MEASURED AIRTIGHTNESS OF TWENTY-FOUR DETACHED HOUSES OVER PERIODS OF UP TO THREE YEARS

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DISCLAIMER

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SUMMARY

The airtightness of 24 new houses was measured on a regular basis over periods of up to three years to evaluate the structures' air barrier systems and to study the possibility of air barrier degradation, as would be indicated by an increase in the measured leakage rate. Ten of the houses were built with the polyethylene air barrier system and 14 using an early version of the Airtight Drywall Approach (ADA). The 24 project houses were architecturally similar and of approximately equal size and general layout; stucco was the predominate wall finish.

The study found that the airtightness of the polyethylene air barrier houses remained stable over their respective monitoring periods. With regards to the critical issue of air barrier degradation, it was concluded that no evidence could be found to indicate polyethylene is unsuited for use as an air barrier material in residential construction. Although two of the 10 houses demonstrated possible, albeit slight, evidence of airtightness degradation, the magnitude of these changes was small and not judged to be of practical significance. All but one of the polyethylene houses met the airtightness requirements of the R-2000 program at the end of their monitoring periods. The project houses with the lowest measured leakage rates were those built with the double wall system and polyethylene air barriers.

The study also found that the airtightness of the 14 ADA houses remained stable during the monitoring period and it was concluded that no evidence could be found to indicate that the ADA system is unsuited for use in residential construction. Although six of the 14 houses displayed possible, but also slight, evidence of airtightness degradation, the magnitude of the changes was small and not of practical significance. All 14 houses met the airtightness requirements of the R-2000 Program at the end of their respective monitoring periods.

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

RÉSUMÉ

On a mesuré l'étanchéité à l'air de 24 maisons neuves de façon régulière, sur des périodes allant jusqu'à trois ans, en vue d'évaluer les dispositifs d'étanchéité à l'air des constructions et d'étudier la possibilité de dégradation de ces dispositifs, qui serait indiquée par une augmentation du taux d'infiltrations et d'exfiltrations. Dix (10) des maisons avaient été étanchéisées à l'aide de polyéthylène, alors que les 14 autres utilisaient la méthode des murs secs étanches à l'air. Les 24 maisons du projet étaient d'une architecture semblable et avaient sensiblement les mêmes dimensions et le même aménagement général; le stuc était le fini principal des murs.

L'étude a révélé que les maisons étanchéisées à l'air à l'aide de polyéthylène avaient gardé une étanchéité stable au cours des périodes de contrôle. Pour ce qui est du problème critique de la dégradation du dispositif d'étanchéité à l'air, aucune preuve à l'effet que le polyéthylène ne convenait pas pour rendre étanches à l'air les constructions résidentielles n'a été révélée. Bien que deux des dix maisons aient présenté des signes, au demeurant faibles mais possibles, d'une dégradation de l'étanchéité à l'air, ces changements ont été jugés mineurs et sans importance d'un point de vue pratique. Toutes les maisons munies de polyéthylène, sauf une, ont satisfait aux exigences du Programme de la maison R-2000 à la fin des périodes de contrôle.

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

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SECTION 1

INTRODUCTION

1.1 AIRTIGHTNESS IN RESIDENTIAL CONSTRUCTION

The term "airtightness" describes the ability of the building envelope to resist air infiltration or exfiltration which is created whenever a pressure differential is developed across openings in the envelope. This pressure differential can be produced by natural forces (i.e. wind or stack effect) or by the house's mechanical systems (i.e. heating or ventilation systems or any other appliances which move air across the envelope).

Ideally, the building envelope should not permit any unintentional air leakage to occur since this can increase energy costs, degrade air quality and comfort, produce moisture-related envelope problems and increase the transmission of outdoor noise to the interior. For example, indoor air quality can be degraded if the infiltrating air is contaminated by pollutants which originate outside the house, such as radon/soil gas or chemicals and toxic substances stored in an attached garage. However, the most serious consequence of air leakage is probably interstitial moisture damage which is a direct result of air exfiltration. This phenomenon can accelerate envelope degradation by permitting moisture deposition and accumulation along the leakage pathways. If it occurs in sufficient quantities, air exfiltration can lead to accelerated rotting of wood and wood product components, insulation wetting and staining and destruction of interior finishes and surfaces.

In practical terms, air leakage cannot be eliminated, but only controlled within prescribed limits. The first quantitative Canadian standard for airtightness in residential construction was established by the R-2000 Program which set limits on the maximum air leakage permitted in R-2000 houses and also specified requirements for testing of all candidate dwellings. Interestingly, the National Building Code does not contain any quantitative requirements for residential airtightness (NRC 1990).

The component, or system, in the building envelope which is responsible for providing airtightness is defined as the air barrier. Given the consequences of uncontrolled air leakage, it is obvious that the air barrier is a critical component of the building and must be designed and constructed to last the life of the structure.

1.2 OBJECTIVES

The objectives of the study described in this report were: to monitor the airtightness of 24 houses over extended periods of time, to comment upon the performance of their air barrier systems and to look for evidence of air barrier degradation as would be indicated by an increase in the measured air leakage rate.

1.3 DESCRIPTION OF THE PROJECT HOUSES AND MONITORING PROGRAM

The 24 project houses used in this study were constructed between 1985 and 1989 by Flair Homes (Manitoba) Ltd., a large Winnipeg tract builder. Airtightness tests were performed on a regular basis to quantify changes in air leakage rates. Additional details on the testing protocol and monitoring program are contained in Section 3.

Houses #1 through #20 were constructed in 1985 and 1986 in the Lakeside Meadows subdivision of Winnipeg and Houses #22 through #24 were completed in 1988 while House #21 was finished in early 1989. With the exception of #21, which was maintained as an unoccupied research structure, all were sold and occupied shortly after completion. Descriptions of the houses and their air and vapour barrier systems are provided in Tables 1 and 2. More detailed descriptions are given in Proskiw (1992). A sample floor plan is shown in Fig. 1.

The houses were all conventional bungalows with full basements and main floor areas of 60 m^2 to 85 m^2 (646 ft^2 to 915 ft^2). They were designed using either the polyethylene air barrier system or the Airtight Drywall Approach (ADA). Several versions of each system were used and in a few instances, the two systems were inter-mixed. In such cases, the structure was classified as a "polyethylene" or "ADA" air barrier house based on the dominant system in use.

1.4 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.

TABLE 1
DESCRIPTION OF PROJECT HOUSES

Feb/92

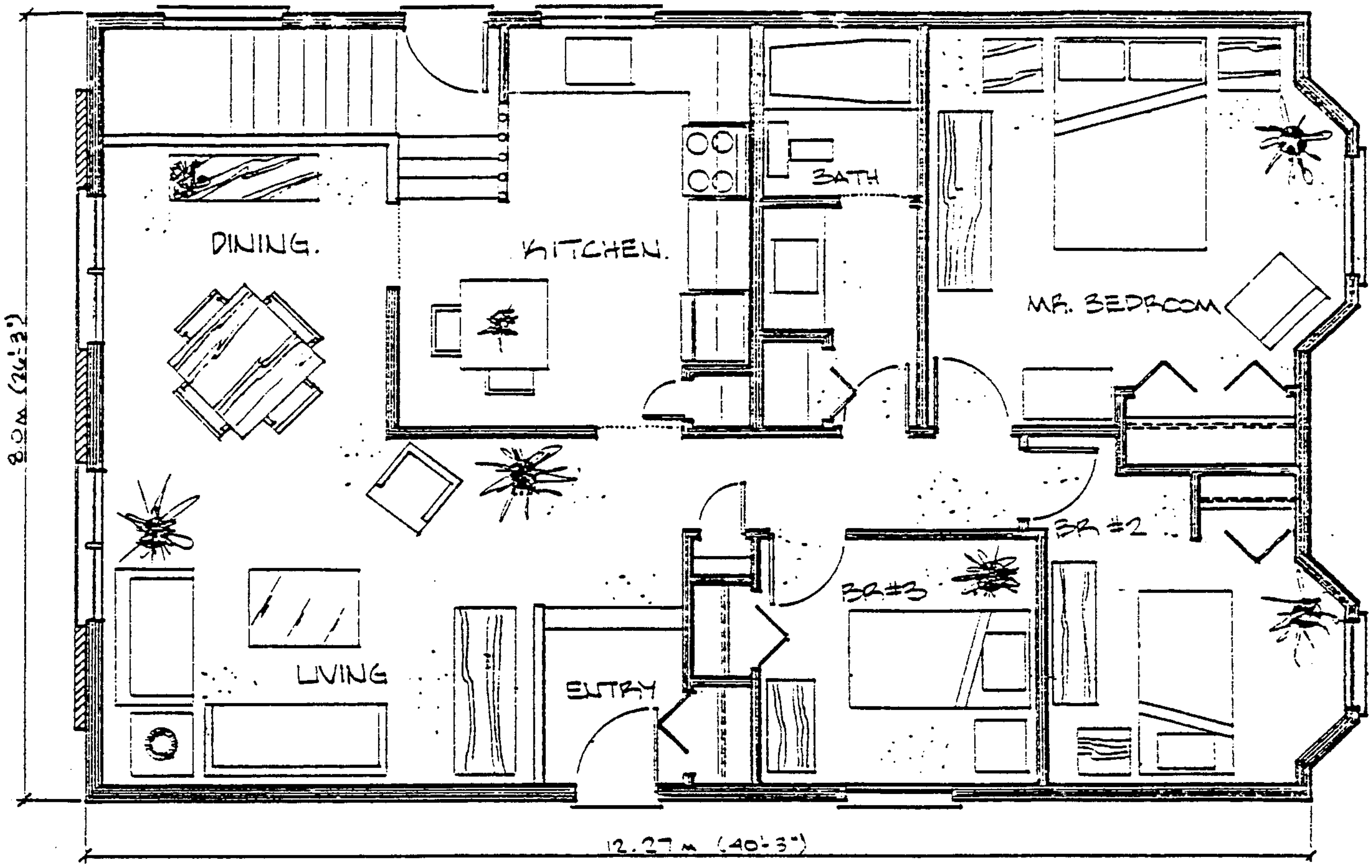
HOUSE	BUILDING ENVELOPE					MECHANICAL SYSTEMS		YEAR COMPLETED	ENERGY STANDARD
	WALL CONSTRUCTION	EXTERIOR WALL FINISH	BASEMENT CONSTRUCTION	CEILING/ATTIC CONSTRUCTION	WINDOWS	SPACE HEATING SYSTEM	VENTILATION SYSTEM		
1-6	38x140 (2x6), Rigid Glass Fibre Insulated Sheathing (Reversed) c/w SBPO Air Retarder	Stucco with Wood or Brick Siding	Cast Concrete	Cathedral & Truss Ceilings	Triple-Glazed; Fixed, Awning & Casement	Electric Forced Air Furnace	Heat Recovery Ventilator	1985	R-2000
7,8	38x140 (2x6)	Stucco with Wood Siding	Cast Concrete	Cathedral & Truss Ceilings	Triple-Glazed; Fixed, Awning & Casement	Electric Forced Air Furnace	Central Exhaust with Make-Up Air Duct	1985	Conventional
9,10	38x140 (2x6)	Stucco with Stone & Wood Siding	Cast Concrete	Cathedral & Truss Ceilings	Triple-Glazed; Fixed, Awning & Casement	Gas Forced Air Furnace	Bathroom Exhaust Fan	1985	Conventional
11-14	38x140 (2x6), Rigid Glass Fibre Insulated Sheathing c/w SBPO Air Retarder	Stucco with Wood, Brick or Stone Siding	Cast Concrete	Truss Ceiling	Triple-Glazed; Fixed, Awning & Casement	Electric Baseboards or Forced Air Furnace	Exhaust-only Heat Pump or Heat Recovery Ventilator	1986	R-2000
15,16	Double Wall	Stucco with Wood Siding	Cast Concrete	Truss Ceiling	Triple-Glazed; Fixed, Awning & Casement	Air-to-Air Heat Pump	Integrated with Space Heating System	1986	R-2000
17,18	Double Wall	Stucco with Brick, Wood or Stone Siding	Cast Concrete	Truss Ceiling	Triple-Glazed; Fixed, Awning & Casement	Electric Baseboards	Heat Recovery Ventilator	1986	R-2000
19,20	38x89 (2x4), Rigid Extruded Polystyrene Sheathing	Stucco with Wood & Brick Siding	Cast Concrete	Truss Ceiling	Triple-Glazed; Fixed, Awning & Casement	Electric Baseboards	Heat Recovery Ventilator	1986	R-2000
21	Predominately 38x140 (2x6) with Interior Strapping	Vinyl & Wood Siding	Cast Concrete	Cathedral & Truss Ceilings	Several Types	Several Types	Several Types	1989	R-2000
22	38x140 (2x6)	Stucco with Wood & Brick Siding	Cast Concrete	Cathedral & Truss Ceilings	Triple-Glazed; Fixed & Awning	Electric Forced Air Furnace	Central Exhaust	1988	Conventional
23	38x140 (2x6) with Interior Strapping	Stucco with Wood Siding	Cast Concrete	Cathedral & Truss Ceilings	Triple-Glazed; Fixed & Awning	Electric Forced Air Furnace	Heat Recovery Ventilator	1988	R-2000
24	38x140 (2x6) with Extruded Polystyrene Sheathing	Stucco with Wood & Brick Siding	Cast Concrete	Cathedral & Truss Ceilings	Triple-Glazed; Fixed, Awning & Casement	Electric Baseboards & Radiant Panels	Heat Recovery Ventilator	1988	R-2000

