◥													
	SWITCHES		◥																	
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING																			
	FRAME				CORNERS OF BDRM WINDOW FRAMING															
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL		◣					◣												
	BASEBOARDS				■	◥														
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL																			
	CHIMNEY																			
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			
	DRYER VENT THRU. CONC. WALL									◣										

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #3

LEAKAGE POINT	◥ = DEC '84 ◣ = FEB '88	Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING	◣		◣	◣	◣				◣										
	FRAMES				◣					■										
	LATCHES																			
	WEATHERSTRIPPING	■			◥															
EXTERIOR DOORS:	MOULDING																			
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING																			
EXTERIOR WALL ELECTRICAL:	OUTLETS	◣		◣	◣	◣				◣										
	SWITCHES																			
	WIRES THRU WALL																			
INTERIOR WALL ELECTRICAL:	OUTLETS		◥																	
	SWITCHES			◣																
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING																			
	FRAME																			
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL									◥	STACK THRU FLOOR									
	BASEBOARDS																			
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL									■										
	CHIMNEY																			
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			
	HRV. INTAKE & EXHAUST THRU CONC. WALL									■										

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #4																				
LEAKAGE POINT	◥ = OCT '84 ◣ = MAR '88	Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING																			
	FRAMES	◣																		
	LATCHES																			
	WEATHERSTRIPPING																			
EXTERIOR DOORS:	MOULDING																			
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING		◣																	
EXTERIOR WALL ELECTRICAL:	OUTLETS	◣	◣		◣	◣	◣													
	SWITCHES		■	BY BACK DOOR																
	WIRES THRU WALL																			
INTERIOR WALL ELECTRICAL:	OUTLETS		◥																	
	SWITCHES																			
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING				CORNERS OF BAY WINDOWS	IN BOTH BEDROOMS														
	FRAME																			
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL																			
	BASEBOARDS				◥	◥														
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL									■										
	CHIMNEY																			
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			
	HRV. EXHAUST THRU CONCRETE WALL									◣										

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #5

LEAKAGE POINT	◥ = DEC '84 ◣ = FEB '88	Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING																			
	FRAMES	◥								◥										
	LATCHES																			
	WEATHERSTRIPPING				◣	◣														
EXTERIOR DOORS:	MOULDING																			
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING																			
EXTERIOR WALL ELECTRICAL:	OUTLETS			◣	◣															
	SWITCHES																			
	WIRES THRU WALL																			
INTERIOR WALL ELECTRICAL:	OUTLETS																			
	SWITCHES			■																
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING																			
	FRAME																			
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL																			
	BASEBOARDS				◥	CORNERS OF BAY WINDOW														
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL																			
	CHIMNEY																			
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #6

LEAKAGE POINT ◥ = MARCH '86 ◣ = FEB '88		Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING	◣		◣																
	FRAMES																			
	LATCHES				◥															
	WEATHERSTRIPPING	◥			◣															
EXTERIOR DOORS:	MOULDING																			
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING		◣																	
EXTERIOR WALL ELECTRICAL:	OUTLETS	◥			◥	■				■	RECROOM SOUTH WALL									
	SWITCHES																			
	WIRES THRU WALL																			
INTERIOR WALL ELECTRICAL:	OUTLETS						◥													
	SWITCHES																			
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING																			
	FRAME																			
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL																			
	BASEBOARDS																			
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL																			
	CHIMNEY																			
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			
	DRYWALL CRACK BETWEEN CEILING & WALL	◣																		

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #7

LEAKAGE POINT
◥ = APRIL '85
◣ = FEB '88

		Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING																			
	FRAMES				◥					■										
	LATCHES																			
	WEATHERSTRIPPING	◥			◥															
EXTERIOR DOORS:	MOULDING																			
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING																			
EXTERIOR WALL ELECTRICAL:	OUTLETS	■			■	■														
	SWITCHES																			
	WIRES THRU WALL																			
INTERIOR WALL ELECTRICAL:	OUTLETS																			
	SWITCHES																			
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING																			
	FRAME																			
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL									■	THRU CEILING									
	BASEBOARDS																			
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL									◥										
	CHIMNEY																			
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #8

LEAKAGE POINT
◥ = MAR '85
◣ = FEB '88

		Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING									■										
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING		◣				◣													
EXTERIOR DOORS:	MOULDING																			
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING		◣																	
EXTERIOR WALL ELECTRICAL:	OUTLETS	■		■																
	SWITCHES		◣																	
	WIRES THRU WALL																			
INTERIOR WALL ELECTRICAL:	OUTLETS		BESIDE BACK DOOR				■													
	SWITCHES																			
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING																			
	FRAME																			
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL				CORNERS OF BAY WINDOWS															
	BASEBOARDS				◣	◣														
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL									◥										
	CHIMNEY																			
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			
	DRYER VENT THRU CONCRETE WALL									◣										
	CANTILEVER FLOOR BELOW BAY IN BEDROOM #2									◣										

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #9

LEAKAGE POINT ◥ = APRIL '85 ◣ = FEB '88		Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING																			
	FRAMES			◣	◣					■										
	LATCHES																			
	WEATHERSTRIPPING																			
EXTERIOR DOORS:	MOULDING																			
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING																			
EXTERIOR WALL ELECTRICAL:	OUTLETS	■		■	■	◥														
	SWITCHES	◣																		
	CEILING FIXTURE			◣																
INTERIOR WALL ELECTRICAL:	OUTLETS																			
	SWITCHES			◣																
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING																			
	FRAME																			
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL		◣							■	THRU CEILING.									
	BASEBOARDS				◣															
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL									◥										
	CHIMNEY									◣	THRU CEILING.									
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #10

◥ = MARCH '86
◣ = FEB '88

LEAKAGE POINT		Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING																			
	FRAMES	◣								◥										
	LATCHES																			
	WEATHERSTRIPPING				◣															
EXTERIOR DOORS:	MOULDING																			
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING		◥																	
EXTERIOR WALL ELECTRICAL:	OUTLETS	◣	◣		◣	■				◣	OWNER-BUILT RECROOM									
	SWITCHES		■																	
	WIRES THRU WALL		BESIDE BACK DOOR																	
INTERIOR WALL ELECTRICAL:	OUTLETS																			
	SWITCHES																			
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING																			
	FRAME																			
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL		◥																	
	BASEBOARDS																			
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL																			
	CHIMNEY									◣	THRU CEILING									
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #11

LEAKAGE POINT
◥ = JULY '87
◣ = FEB '88

		Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement
WINDOWS:	MOULDING									
	FRAMES	◣	◣							
	LATCHES									
	WEATHERSTRIPPING		◥							
EXTERIOR DOORS:	MOULDING									
	FRAMES									
	LATCHES									
	WEATHERSTRIPPING		■							
EXTERIOR WALL ELECTRICAL:	OUTLETS	■			◣	■				
	SWITCHES		■							
	WIRES THRU WALL		BESIDE BACK DOOR							
INTERIOR WALL ELECTRICAL:	OUTLETS									
	SWITCHES									
	WIRES THRU WALL									
FIREPLACE:	AROUND UNIT									
	DAMPER/DOORS									
ATTIC HATCH:	MOULDING									
	FRAME									
	WEATHERSTRIPPING									
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL									
	BASEBOARDS		◣							
	FLOOR DRAIN/SUMP		BACK DOOR LANDING							
	ELECTRICAL PANEL									
	CHIMNEY									
	JOISTS OVER ATTACHED GARAGE									
	HEADER AREA									
	OWNER-INSTALLED PLASTIC PIPE THRU CONC. WALL.									◣

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #12

LEAKAGE POINT	◥ = MARCH'86 ◣ = FEB '88	Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING		CORNERS OF PLASTIC GLAZING "PUTTY" HOLDING GLASS IN FRAMES							?										
	FRAMES	◣								◣										
	LATCHES																			
	WEATHERSTRIPPING		◣			◣														
EXTERIOR DOORS:	MOULDING																			
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING		◣																	
EXTERIOR WALL ELECTRICAL:	OUTLETS	■	◣		■	■														
	SWITCHES		◣																	
	WIRES THRU WALL																			
INTERIOR WALL ELECTRICAL:	OUTLETS		BESIDE BACK DOOR																	
	SWITCHES																			
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING																			
	FRAME																			
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL		◣																	
	BASEBOARDS																			
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL																			
	CHIMNEY																			
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			
	DRYER VENT THRU CONCRETE WALL									◣										
	HAB. EXHAUST VENT THRU. CONC. WALL									◣										