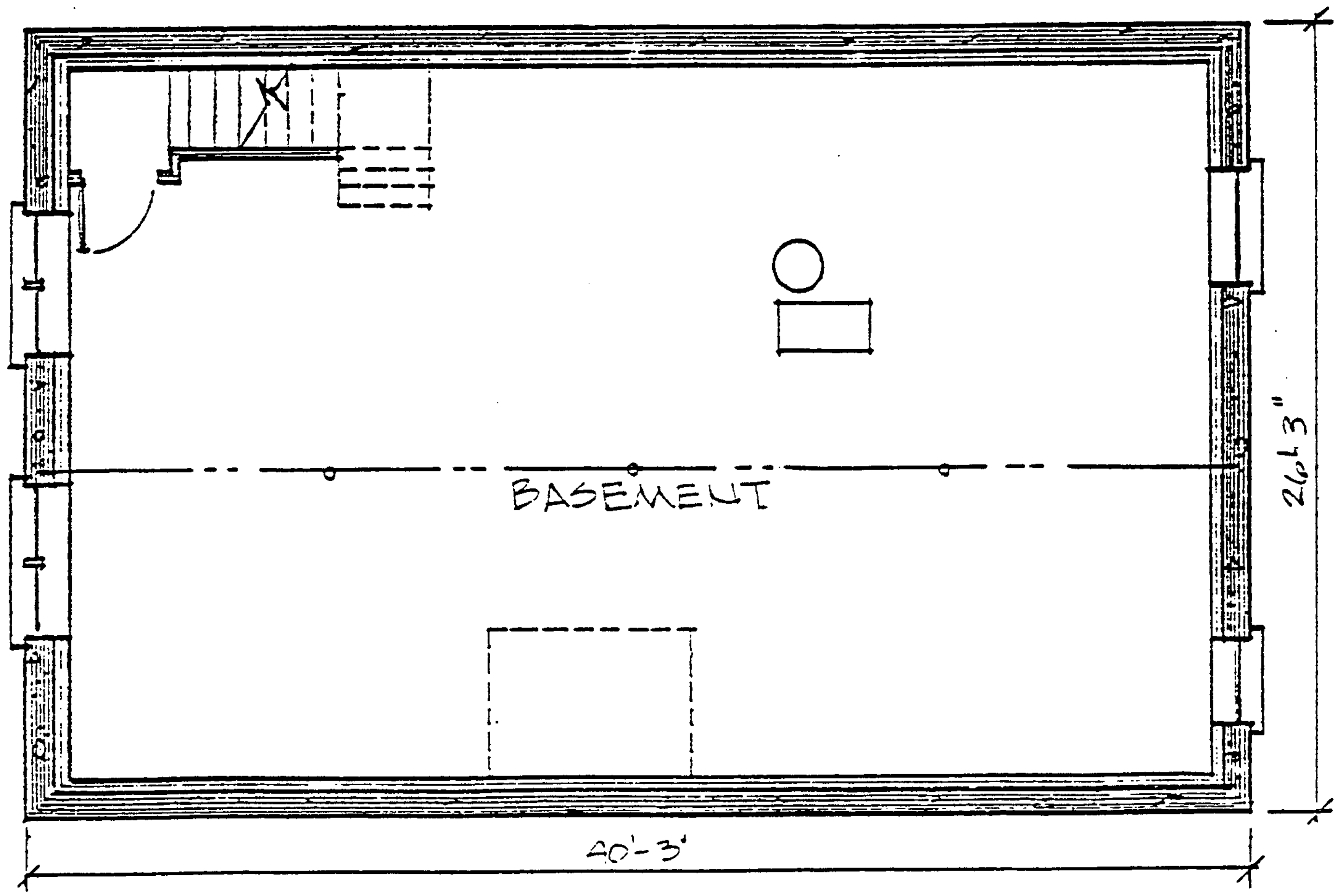
TABLE 2
AIR AND VAPOUR BARRIER DETAILS

Feb/92

HOUSE	AIR BARRIER							VAPOUR BARRIER		
	TYPE	SEALING METHOD					CREW	WALLS	CEILING	BASEMENT
		HEADERS	CANTILEVERS	PARTITION WALLS AT CEILING	WINDOW & DOOR ROUGH OPENINGS	ELECTRICAL OUTLETS				
1-6	ADA	Closed Cell Polyethylene Gaskets	Closed Cell Polyethylene Gaskets	Gaskets	Gaskets	Poly-Pan Boxes & Gaskets	A	Paint	Paint	Paint
7,8	ADA	Closed Cell Polyethylene Gaskets	Closed Cell Polyethylene Gaskets	Gaskets	Gaskets	Poly-Pan Boxes & Gaskets	A	Paint	Paint	Paint
9,10	4 mil Polyethylene	None	None	Unsealed Polyethylene	Unsealed Polyethylene	Unsealed Polyethylene	A	Polyethylene	Polyethylene	Polyethylene
11-14	Simplified ADA	None	None	None	Ethafoam Rod Gaskets	Poly-Pan Boxes & Gaskets	B	Paint	Paint	Paint
15,16	6 mil Polyethylene	Caulking	Caulking	Sealed Polyethylene	Sealed Polyethylene	Sealed Polyethylene	B	Polyethylene	Polyethylene	Polyethylene
17,18	6 mil Polyethylene	Caulking	Caulking	Sealed Polyethylene	Sealed Polyethylene	Sealed Polyethylene	B	Polyethylene	Polyethylene	Polyethylene
19,20	ADA	Closed Cell Polyethylene & Neoprene Gaskets	Closed Cell Polyethylene & Neoprene Gaskets	Neoprene Gaskets	Ethafoam Rod Gaskets	Poly-Pan Boxes & Gaskets	B	Paint	Paint	Paint
21	Primarily 6 mil Polyethylene	Sealed Polyethylene	Sealed Polyethylene & SBPO Air Retarder	Sealed Polyethylene	Various	Sealed Polyethylene	C	Polyethylene	Polyethylene	Polyethylene
22	Primarily 6 mil Polyethylene	Sealed Polyethylene & SBPO Air Retarder	Sealed Polyethylene & SBPO Air Retarder	Saturated Urethane Open Cell Gaskets	Various	Polyethylene	D	Polyethylene	Polyethylene	Polyethylene
23	6 mil Polyethylene	Sealed Polyethylene & SBPO Air Retarder	Sealed Polyethylene & SBPO Air Retarder	Sealed Polyethylene	Various	Sealed Polyethylene	D	Polyethylene	Polyethylene	Polyethylene
24	6 mil Polyethylene	Sealed Polyethylene & SBPO Air Retarder	Sealed Polyethylene & SBPO Air Retarder	Saturated Urethane Open Cell Gaskets	Various	Polyethylene	D	Polyethylene	Polyethylene	Polyethylene

FIGURE 1


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


BASEMENT
26'-3"
40'-3"

SECTION 2

AIR BARRIERS

2.1 THEORY OF AIR BARRIER DESIGN

The primary requirements of an effective air barrier are generally defined to include:

a) Low permeability to air flow
b) Structural strength to withstand air pressure loads
c) Continuity to reduce leakage
d) Durability to last the life of the building
e) Rigidity to provide pressure equalization behind exterior cladding

The air barrier may consist of a single material or an assembly of materials. In residential construction sheet polyethylene is the most commonly used material with the joints and penetrations either sealed or stapled in place, although the airtightness may suffer if the latter technique is used. In most applications, the polyethylene also functions as the vapour barrier.

A second system, which has gained some acceptance in recent years, is the Airtight Drywall Approach in which the drywall functions as the air barrier and uses strategically placed gaskets at joints and penetrations. Paint, with a low water vapour permeance, or polyethylene is used as the vapour barrier.

In the last few years, sheet materials such as spun-bonded polyolefin (SBPO) have also become available which provide unique properties and opportunities for improving airtightness. These materials function as air retarders (not air barriers), yet provide a high permeance to water vapour allowing them to be located at any position within the envelope whereas combined air/vapour barriers, such as sheet polyethylene, must be located close to the warm side to control condensation caused by vapour diffusion.

At the present time, there is considerable debate as to which air barrier system is most appropriate for Canadian conditions. The so-called "poly approach" is viewed as the more traditional and better-understood technique while proponents of ADA argue that it will have a longer lifespan and be better able to withstand the severe pressure forces to which air barriers can be exposed.

A central issue in the debate has been the requirement for structural strength, specifically the maximum load the air barrier must be designed to resist. These loads are created by stack effect, wind action and operation of the mechanical systems. In residential construction, pressure loads due to stack effect seldom exceed 10 to 20 Pascals (Pa) while loads created by mechanical systems may, in extreme cases, be slightly larger. Wind action however, can generate pressures on an exposed building surface of over 1000 Pa for extended periods of time and perhaps 2500 Pa for short periods, i.e. a few seconds, during gusts.

Another criticism of polyethylene air barriers has been their durability, specifically whether they can last the life of the structure or whether chemical, physical or mechanical forces will destroy the material. One outcome of this criticism has been the establishment of a new product standard - CGSB Standard CAN2-51.34-M86, "Vapour Barrier, Polyethylene Sheet, For Use in Building Construction" (CGSB 1986).

2.2 PREVIOUS STUDIES

The study of residential airtightness has been a favourite topic of building scientists for several years. One of the first facts realized about this subject was that airtightness is not a fixed characteristic of a structure but can increase, decrease or fluctuate over time. For example, Persily (1982) measured the airtightness of a single, unoccupied wood frame structure located in New Jersey and found seasonal variations of 25% in the air change rate at 50 Pascals (ac/hr_{50}, discussed in Section 3). He postulated that changes in the moisture content of the framing members were responsible for the variations since these can induce dimensional variations in crack size and geometry as the wood expands and contracts in response to environmental conditions. Kim and Shaw (1986) explored this issue in more detail using two unoccupied Ottawa houses and reported seasonal variations of approximately 20% with 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 airtightness and the humidity ratio of the indoor air which further supports the swelling/shrinking theory for wood frame members.

Howell and Mayhew (1987) tested six Edmonton houses over a two year period and found the ADA houses in the sample were tighter than the conventional structures. (Note: these "conventional" houses were different from the "conventional" structures described in this report.) They also observed that at the end of the test period, the ADA houses had become leakier while airtightness levels of the conventional structures were unchanged. They attributed the degradation in airtightness to deterioration of the caulked joints between the basement drywall and the floor joists - a technique not used in the Flair houses.

Buchan, Lawton, Parent Ltd. (1988) reported the initial and final airtightness levels of 90 houses over periods ranging from 3 to 63 months and found that the airtightness only changed significantly in 9 houses. They concluded that their observations did not support the hypothesis that polyethylene degraded when used as an air barrier in residential construction.