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #13

LEAKAGE POINT ◥ = JULY '86 ◣ = FEB '88		Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING	CORNERS OF PLASTIC GLAZING "PUTTY" HOLDING GLASS IN FRAMES																		
	FRAMES	■	↙	◥	↙	◥	↙													
	LATCHES																			
	WEATHERSTRIPPING		■		■		■			■										
EXTERIOR DOORS:	MOULDING																			
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING		◥																	
EXTERIOR WALL ELECTRICAL:	OUTLETS	◥	◥		■	◥				◥	OWNER BUILT RECROOM									
	SWITCHES		◥																	
	WIRES THRU WALL		BESIDE BACK DOOR																	
INTERIOR WALL ELECTRICAL:	OUTLETS																			
	SWITCHES																			
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING																			
	FRAME																			
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL																			
	BASEBOARDS																			
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL																			
	CHIMNEY																			
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #14

LEAKAGE POINT
◥ = MARCH '86
◣ = FEB '88

		Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement									
WINDOWS:	MOULDING																		
	FRAMES	◣																	
	LATCHES																		
	WEATHERSTRIPPING	◣			◣	■													
EXTERIOR DOORS:	MOULDING																		
	FRAMES																		
	LATCHES																		
	WEATHERSTRIPPING		◣																
EXTERIOR WALL ELECTRICAL:	OUTLETS	■			■	■													
	SWITCHES		■																
	WIRES THRU WALL		BESIDE BACK DOOR																
INTERIOR WALL ELECTRICAL:	OUTLETS																		
	SWITCHES																		
	WIRES THRU WALL																		
FIREPLACE:	AROUND UNIT																		
	DAMPER/DOORS																		
ATTIC HATCH:	MOULDING																		
	FRAME																		
	WEATHERSTRIPPING																		
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL																		
	BASEBOARDS																		
	FLOOR DRAIN/SUMP																		
	ELECTRICAL PANEL																		
	CHIMNEY																		
	JOISTS OVER ATTACHED GARAGE																		
	HEADER AREA																		
	HRV. INTAKE & EXHAUST THRU CONC. WALL									◥									

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #15

LEAKAGE POINT

◥ = JULY '86

◣ = FEB '88

		Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING																			
	FRAMES	◥	◥		◥															
	LATCHES				◥	■	◥													
	WEATHERSTRIPPING																			
EXTERIOR DOORS:	MOULDING																			
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING		■																	
EXTERIOR WALL ELECTRICAL:	OUTLETS																			
	SWITCHES																			
	WIRES THRU WALL																			
INTERIOR WALL ELECTRICAL:	OUTLETS																			
	SWITCHES																			
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING																			
	FRAME																			
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL																			
	BASEBOARDS																			
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL																			
	CHIMNEY																			
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			
	CORNER OF FRAMING BELOW DROPPED FRONT ENTRANCE LANDING. PEACH									◣ ■										

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #16

LEAKAGE POINT
◥ = MARCH '86
◣ = FEB '88

		Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING																			
	FRAMES	■			■	◥														
	LATCHES																			
	WEATHERSTRIPPING	◣																		
EXTERIOR DOORS:	MOULDING																			
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING	◥	◣																	
EXTERIOR WALL ELECTRICAL:	OUTLETS			◥																
	SWITCHES																			
	WIRES THRU WALL																			
INTERIOR WALL ELECTRICAL:	OUTLETS																			
	SWITCHES																			
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING																			
	FRAME																			
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL																			
	BASEBOARDS																			
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL																			
	CHIMNEY																			
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			
	PEACH INTAKE & EXHAUST THRU CONC. WALL									◥										
	PEACH									■										

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #17

LEAKAGE POINT	◥ = MARCH '86 ◣ = MARCH '88	Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING		◣	◣	CORNERS OF PLASTIC GLAZING "PUTTY" HOLDING GLASS INTO FRAMES															
	FRAMES				◥		◥			◥										
	LATCHES																			
	WEATHERSTRIPPING																			
EXTERIOR DOORS:	MOULDING																			
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING	◣	◣																	
EXTERIOR WALL ELECTRICAL:	OUTLETS																			
	SWITCHES																			
	WIRES THRU WALL																			
INTERIOR WALL ELECTRICAL:	OUTLETS																			
	SWITCHES																			
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING																			
	FRAME																			
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL																			
	BASEBOARDS																			
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL																			
	CHIMNEY																			
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			
	NILAN INTAKE & EXHAUST THRU CONC. WALL									◥										
	OWNER-INSTALLED CENTRAL VAC. EXHAUST THRU CONC. WALL									◣										

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #18

LEAKAGE POINT	◥ = JULY '86 ◣ = FEB '88	Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING																			
	FRAMES	■		■		◥				■										
	LATCHES				◥		◥													
	WEATHERSTRIPPING		◥																	
EXTERIOR DOORS:	MOULDING																			
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING		■																	
EXTERIOR WALL ELECTRICAL:	OUTLETS																			
	SWITCHES		■																	
	WIRES THRU WALL		BESIDE BACK DOOR																	
INTERIOR WALL ELECTRICAL:	OUTLETS																			
	SWITCHES																			
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING																			
	FRAME																			
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL																			
	BASEBOARDS																			
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL																			
	CHIMNEY																			
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			
	TEARS IN A.V.B. AROUND WINDOW OPENINGS									■										

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #19

◥ = MARCH '86
◣ = FEB. '88

LEAKAGE POINT		Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement										
WINDOWS:	MOULDING																			
	FRAMES	■		■	■	■	◣			■										
	LATCHES																			
	WEATHERSTRIPPING				◣		◥													
EXTERIOR DOORS:	MOULDING	◣																		
	FRAMES																			
	LATCHES																			
	WEATHERSTRIPPING	◣	■																	
EXTERIOR WALL ELECTRICAL:	OUTLETS	■	◣		■	■														
	SWITCHES		■																	
	WIRES THRU WALL		BESIDE BACK DOOR																	
INTERIOR WALL ELECTRICAL:	OUTLETS						■													
	SWITCHES																			
	WIRES THRU WALL																			
FIREPLACE:	AROUND UNIT																			
	DAMPER/DOORS																			
ATTIC HATCH:	MOULDING																			
	FRAME																			
	WEATHERSTRIPPING																			
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL																			
	BASEBOARDS																			
	FLOOR DRAIN/SUMP																			
	ELECTRICAL PANEL																			
	CHIMNEY																			
	JOISTS OVER ATTACHED GARAGE																			
	HEADER AREA																			
	HRV INTAKE & EXHAUST THRU CONC. WALL									◥										
	OWNER INSTALLED WIRING UNDER CANTILEVER									◣										
	FLOOR BAY WINDOW BEDROOM #2																			

UNIES Ltd. AIRTIGHTNESS TEST DATA FORM - AIR LEAKAGE SEALING CHECKLIST HOUSE #20

LEAKAGE POINT ◥ = MARCH'86 ◣ = FEB '88		Living Area	Kitchen	Dining	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom 1	Bathroom 2	Basement
WINDOWS:	MOULDING		◣	◣	CORNERS OF PLASTIC GLAZING "PUTTY" HOLDING GLASS IN FRAMES					
	FRAMES	◥		◥						■
	LATCHES									
	WEATHERSTRIPPING				■	■				
EXTERIOR DOORS:	MOULDING									
	FRAMES									
	LATCHES									
	WEATHERSTRIPPING		■							
EXTERIOR WALL ELECTRICAL:	OUTLETS	■	■		■	■				
	SWITCHES BESIDE BACK DOOR →		◥							
	WIRES THRU WALL									
INTERIOR WALL ELECTRICAL:	OUTLETS						◥			
	SWITCHES		◥							
	WIRES THRU WALL									
FIREPLACE:	AROUND UNIT									
	DAMPER/DOORS									
ATTIC HATCH:	MOULDING									
	FRAME									
	WEATHERSTRIPPING									
OTHER LEAKAGE AREAS:	PLUMBING THRU WALL									
	BASEBOARDS									
	FLOOR DRAIN/SUMP									
	ELECTRICAL PANEL									◥
	CHIMNEY									
	JOISTS OVER ATTACHED GARAGE									
	HEADER AREA									
	HRV INTAKE & EXHAUST THRU CONC. WALL									◥
	DRYER VENT THRU CONC. WALL									◣