European experiences with airtightness have been somewhat different, possibly due to variations in construction practices and/or air barrier design. The Air Infiltration Centre (1985) observed that changes in airtightness typically occurred in the first year after construction. They reported examples of five Swedish houses which exhibited a 70% increase in their ac/hr_{50} values in the first year and then maintained a constant airtightness thereafter. Three British houses were also reported to have experienced an average 83% increase in the first year. Carlsson and Kronvall (1984) reported that airtightness levels remained constant in 15 Swedish "timber-framed" houses when tested at completion and then again after 1.5 to 4.5 years. It is not known how applicable these results are to North American construction.

A major cross-country study, conducted in 1989, of the airtightness of approximately 200 new, conventional (i.e. non energy efficient) houses found significant variations depending on location (Hamlin et al 1990). The tightest houses were found to be those built in Winnipeg while the leakiest were in Vancouver, see Fig. 2. Although the project did not explore the effect of house age upon airtightness, the results are noted here to offer a benchmark for the Flair study.

FIGURE 2(a)

AC/HR50 OF NEW, CONVENTIONAL HOUSES
(FROM HAMLIN et al 1990)

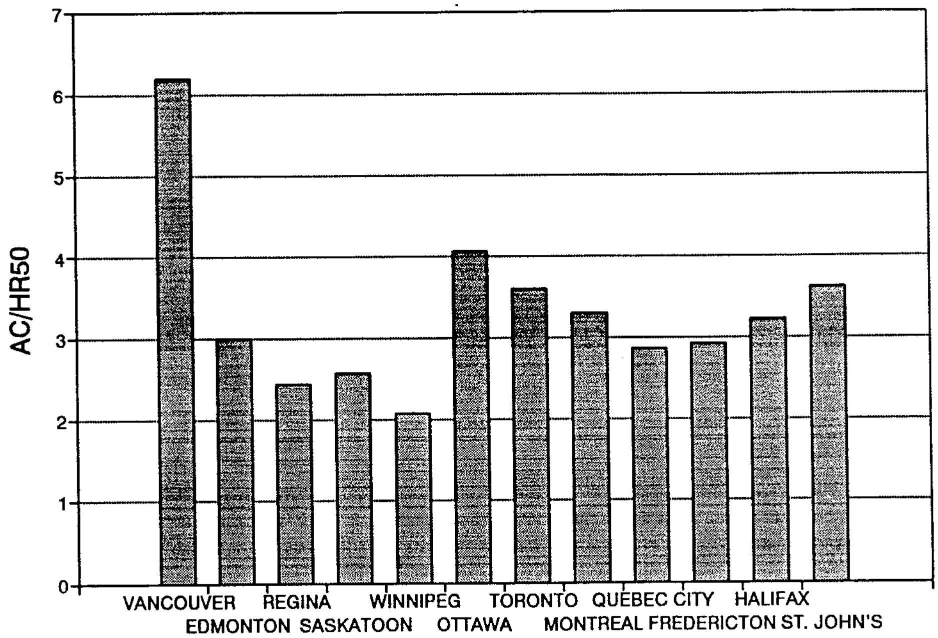
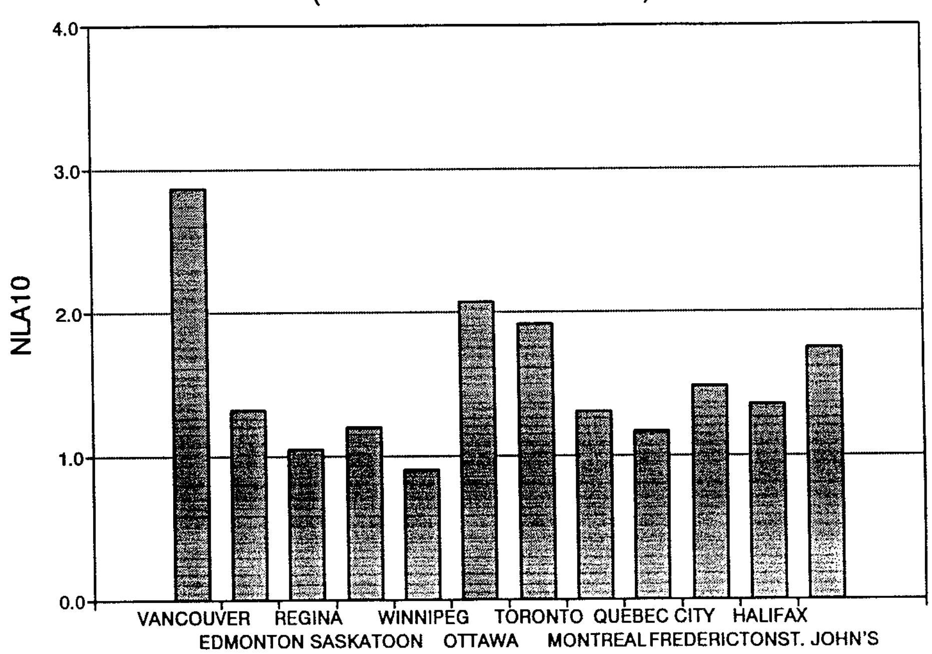


FIGURE 2(b)

NLA10 OF NEW, CONVENTIONAL HOUSES
(FROM HAMLIN et al 1990)



SECTION 3

MONITORING PROGRAM

3.1 TESTING METHODOLOGY

Airtightness tests were performed at regular intervals on the 24 project houses in accordance with CAN/CGSB-149.10-M86 "Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method" (CGSB 1986). This procedure measures the air leakage rate of the building envelope at various indoor-to-outdoor pressure differentials ranging from 15 to 50 Pascals. Using this data, a regression curve is produced from which the airtightness is expressed as a leakage parameter at a specified pressure differential. The test characterizes the leakage of the entire envelope assembly, not just the defined "air barrier". The testing schedule for the project houses is summarized in Fig. 3.

In this report, airtightness results are expressed using two methods: the air change rate at 50 Pascals (ac/hr_{50}) and the Normalized Leakage Area at 10 Pascals (NLA_{10}). The former is considered by some to be more representative of the "true" airtightness since it does not rely on extrapolation beyond the range of the experimental data.

For comparison purposes, the R-2000 Standard requires that the measured airtightness be less than 1.50 ac/hr_{50} or the NLA_{10} not exceed 0.7 cm^2/m^2. These values are unofficially regarded within the building science community as representative of a high level of airtightness and are often cited as the boundary between "tight" and "non-tight" construction.

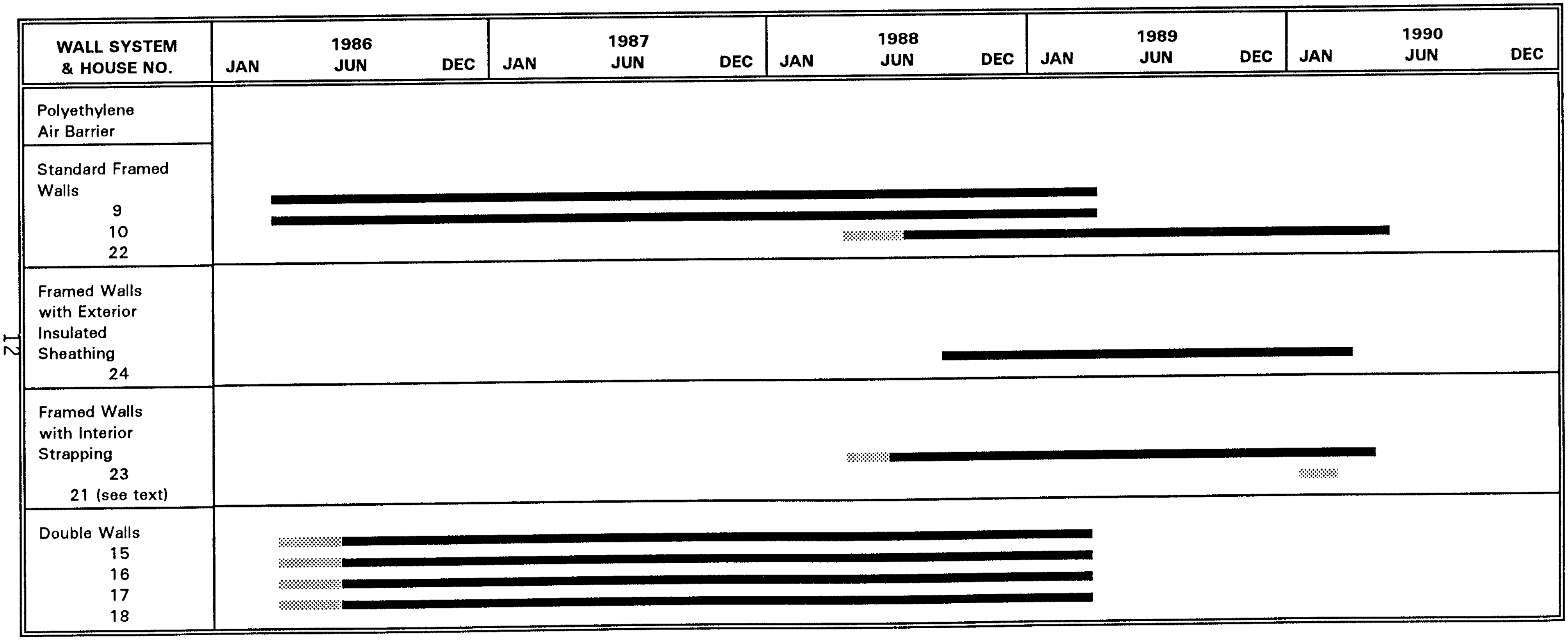
3.2 CONDITION OF THE HOUSES

The initial airtightness tests on the project houses were performed shortly after their completion, but prior to their occupancy. In roughly half the cases, tests were also performed prior to the application of stucco. This is noted because stucco can have a significant impact upon airtightness.

During the monitoring period, regular contact was maintained with the occupants and the houses were routinely inspected to identify any physical changes which may have occurred that would have affected their airtightness. Few such changes were observed and these were judged to have been typical for new houses in the first few years following construction: degradation of door and window weatherstripping, cracking of the basement floor slab and general movement of the structure. Some basement development was performed by the homeowners in Houses #1, #9, #10, #13, #14, #15, #17 and #20, but this is not believed to have had a major impact on airtightness. A wood stove was also installed in House #14 in January 1989; data collected after this date was excluded from the analysis for this structure.

FIGURE 3(a)

MONITORING SCHEDULE

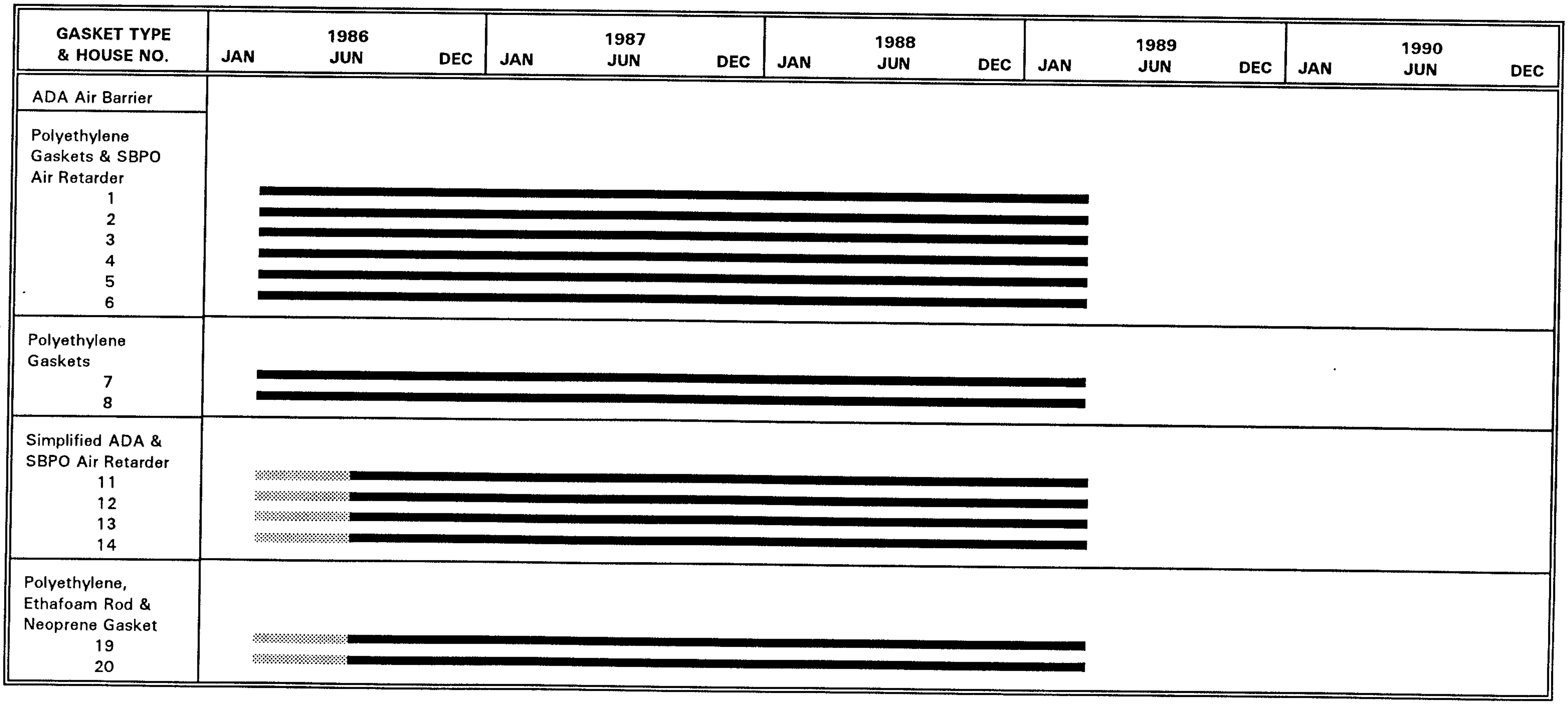


NOTES:

1. (shaded) = No Stucco
2. (solid) = Stucco

FIGURE 3(b)

MONITORING SCHEDULE



NOTES:

1. (shaded) = No Stucco
2. (solid) = Stucco

3.3 AIRPORT WIND DATA

The magnitude of the wind loading on a house envelope is difficult to express succinctly because of the wide variations in wind pressure which result from localized turbulence and micro-flow behaviour. For this study, airport wind data was used to provide a rough indication of the wind environment experienced by the houses. Figure 4 shows the monthly two minute maximum and maximum gust winds recorded 10 m above ground level at Winnipeg International Airport, located approximately 15 km from Houses #1 to #20 and 7 km from Houses #21 to #24. Figure 5 shows the corresponding velocity pressures.

3.4 ANALYSIS METHODS

Air barrier deterioration is most clearly demonstrated by a degradation in airtightness, however it is necessary to consider how a "change" in airtightness should be defined. For this study, four analysis methods were used to evaluate changes in airtightness:

1. Visual Examinations

A visual examination of the airtightness versus time plot was made for each house to identify any change in leakage. This is a useful method of highlighting permanent, significant changes in airtightness. "Significant", in this context, can be defined as an irreversible increase in leakage of sufficient magnitude as to be obvious from visual examination of the data. The difficulty, of course, lies in objectively defining what constitutes a significant change and is further compounded by the uncertainty of knowing whether the observed change was permanent and whether it was due to a unknown physical alteration unrelated to air barrier degradation.

2. Variation Between the First and Last Airtightness Tests

The absolute and percentage changes in airtightness were compared using the results of the first and last tests. The major weaknesses of this method of analysis are its susceptibility to measurement error, since only two data points are used, and the possibility of error caused by seasonally-induced variations in airtightness if the tests were made at different times of year. Also, this method does not distinguish between a slow, gradual degradation in airtightness and a single-event change.

3. Variation Between the First and Last Seasonally Coincident Airtightness Tests

This is similar to the previous method, except it has the advantage that the seasonal impact on airtightness is eliminated since only seasonally coincident data is used in the analysis.

FIGURE 4

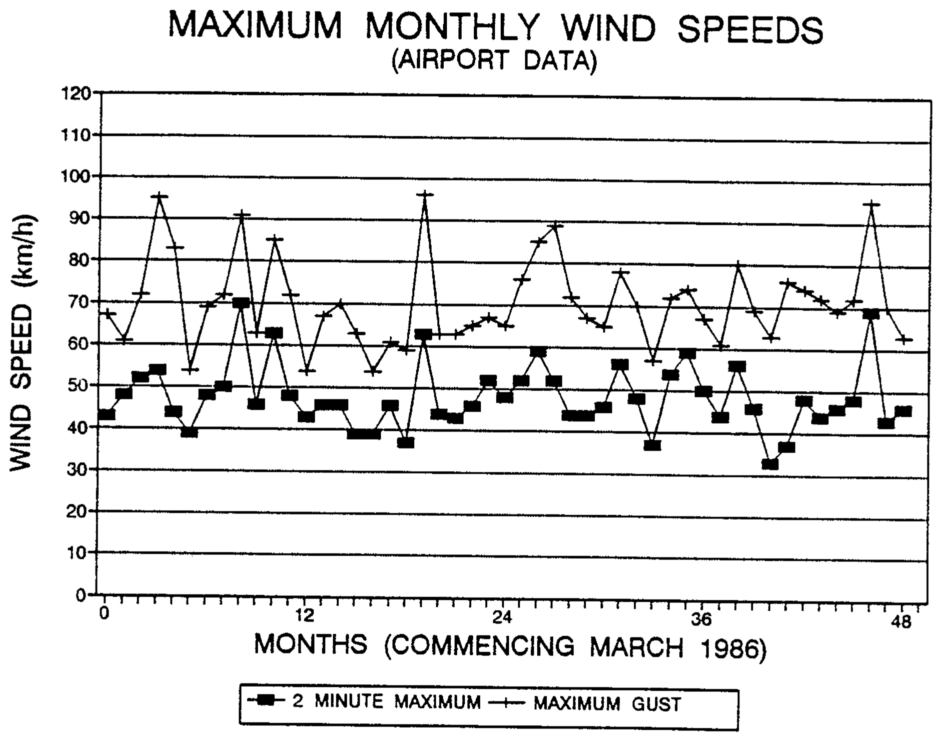
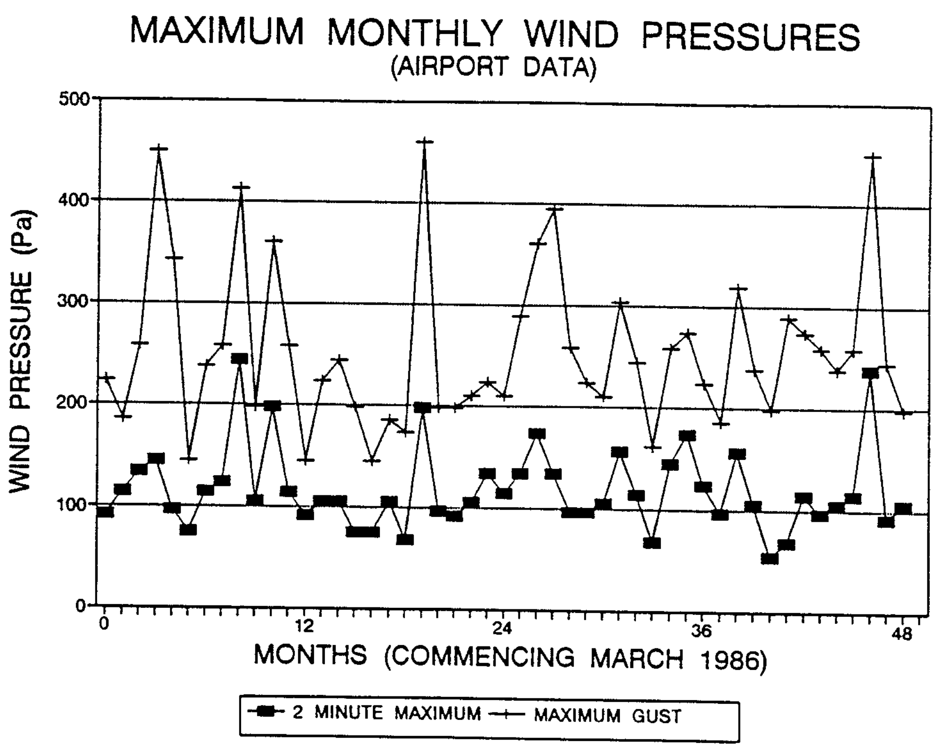


FIGURE 5



4. Statistical Tests

Statistical analyses can also be used to shed light on the significance of observed variations in house airtightness. Degradation of airtightness is essentially a question of determining whether a dependency exists between two parameters - airtightness and time. If a relationship does not exist, then no correlation between the two parameters should be observable. This concept can be expressed mathematically (using ac/hr_{50} data as an example) with a regression equation of the form:

$$ac/hr_{50} = \alpha + \beta (t) \tag{1}$$

where:
α = Initial ac/hr_{50} at the start of the monitoring period
β = Slope of the regression equation
t = Time.

If no degradation occurred, then β should equal zero whereas a positive value for β would indicate an increase in leakage with time. This approach has the advantage that data from intermediate tests can be utilized thereby increasing experimental confidence. This is particularly valuable in the absence of catastrophic failures since degradation can occur at a leisurely pace over the monitoring period, such that the change is not readily apparent yet still of significance relative to the life of the structure.

For each house, the following null hypothesis was formulated:

$$H : \beta = 0 \tag{2}$$

A regression equation, of the form given in Eq. 1, was computed to determine β, which was then compared to the zero value assumed in the null hypothesis. The significance of the difference was then evaluated by calculating the one-sided t-statistic with the appropriate degrees of freedom. This produced the probability that the observed difference between the sample value of β (from the regression equation) would be equal to, or greater than, the population mean (i.e. the true value). A 5% level of significance was used as a cut-off criterion. In other words, if the t-test indicated that the null hypothesis should be rejected, this meant there was a 5% probability that the conclusion would be incorrect. The one-sided, rather than two-sided, t-statistic was used because a reduction in leakage would not be indicative of air barrier degradation.

Another way to quantify the variation in the dependent variable (airtightness) due to the independent variable (time) is the coefficient of determination, r^2. In this application, it describes the percentage of the variation in airtightness which is due to the time dependency. For this analysis, an r^2 value of 0.60 was used to highlight possible dependencies.

These four methods were used to analyze the ac/hr_{50} and NLA_{10} data for each of the project houses. However, no single method was regarded as providing a definitive statement on whether the airtightness was degrading with time. This assessment was made after consideration of the data, the analysis methods and the houses themselves. Finally, the analysis was restricted to data collected from the houses in a post-stucco condition.

3.5 AIR LEAKAGE LOCATIONS

Inspections were conducted at the beginning and end of the monitoring period to identify air leakage locations in the envelopes and to highlight patterns in source distribution. Sources were qualitatively categorized as either "minor" or "major", by the testing technician.

Significant observations from these inspections are included as part of the discussion in the next two sections. Mention is made of changes in source strength or frequency for the major locations (particularly those other than doors, windows and other obvious penetrations) since such changes could be indicative of air barrier degradation.

SECTION 4

PERFORMANCE OF THE POLYETHYLENE AIR BARRIER SYSTEMS

4.1 TYPES OF WALL SYSTEMS

The ten project houses which used the polyethylene air barrier system were constructed with four types of main wall systems:

- o Standard frame walls (Houses #9, #10 and #22)
- o Frame walls with exterior insulated sheathing (House #24)
- o Frame walls with interior strapping (Houses #21 and #23)
- o Double walls (Houses #15 to #18)

In the following discussion, the performance of the project houses is reviewed on the basis of their wall type because the walls would have been subjected to the most severe wind loadings and therefore any degradation of airtightness would likely have resulted from damage to the wall air barrier. In contrast, the ceiling air barrier was aerodynamically shielded by the roof system and would also have received support from the ceiling drywall and, to a degree, the (weight of) insulation above. In the basement, the concrete walls and slab formed the primary air barrier since the interior polyethylene was only loosely attached. Previous experiences with testing partially completed houses have shown that very low leakage rates can be achieved even with bare, cast concrete basement walls.