TABLE 2
AIRTIGHTNESS TEST RESULTS
Air Changes Per Hour @ 50 Pascals (ac/hr_{50})

HOUSE #	DATE OF TEST						
1	Mar.25/86 1.669		Nov.21/86 1.475	Feb.14/87 1.568			Feb.29/88 1.479
2		Jul.16/86 1.053	Nov.24/86 1.171	Feb.18/87 1.119	Jul.6/87 0.977	Nov.18/87 1.047	Mar.8/88 1.169
3	Mar.15/86 1.509		Nov.25/86 1.539	Feb.15/87 1.852	Jul.8/87 1.486		Mar.4/88 1.689
4	Mar.25/86 1.455		Nov.26/86 1.311	Feb.17/87 1.299	Jul.13/87 1.115		Mar.3/88 1.415
5	Mar.24/86 1.118		Nov.26/86 1.264	Feb.20/87 1.104	Jul.9/87 1.144		Mar.2/88 1.049
6	Mar.15/86 1.205		Nov.24/86 1.255	Feb.14/87 1.306	Jul.10/87 1.187		Feb.29/88 1.417
7	Mar.25/86 1.166		Nov.26/86 1.522	Feb.16/87 2.196			
8	Mar.14/86 1.588		Dec.1/86 1.392	Feb.20/87 1.740	Jul.20/87 1.342		Mar.2/88 1.444
9	Mar.24/86 1.622	Jul.16/86 1.655	Nov.24/86 1.741	Feb.15/87 1.838	Jul.23/87 1.484	Nov.25/87 1.684	Mar.2/88 1.781
10	Mar.26/86 1.281	Jul.14/86 1.152	Nov.21/86 1.429	Feb.21/87 1.386	Jul.14/87 1.167	Nov.30/87 1.038	Mar.8/88 1.032
11	Mar.22/86 1.694*	Jun.11/86 0.892	Nov.26/86 0.962	Feb.16/87 0.881	Jul.9/87 0.879		Mar.2/88 1.007
12	Mar.23/86 1.593*	May 28/86 1.120	Nov.20/86 0.960	Feb.16/87 0.979	Jul.8/87 0.878		Mar.9/88 0.980
13	Apr.25/86 1.268*	Jul.18/86 0.836	Dec.8/86 0.830	Feb.18/87 0.761	Jul.8/87 1.043		Mar.9/88 0.938
14	Mar.22/86 1.319*	Jun.10/86 1.136		Feb.19/87 0.955	Jul.15/87 0.989		Mar.3/88 1.155
15	Mar.15/86 1.473*	May 7/86 1.328	Nov.20/86 1.257	Feb.20/87 1.152			Mar.3/88 1.104
16	Mar.26/86 1.258*	Jul.14/86 1.292	Nov.21/86 1.382	Feb.17/87 1.405			Mar.9/88 1.519
17	Mar.24/86 0.549*	Jul.29/86 0.363	Nov.20/86 0.713	Feb.13/87 0.437	Aug.25/87 0.570	Dec.1/87 0.384	Mar.24/88 0.564
18	Mar.16/86 0.486*	Jul.28/86 0.416	Nov.29/86 0.478	Feb.19/87 0.480	Jul.22/87 0.385	Nov.24/87 0.418	Mar.2/88 0.434
19	Mar.23/86 1.049*	Jul.14/86 0.807	Dec.8/86 0.842	Feb.17/87 0.908	Jul.16/87 0.715		Feb.29/88 1.038
20	Mar.23/86 1.126*	Jul.25/86 0.708	Nov.25/86 0.815	Feb.13/87 0.731	Jul.17/87 1.008		Mar.8/88 0.797

NOTES

1. * Indicates no stucco.

TABLE 3
AIRTIGHTNESS TEST RESULTS
Normalized Leakage Area @ 10 Pascals (NLA_{10})

HOUSE #	DATE OF TEST						
1	Mar.25/86 0.577		Nov.21/86 0.467	Feb.14/87 0.380			Feb.29/88 0.477
2		Jul.16/86 0.410	Nov.24/86 0.603	Feb.18/87 0.451	Jul.6/87 0.400	Nov.18/87 0.425	Mar.8/88 0.503
3	Mar.15/86 0.513		Nov.25/86 0.517	Feb.15/87 0.762	Jul.8/87 0.564		Mar.4/88 0.656
4	Mar.25/86 0.585		Nov.26/86 0.482	Feb.17/87 0.551	Jul.13/87 0.437		Mar.3/88 0.643
5	Mar.24/86 0.444		Nov.26/86 0.450	Feb.20/87 0.432	Jul.9/87 0.334		Mar.2/88 0.341
6	Mar.15/86 0.473		Nov.24/86 0.488	Feb.14/87 0.613	Jul.10/87 0.366		Feb.29/88 0.581
7	Mar.25/86 0.433		Nov.26/86 0.637	Feb.16/87 0.981			
8	Mar.14/86 0.857		Dec.1/86 0.636	Feb.20/87 0.745	Jul.20/87 0.620		Mar.2/88 0.664
9	Mar.24/86 0.560	Jul.16/86 0.587	Nov.24/86 0.566	Feb.15/87 0.623	Jul.23/87 0.596	Nov.25/87 0.641	Mar.2/88 0.659
10	Mar.26/86 0.588	Jul.14/86 0.418	Nov.21/86 0.642	Feb.21/87 0.805	Jul.14/87 0.404	Nov.30/87 0.441	Mar.8/88 0.392
11	Mar.22/86 0.753*	Jun.11/86 0.345	Nov.26/86 0.396	Feb.16/87 0.317	Jul.9/87 0.282		Mar.2/88 0.370
12	Mar.23/86 0.835*	May 28/86 0.468	Nov.20/86 0.417	Feb.16/87 0.329	Jul.8/87 0.318		Mar.9/88 0.405
13	Apr.25/86 0.569*	Jul.18/86 0.360	Dec.8/86 0.314	Feb.18/87 0.401	Jul.8/87 0.437		Mar.9/88 0.403
14	Mar.22/86 0.754*	Jun.10/86 0.490		Feb.19/87 0.516	Jul.15/87 0.393		Mar.3/88 0.467
15	Mar.15/86 0.774*	May 7/86 0.655	Nov.20/86 0.597	Feb.20/87 0.547			Mar.3/88 0.539
16	Mar.26/86 0.677*	Jul.14/86 0.675	Nov.21/86 0.714	Feb.17/87 0.711			Mar.9/88 0.777
17	Mar.24/86 0.278*	Jul.29/86 0.154	Nov.20/86 0.340	Feb.13/87 0.166	Aug.25/87 0.250	Dec.1/87 0.132	Mar.24/88 0.307
18	Mar.16/86 0.259*	Jul.28/86 0.227	Nov.29/86 0.190	Feb.19/87 0.192	Jul.22/87 0.155	Nov.24/87 0.138	Mar.2/88 0.171
19	Mar.23/86 0.444*	Jul.14/86 0.232	Dec.8/86 0.320	Feb.17/87 0.347	Jul.16/87 0.279		Feb.29/88 0.402
20	Mar.23/86 0.560*	Jul.25/86 0.298	Nov.25/86 0.287	Feb.13/87 0.208	Jul.17/87 0.444		Mar.8/88 0.299

NOTES

1. * Indicates no stucco.