The measured airtightness results are given in Tables 3 and 4 and Figs. 6 to 11; the former also include the absolute and percentage variations between the first and last tests and the first and last seasonally coincident tests. Results of the statistical analysis are shown in Table 5. A summary of the results, using the four analysis methods, is given in Table 6.

4.2 STANDARD FRAME WALLS

4.2.1 Description

Houses #9 and #10 were typical of "conventional" prairie construction and used 4 mil polyethylene, stapled in place, directly behind the drywall with no sealing between joints or at penetrations. Standard 38x140 (2x6) framing was used for the main walls. Door and window rough openings were packed with pieces of glass fibre insulation. Stucco was used on three of the four walls.

House #22 used a simplified air barrier system with polyethylene on the walls, ceiling and (as the vapour barrier) in the basement with a SBPO air retarder wrap on headers and cantilevers. Joints and penetrations in the air barrier and air retarder were carefully sealed. Another departure from the conventional polyethylene approach was the use of gaskets at the top of partition walls.

TABLE 3

ac/hr$_{50}$ RESULTS - POLYETHYLENE AIR BARRIER HOUSES

WALL SYSTEM & HOUSE NO.	MAR/86	JUL/86	NOV/86	FEB/87	JUL/87	NOV/87	FEB/88	MAY/88	JUN/88	JUL/88	AUG/88	NOV/88	MAR/89	JUN/89	AUG/89	DEC/89	JAN/90	MAR/90	APR/90
Standard Framed Walls																			
9	1.622	1.655	1.741	1.838	1.484	1.684	1.781			1.739		1.729	1.774						
10	1.281	1.152	1.429	1.386	1.167	1.038	1.032			1.199		1.243	1.187						
22								1.588*		0.955						0.939			1.144
Framed Walls with Exterior Insulated Sheathing																			
24											1.385				1.391	1.313		1.290	
Framed Walls with Interior Strapping																			
23								1.917*	1.432					1.322		1.267			1.341
21 (see text)																			
Double Walls																			
15	1.473*	1.328	1.257	1.152		1.104				1.221			1.187						
16	1.258*	1.292	1.382	1.405		1.519							1.495						
17	0.549*	0.363	0.713	0.437	0.570	0.384	0.564			0.435		0.452	0.395						
18	0.486*	0.416	0.478	0.480	0.385	0.418	0.434			0.489		0.382	0.436						

CHANGE BETWEEN FIRST (POST-STUCCO) TEST AND FINAL TEST

WALL SYSTEM & HOUSE NO.	ABSOLUTE CHANGE[2] (ac/hr$_{50}$)	%[2]	NO. OF MONTHS
Standard Framed Walls			
9	0.152	9	36
10	-0.094	-7	36
22	0.189	20	21
Framed Walls with Exterior Insulated Sheathing			
24	-0.095	-7	19
Framed Walls with Interior Strapping			
23 / 21 (see text)	-0.091	-6	22
Double Walls			
15	-0.141	-11	32
16	0.204	16	32
17	0.032	9	32
18	0.020	5	32

CHANGE BETWEEN FIRST (POST-STUCCO) TEST AND FINAL SEASONALLY-COINCIDENT TEST

WALL SYSTEM & HOUSE NO.	ABSOLUTE CHANGE[2] (ac/hr$_{50}$)	%[2]	NO. OF MONTHS
Standard Framed Walls			
9	0.152	9	36
10	-0.094	-7	36
22	N/A	N/A	N/A
Framed Walls with Exterior Insulated Sheathing			
24	0.058	0.4	12
Framed Walls with Interior Strapping			
23 / 21 (see text)	-0.109	-8	12
Double Walls			
15	0.036	3	25
16	0.090	6	25
17	-0.041	-10	25
18	-0.044	-9	25

NOTES:
1. * = No Stucco
2. A -ve indicates the house became more airtight.

TABLE 4

NLA_{10} RESULTS - POLYETHYLENE AIR BARRIER HOUSES

WALL SYSTEM & HOUSE NO.	MAR/86	JUL/86	NOV/86	FEB/87	JUL/87	NOV/87	FEB/88	MAY/88	JUN/88	JUL/88	AUG/88	NOV/88	MAR/89	JUN/89	AUG/89	DEC/89	JAN/90	MAR/90	APR/90
Standard Framed Walls																			
9	0.559	0.587	0.566	0.623	0.596	0.641	0.659			0.619		0.613	0.606						
10	0.588	0.418	0.642	0.805	0.404	0.441	0.392			0.468		0.517	0.644						
22								0.697*		0.372						0.361			0.445
Framed Walls with Exterior Insulated Sheathing																			
24											0.572				0.640	0.771		0.581	
Framed Walls with Interior Strapping																			
23								0.933*	0.652					0.549		0.540			0.816
21 (see text)																			
Double Walls																			
15	0.774*	0.655	0.597	0.547		0.539				0.659			0.593						
16	0.677*	0.675	0.714	0.711		0.777							0.715						
17	0.278*	0.154	0.340	0.166	0.250	0.132	0.307			0.166		0.193	0.149						
18	0.259*	0.227	0.190	0.192	0.155	0.138	0.171			0.177		0.141	0.177						

CHANGE BETWEEN FIRST (POST-STUCCO) TEST AND FINAL TEST

WALL SYSTEM & HOUSE NO.	ABSOLUTE CHANGE[2] (NLA_{10})	%[2]	NO. OF MONTHS
Standard Framed Walls			
9	0.047	8	36
10	0.056	10	36
22	0.073	19	21
Framed Walls with Exterior Insulated Sheathing			
24	0.009	2	19
Framed Walls with Interior Strapping			
23	0.164	25	22
21 (see text)			
Double Walls			
15	-0.062	-9	32
16	0.039	6	32
17	-0.005	-3	32
18	-0.050	-22	32

CHANGE BETWEEN FIRST (POST-STUCCO) TEST AND FINAL SEASONALLY-COINCIDENT TEST

WALL SYSTEM & HOUSE NO.	ABSOLUTE CHANGE[2] (NLA_{10})	%[2]	NO. OF MONTHS
Standard Framed Walls			
9	0.047	8	36
10	0.056	10	36
22	N/A	N/A	N/A
Framed Walls with Exterior Insulated Sheathing			
24	0.068	12	12
Framed Walls with Interior Strapping			
23	-0.103	-16	12
21 (see text)			
Double Walls			
15	0.046	8	25
16	0.004	1	25
17	-0.017	-12	25
18	-0.015	-8	25

NOTES: 1. * = No Stucco
2. A -ve indicates the house became more airtight.

FIGURE 6(a)

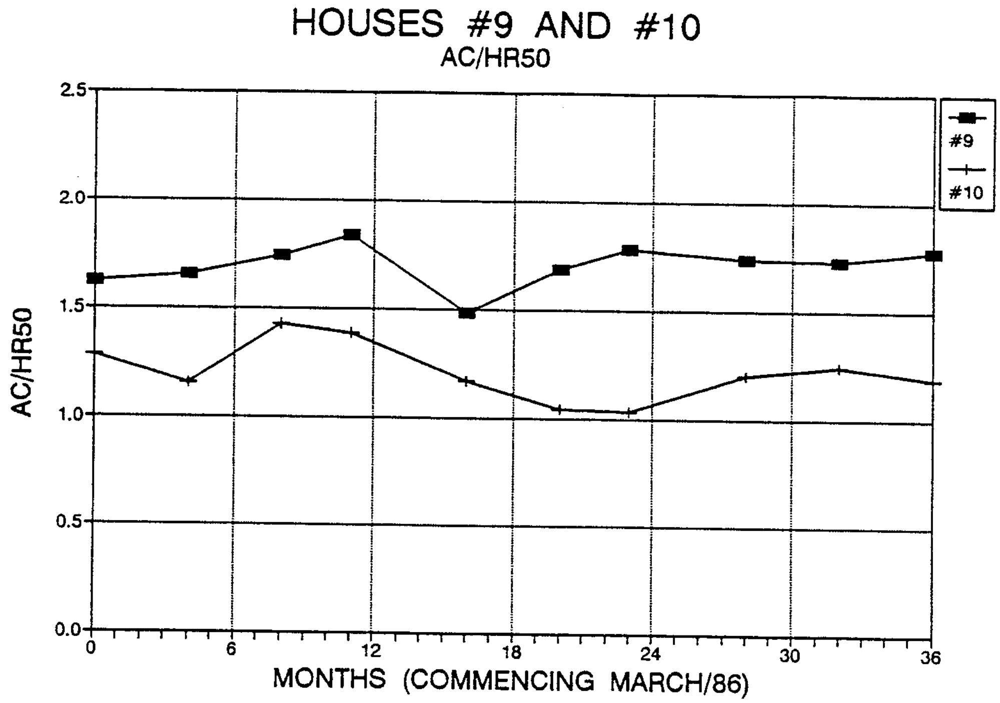


FIGURE 6(b)

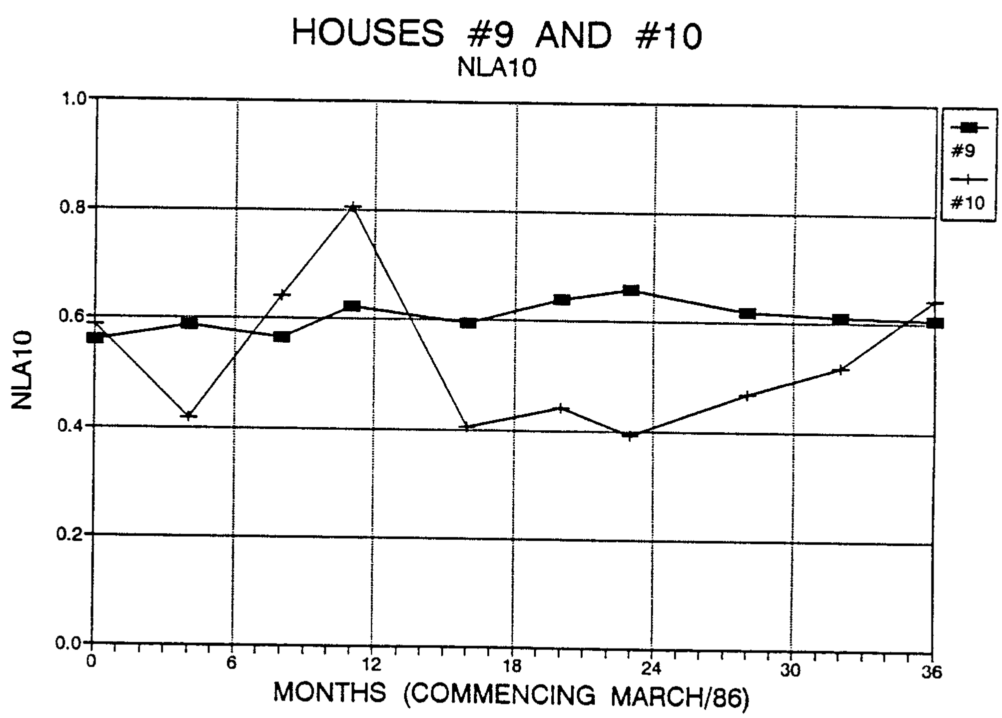


FIGURE 7(a)