TABLE 4

CHANGE IN AIRTIGHTNESS BETWEEN INITIAL AND MOST RECENT TESTS

HOUSE #	AC/HR_{50}				NLA_{10}				MONTHS BETWEEN INITIAL AND MOST RECENT TEST
	INITIAL	FINAL	ABS. CHG.	%	INITIAL	FINAL	ABS. CHG.	%	
1	1.669	1.479	-0.189	-11.4	0.577	0.477	-0.101	- 17.5	23
2	1.053	1.169	0.117	11.1	0.410	0.503	0.093	22.7	20
3	1.509	1.689	0.180	11.0	0.513	0.656	0.143	27.9	24
4	1.455	1.415	-0.040	- 2.8	0.585	0.643	0.058	9.9	23
5	1.118	1.049	-0.069	- 6.2	0.444	0.341	-0.103	- 23.2	23
6	1.205	1.417	0.212	17.6	0.473	0.581	0.108	22.9	23
7	1.166	2.196	1.029	88.3	0.433	0.981	0.548	126.4	11
8	1.588	1.444	-0.145	- 9.1	0.857	0.664	-0.193	- 22.5	24
9	1.622	1.781	0.160	9.9	0.559	0.659	0.100	17.0	23
10	1.281	1.032	-0.248	-19.4	0.588	0.392	-0.197	- 33.4	23
11	0.892	1.007	0.115	12.8	0.345	0.370	0.026	7.5	21
12	1.120	0.980	-0.140	-12.5	0.468	0.405	-0.063	- 13.4	21
13	0.836	0.938	0.101	12.1	0.360	0.403	0.043	12.1	20
14	1.136	1.155	0.019	1.7	0.490	0.467	-0.023	- 4.7	21
15	1.328	1.104	-0.225	-16.9	0.655	0.539	-0.115	- 17.6	22
16	1.292	1.519	0.227	17.6	0.675	0.777	0.102	15.1	20
17	0.363	0.564	0.200	55.2	0.154	0.307	0.153	99.9	20
18	0.416	0.434	0.018	4.3	0.227	0.171	-0.056	- 24.7	20
19	0.807	1.038	0.231	28.6	0.232	0.402	0.170	73.4	20
20	0.708	0.797	0.089	12.6	0.298	0.299	0.001	0.4	20

MEANS:	AC/HR_{50}		NLA_{10}	
	ABS. CHG.	%	ABS. CHG.	%
#1 - #6	0.035	3.4	0.033	7.1
#7 & #8	0.442	39.6	0.177	51.9
#9 & #10	-0.044	- 4.8	-0.048	- 7.7
#11 - #14	0.024	3.5	-0.004	0.3
#15 - #18	0.055	15.0	0.021	18.2
#19 & #20	0.160	20.6	0.086	36.9

NOTES

1. Nomenclature convention: a negative (-) change in airtightness indicates the structure became more airtight.

TABLE 4 (b)

N_2O-DETERMINED APPARENT ZONE VENTILATION RATES (LITRES/SECOND)

HOUSE	VENTILATION SYSTEM	INTERIOR DOOR POSITION	MODE OF OPERATION OF VENTILATION SYSTEM DURING TESTS	DESIGN ZVR	ZONE 1	ZONE 2	ZONE 3	ZONE 4
				LOW	8.8	10.6	26.4	10.4
				HIGH	11.8	14.3	35.5	14.3
11	Exhaust-Only Heat Pump HRV	Open	Speed 4		7.2	9.2	24.7	0
		Closed	Speed 4		8.0	6.8	14.9	31.9
12		Open	Speed 1		2.9	5.4	9.1	0
		Closed	Speed 1		2.7	3.4	8.5	11.7
13	Combined HRV/Forced Air Heating System	Open	Low		4.7	7.5	32.4	41.0
		Closed	Low		5.6	9.2	21.0	41.6
14		Open	Low		4.3	6.7	17.2	35.8
		Closed	Low		4.5	6.9	15.9	32.5
15	Integrated Heat Pump HRV, Space & DHW Heating System	Open	High		5.5 (5.5)	8.2 (8.3)	20.3 (23.7)	37.7 (17.6)
		Closed	Low		2.2	3.7	8.5	15.0
16		Open	High		4.6	6.9	14.9	20.8
		Closed	Low		2.3	3.3	9.1	16.9
17	Heat Pump HRV with Dedicated Ventilation System	Open	Low		5.3	8.2	19.6	41.6
		Closed	Low		9.3	7.2	14.5	42.9
18		Open	Low		5.0	7.9	15.9	44.9
		Closed	Low		8.2	6.0	17.2	42.9
19	HRV with Dedicated Ventilation System	Open	High		10.8	17.0	37.5	16.9
		Closed	High		12.5	12.5	29.4	37.7
20		Open	High		4.4	7.5	32.8	54.6
		Closed	High		12.9	4.2	24.7	55.3

Notes

1. Apparent ZVR values include natural air infiltration.
2. Bracketted figures for House #15 were re-test values, with drain holes in bottom of HRV cabinet blocked.