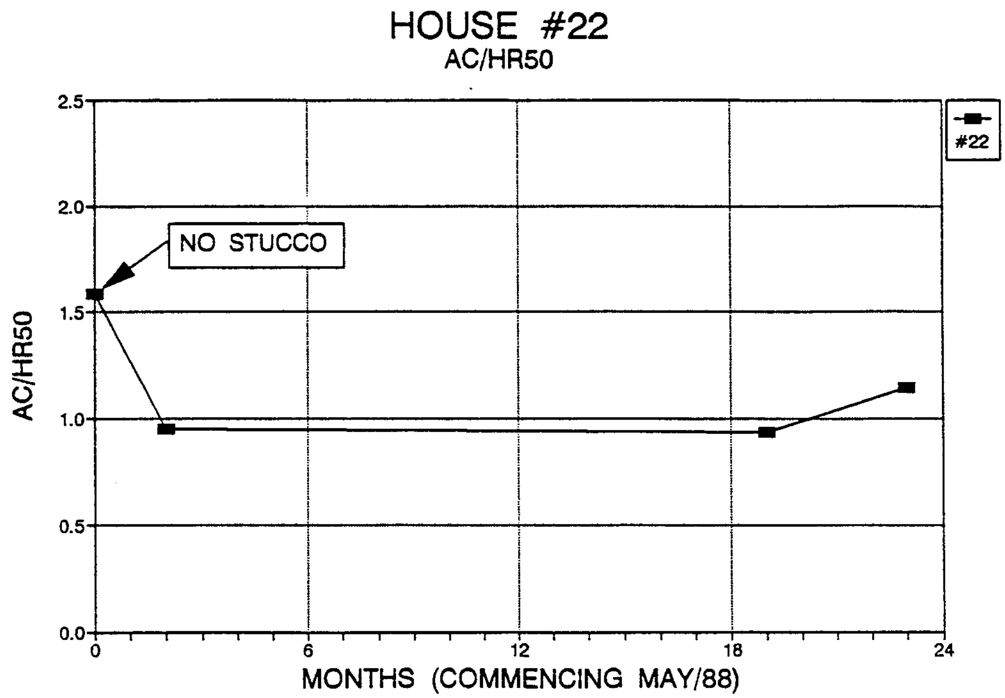


FIGURE 7(b)

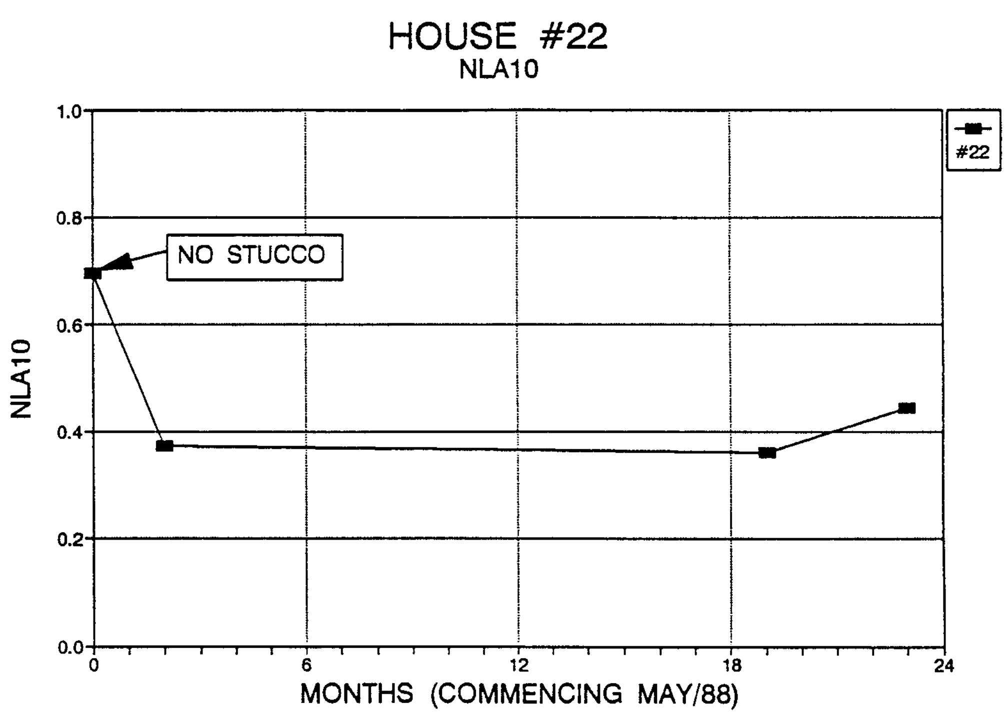


FIGURE 8(a)

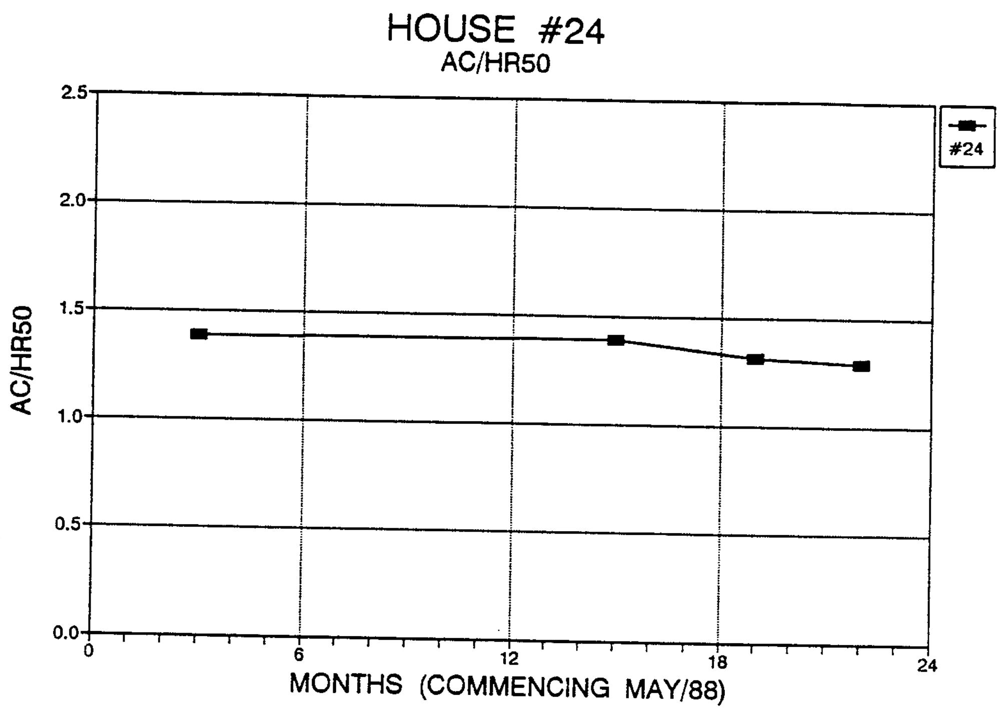


FIGURE 8(b)

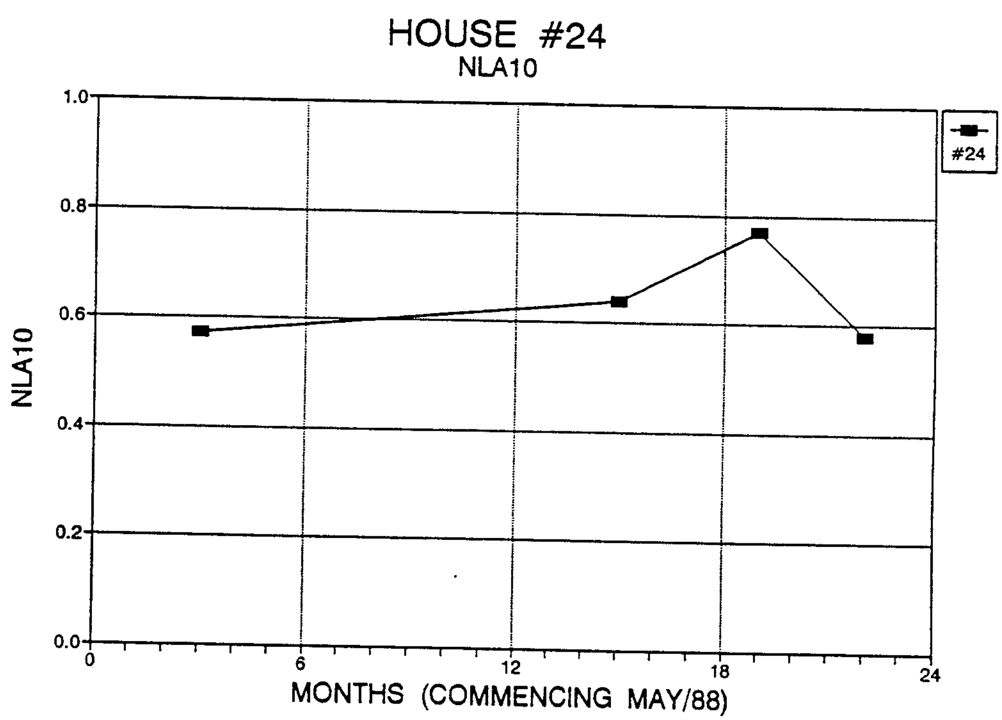


FIGURE 9(a)

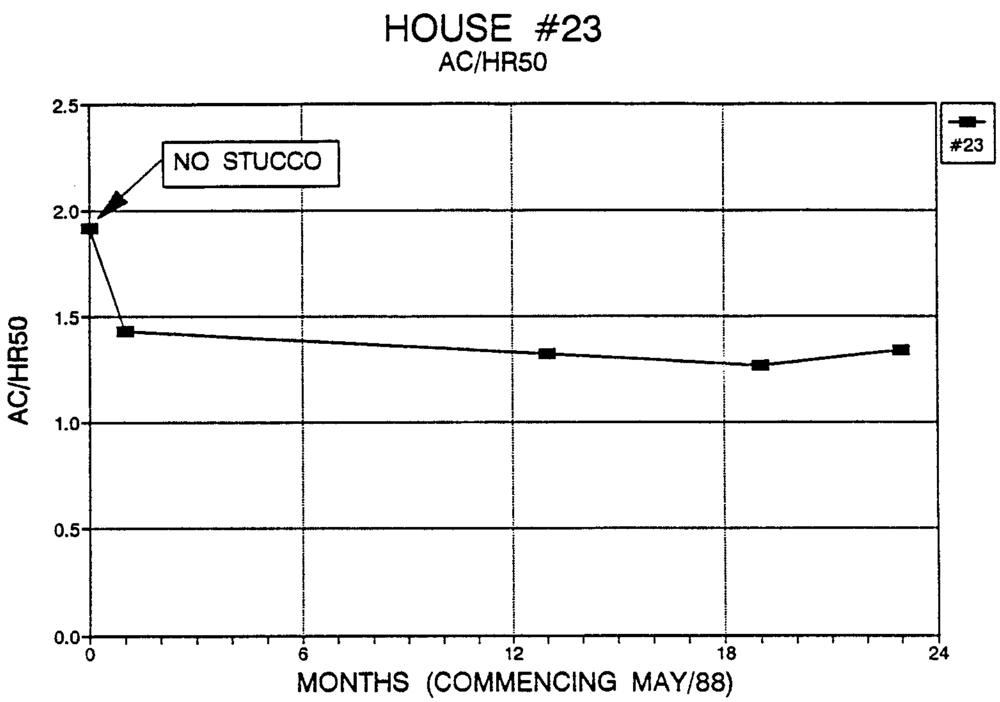


FIGURE 9(b)

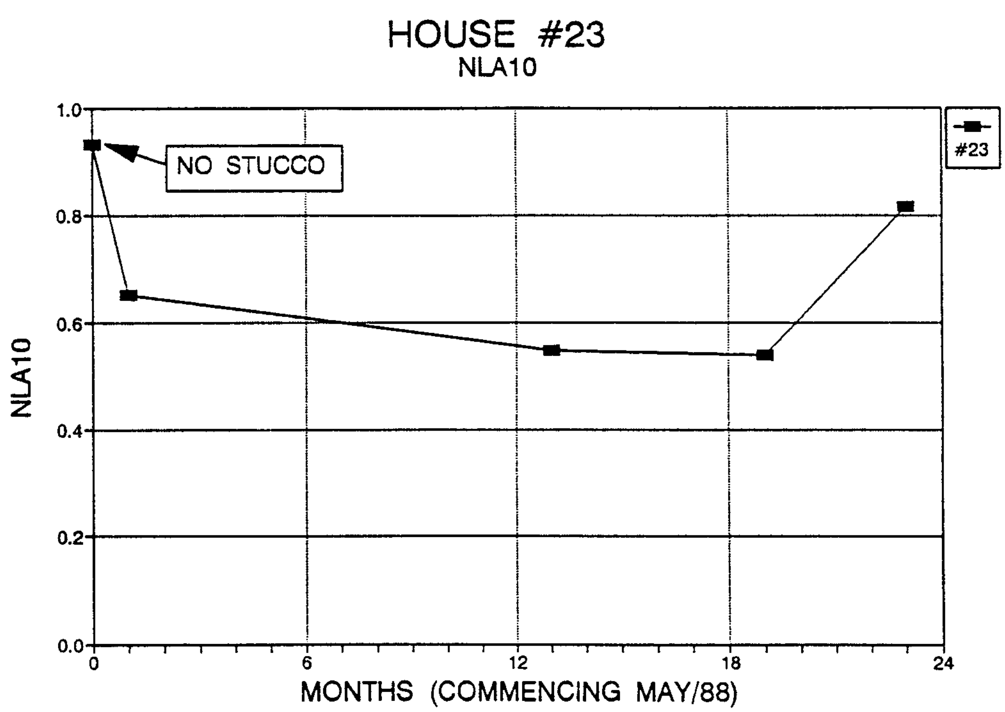


FIGURE 10(a)

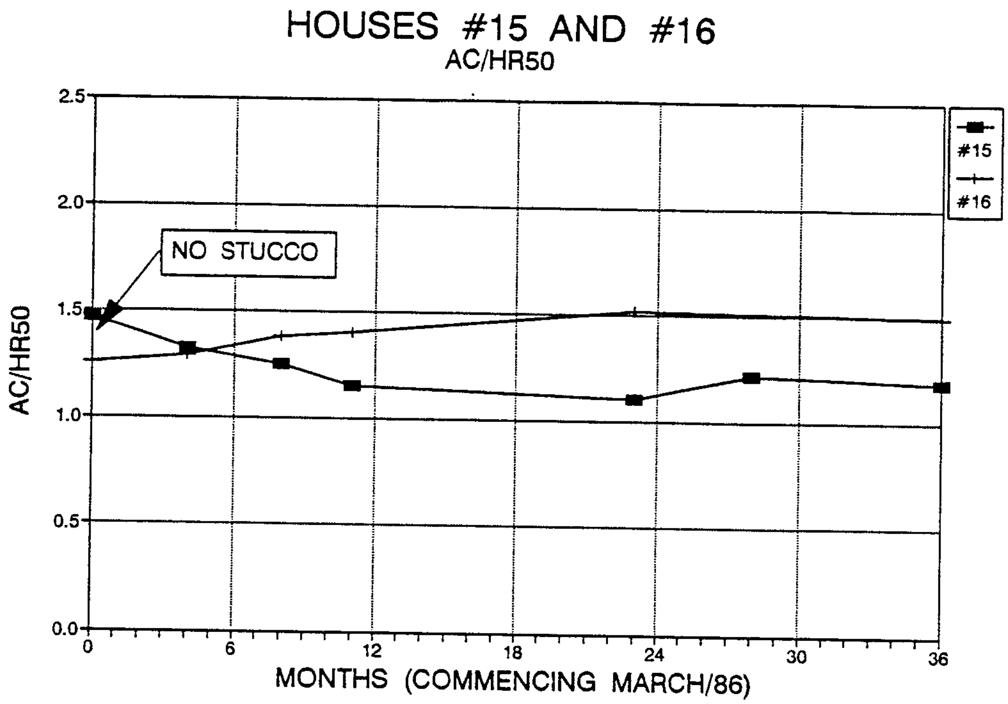


FIGURE 10(b)

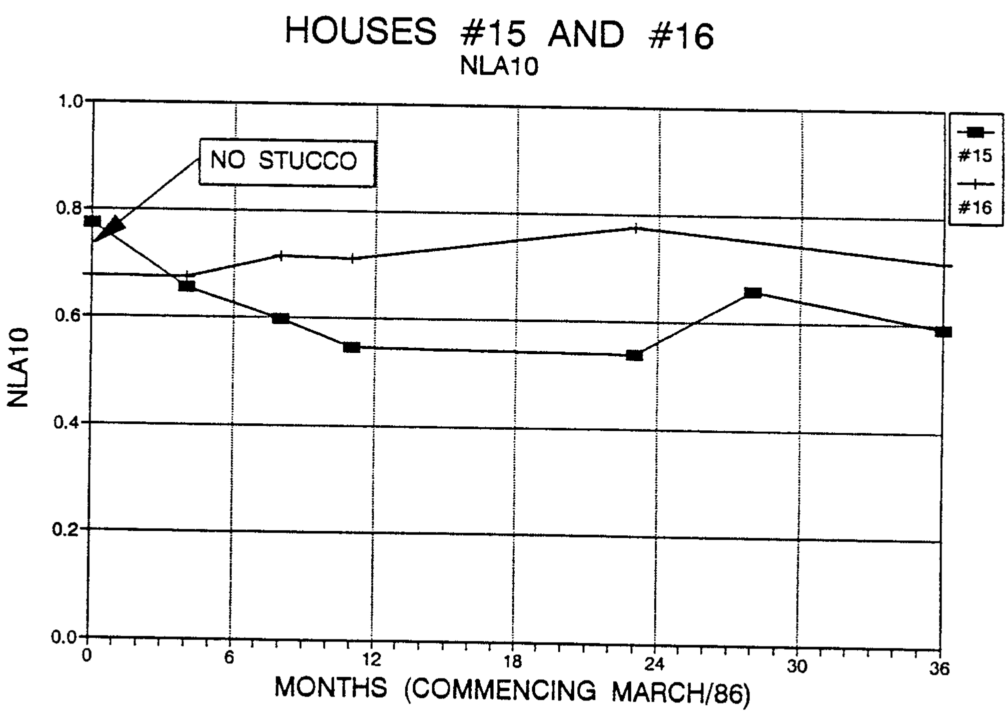


FIGURE 11(a)

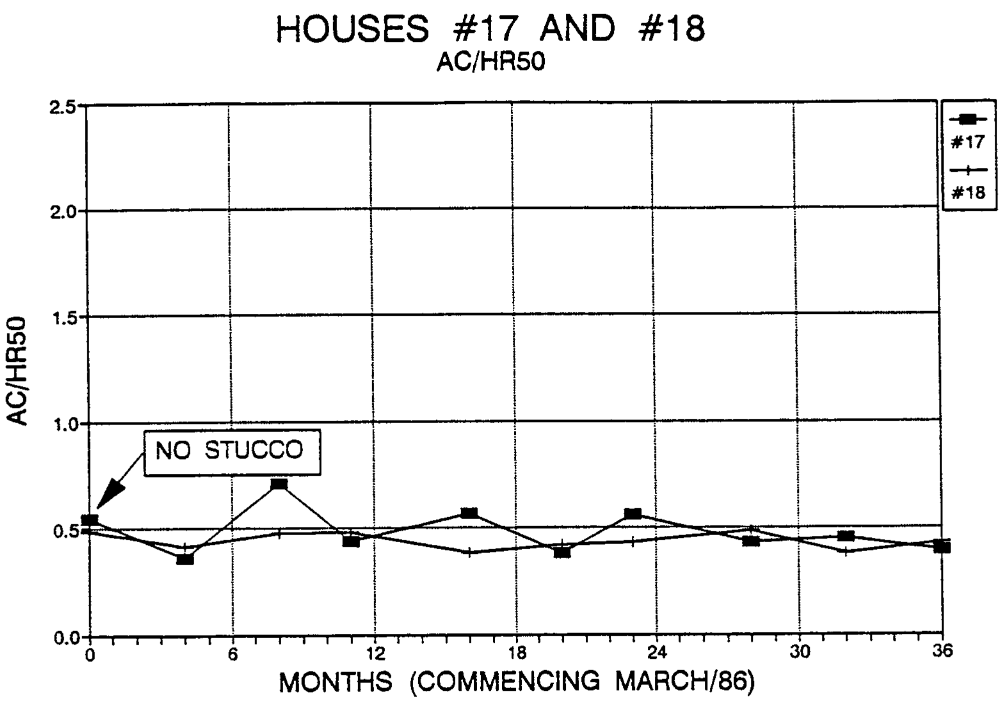


FIGURE 11(b)

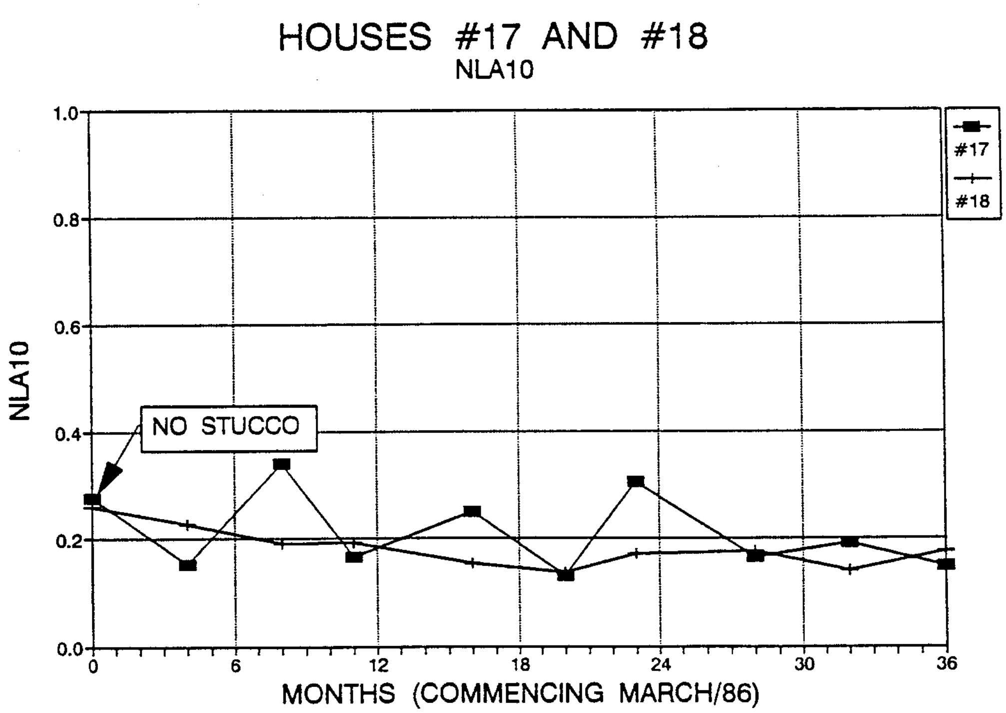


TABLE 5

STATISTICAL ANALYSES - POLYETHYLENE AIR BARRIER HOUSES

ac/hr_{50} DATA

WALL SYSTEM AND HOUSE NO.	α	β	n	t-STATISTIC	PROBABILITY (P)	NULL HYPOTHESIS (H_o)	COEFFICIENT OF DETERMINATION (r^2)
Standard Framed Walls							
9	1.656	0.00273	10	-0.994	0.175	ACCEPT	0.110
10	1.280	-0.00385	10	1.091	0.154	ACCEPT	0.129
22	0.924	0.00605	3	-0.735	0.299	ACCEPT	0.351
Framed Walls with Exterior Insulated Sheathing							
24	1.401	-0.00478	4	1.770	0.110	ACCEPT	0.610
Framed Walls with Interior Strapping							
23 21 (see text)	1.418	-0.00555	4	1.751	0.111	ACCEPT	0.605
Double Walls							
15	1.267	-0.00320	6	1.180	0.152	ACCEPT	0.258
16	1.320	0.00604	5	-2.930	0.031	REJECT	0.741
17	0.534	-0.00278	9	0.737	0.243	ACCEPT	0.072
18	0.448	-0.00063	9	0.468	0.327	ACCEPT	0.030

NLA_{10} DATA

WALL SYSTEM AND HOUSE NO.	α	β	n	t-STATISTIC	PROBABILITY (P)	NULL HYPOTHESIS (H_o)	COEFFICIENT OF DETERMINATION (r^2)
Standard Framed Walls							
9	0.580	0.00150	10	-2.007	0.040	REJECT	0.335
10	0.557	-0.00142	10	0.364	0.363	ACCEPT	0.016
22	0.360	0.00224	3	-0.657	0.315	ACCEPT	0.302
Framed Walls with Exterior Insulated Sheathing							
24	0.589	0.00444	4	-0.626	0.298	ACCEPT	0.164
Framed Walls with Interior Strapping							
23 21 (see text)	0.587	0.00371	4	-0.408	0.361	ACCEPT	0.077
Double Walls							
15	0.603	-0.00026	6	0.129	0.452	ACCEPT	0.004
16	0.696	0.00136	5	-0.952	0.206	ACCEPT	0.232
17	0.241	-0.00173	9	0.697	0.254	ACCEPT	0.065
18	0.204	-0.00150	9	1.957	0.046	ACCEPT	0.354

NOTES:

1. See text for descriptions of α and β.
2. Number of data points = n.
3. "Probability" gives the probability that the observed difference between β and the assumed value of zero could be greater than or equal to that observed.

TABLE 6

ANALYSIS SUMMARY

POLYETHYLENE AIR BARRIER HOUSES

WALL SYSTEM & HOUSE NO.	TOTAL MONITORING PERIOD (MONTHS)	EVIDENCE OF AIR BARRIER DEGRADATION?			
		ANALYSIS METHOD			
		1	2	3	4
Standard Framed Walls					
9	36	NO	NO	NO	POSSIBLE
10	36	NO	NO	NO	NO
22	21	NO	NO	NO	NO
Framed Walls with Exterior Insulated Sheathing					
24	19	NO	NO	NO	NO
Framed Walls with Interior Strapping					
23	22	NO	NO	NO	NO
21	0.3	--	NO	--	--
Double Walls					
15	32	NO	NO	NO	NO
16	32	NO	NO	NO	POSSIBLE
17	32	NO	NO	NO	NO
18	32	NO	NO	NO	NO

ANALYSIS METHOD:

1. Visual examination.
2. Variation between first and last airtightness tests.
3. Variation between first and last seasonally coincident airtightness tests (see note 1).
4. Statistical tests.

<u>NOTES</u>

1. Monitoring period for Analysis Method 3 may be less than Total Monitoring Period, see Tables 3 and 4.

4.2.2 Measured Airtightness

The two conventional houses, #9 and #10, were among the leakiest in the project, although they were still able to meet the airtightness requirements of the R-2000 Program. These results are consistent with the 1989 survey of conventional housing in which the mean airtightness of the 20 Winnipeg houses was 2.08 ac/hr_{50}, with an NLA_{10} of 0.91 cm^2/m^2 (Hamlin 1990). Pre-stucco airtightness data was not available for #9 and #10.

House #22 was significantly tighter than #9 and #10, probably due to the SBPO header and cantilever wraps and the use of sealant to control leakage at joints and penetrations. However, the stucco was found to have a significant impact on airtightness in House #22, reducing the ac/hr_{50} by 40% and the NLA_{10} by 47%. Air leakage in these houses was found at electrical outlets, especially on exterior walls, and the bottom plate area of walls in #9 and #10 - indicative of the absence of sealing.

As summarized in Table 6, the data analysis did not identify significant evidence of airtightness degradation. The only indication of a possible problem was suggested by one of the statistical tests for House #9 in which the null hypothesis was rejected for the NLA_{10} data.

It was concluded that no indication was found of significant airtightness degradation in the three, stucco-covered standard frame wall houses constructed with polyethylene air barrier systems, over monitoring periods of 21 to 36 months.

4.3 FRAME WALLS WITH EXTERIOR INSULATED SHEATHING

4.3.1 Description

House #24 used a frame wall with exterior insulated sheathing (rigid glass fibre) and a simplified air barrier system with polyethylene on the main walls, ceiling and basement, and a SBPO wrap around the headers. Joints and penetrations were sealed and gaskets were used at the top of partition walls. Door and window penetrations were sealed using a variety of methods.

4.3.2 Measured Airtightness

Through the 19 months of monitoring, the airtightness remained relatively constant, particularly with respect to the ac/hr_{50} data. The most significant air leakage locations found were the undersides of two cantilevers (which projected the floor system out past the foundation). Leakage at these locations appeared to increase over the monitoring period.

Based on these results, it was concluded that no indication was found of significant airtightness degradation, over a 19 month monitoring period, in the one house constructed with a polyethylene air barrier and stucco-covered, frame walls and exterior insulated sheathing.

4.4 FRAME WALLS WITH INTERIOR STRAPPING

4.4.1 Description

House #23 used a frame wall with interior strapping and a sandwiched air barrier with the cavities on both sides of the polyethylene filled with insulation. All major joints and penetrations in the wall and ceiling air barriers were sealed. Polyethylene was used as the vapour barrier in the basement.

House #21 was built as a composite structure utilizing 6 mil polyethylene as the air barrier on the south and (most of the) north, east and west walls and on the ceiling. Approximately 20% of the exterior wall area was constructed using an ADA air barrier. The house was classified as a polyethylene air barrier structure because it was the dominant system used. Wall construction in the polyethylene sections consisted of framing and interior strapping with polyethylene sandwiched between the framing and strapping. No insulation was used in the spaces between the polyethylene and the drywall, thereby providing a worst-case wind loading application for the air barrier since only minimal structural support was provided by the drywall. The wall exterior was covered with a (SBPO) air retarder and vertical vinyl siding on horizontal strapping. This was the only house in the study to use polyethylene manufactured to the CAN2-51.34-M86 (1986).

4.4.2 Measured Airtightness

The 20 months of data available for House #23 showed that it became slightly more airtight over the monitoring period. Stucco was found to produce a significant reduction in airtightness, decreasing the ac/hr_{50} rate by 25% and the NLA_{10} by 30%.

House #21 was not subjected to regular testing because various modifications were performed during the project which would have affected its airtightness. However, during one period between modifications, a wind storm occurred which produced (airport-recorded) gusts of 96 km/h. Although site winds were not measured, they are believed to have been relatively severe. A commercial structure, located approximately 50 m (160 ft) from House #21, had roughly 50 m^2 (500 ft^2) of brick facade stripped away during the storm. Airtightness tests, performed on House #21 approximately one week prior and two days after the storm, showed that the ac/hr_{50} results were unchanged while the NLA_{10} increased by 13%. Although the final airtightness rate exceeded that permitted in R-2000 construction, this probably resulted from some of the unique features of the house which pertained to its use as a test structure and would not be typical of normal construction.

The major air leakage locations found in House #23 were the exterior wall electrical switches and outlets, baseboards in the living area and the header area in the basement; leakage at these locations also appeared to increase over the monitoring period. Leakage locations in House #21 included an exterior wall electrical outlet whose penetration through the air barrier had not been properly sealed and the undersides of two cantilevers, despite the use of SBPO air retarders on the undersides.

It was concluded that no indication was found of significant airtightness degradation in the two houses constructed using a polyethylene air barrier and frame walls with interior strapping. The first house was stucco-covered and was monitored over a 22 month period while the second was covered with vinyl siding and was tested before and after a wind storm which caused extensive envelope damage to an adjacent structure.

4.5 DOUBLE WALLS

4.5.1 Description

Houses #15 through #18 were built using double wall construction with a 6 mil polyethylene air barrier sandwiched between the studs and sheathing on the exterior side of the inner wall. Sealant was used extensively at major joints and penetrations including all door and window openings. The framing crew, who were responsible for installation of the air barrier, exercised considerable care in identifying and sealing potential leakage sites.

Although identical envelope systems were used in the four houses, #15 and #16 contained air-to-air heat pumps which used large capacity ductwork from the indoors and outdoors. Testing subsequently found the ductwork to be a significant source of air leakage which degraded the airtightness of these two houses.

4.5.2 Measured Airtightness

The two double wall houses which did not contain the heat pumps (#17 and #18) were the tightest houses in the project with airtightness levels approximately one-third the maximum permitted by the R-2000 Program. Leakage rates for Houses #15 and #16 were approximately 2.5 times greater than those of #17 and #18. Stucco was found to produce a minimal impact on the airtightness of the four houses. The only major sources of leakage found during the inspections were the heat pumps and their associated ductwork, particularly at the filter housings and vibration isolators. No major sources of leakage were identified in the envelopes of the four houses.

As shown in Table 6, the data analysis did not identify major evidence of airtightness degradation. The only indications otherwise were that the null hypothesis was rejected for the ac/hr_{50} data for House #16 and the corresponding coefficient of determination was judged to be excessive. This apparent degradation may have resulted from increased leakage in the heat pump ductwork rather than the house envelope. With the majority of the total house leakage occurring through the ductwork, even small changes would have produced large percentage impacts.

Based on these results, it was concluded that no evidence was found to indicate significant airtightness degradation in the four houses constructed with polyethylene air barriers and stucco-covered, double walls over a monitoring period of 32 months.

4.6 COMMENTARY

Ten project houses were constructed using the polyethylene air barrier system on the exterior walls and ceilings. The wall systems consisted of the four types most commonly used in residential construction, with stucco as the dominant wall finish. Monitoring periods ranged up to three years and exposure conditions included (airport-measured) wind gusts of up to 96 km/hr.

The polyethylene air barrier systems used on the four wall types were able to achieve airtightness levels comfortably within the requirements of the R-2000 Program, with the double wall houses displaying the lowest leakage rates.

Possible, albeit slight, evidence of airtightness degradation was displayed by two of the ten houses. However the observed increases in air leakage were small and all but one of the ten houses (#21) met the airtightness requirements of the R-2000 Standard at the end of their monitoring periods; including the conventional structures which were not designed to the Standard. While it is not possible to project these results over the life of the houses, it was concluded that no evidence was found to indicate that polyethylene is an unsuited for use as an air barrier material in residential construction.

Airtightness data was available for pre-and-post stucco conditions for six of the houses. Stucco was found to have no effect on the airtightness of the four double wall houses but did produce significant reductions in airtightness for the two houses which used either standard frame walls or frame walls with interior strapping. This suggests that the latter two air barrier/wall system combinations permitted leakage sites to exist which the stucco ultimately sealed (at least partially), whereas these same leakage areas were not in evidence in the double wall houses.

SECTION 5

PERFORMANCE OF THE ADA AIR BARRIER SYSTEMS

5.1 TYPES OF WALL SYSTEMS

The Airtight Drywall Approach was used in 14 of the project houses. For analysis purposes, the houses were categorized on the basis of the gasket method used and the presence of an SBPO air retarder:

- o Polyethylene gaskets and SBPO air retarder (Houses #1 to #6)
- o Polyethylene gaskets (Houses #7 and #8)
- o Simplified ADA and SBPO air retarder (Houses #11 to #14)
- o Ethafoam rod, polyethylene and neoprene gaskets (Houses #19 and #20)

It should be noted that development on the ADA system has continued since the project houses were constructed and improved gasket types and methods have come into use. For example, open-celled gasket materials are now more frequently used because they possess superior compression-rebound characteristics. In contrast, the ADA houses in the study were constructed with closed cell gaskets which are not as effective over extended time periods.

The measured airtightness results are given in Tables 7 and 8 and Figs. 12 to 15 and the statistical analysis is summarized in Table 9. A summary of the results, using the four analysis methods, is provided in Table 10.

5.2 POLYETHYLENE GASKETS AND SBPO AIR RETARDER

5.2.1 Description

Houses #1 through #6 used an early version of the ADA system in which closed cell polyethylene sill plate gaskets were used at the floor system/foundation intersection along with "poly-pan" boxes and foam gaskets around electrical outlets on exterior walls. An untaped SBPO air retarder was attached to the exterior insulated sheathing with the latter reversed so that the air retarder was sandwiched between the sheathing and framing.

5.2.2. Measured Airtightness

The initial airtightness levels were found to be similar, or slightly below, that required by the R-2000 Program. Levels were relatively stable over the 32 to 36 monitoring periods for Houses #1 to #5 whereas House #6 displayed possible evidence of airtightness degradation although this observation is heavily influenced by the NLA_{10} result from the final test. The statistical tests did not identify a problem for House #6. Pre-stucco test data was not available for any of the houses. The only sources of air leakage identified on a regular basis were the electrical outlets and switches on exterior walls.

TABLE 7
ac/hr_{50} RESULTS - ADA HOUSES

GASKET TYPE & HOUSE NO.	MAR/86	JUL/86	NOV/86	FEB/87	JUL/87	NOV/87	FEB/88	MAY/88	JUN/88	JUL/88	AUG/88	NOV/88	MAR/89	JUN/89	AUG/89	DEC/89	MAR/90	APR/90
Polyethylene Gaskets & SBPO Air Retarder																		
1	1.669		1.475	1.568			1.479					1.650	1.448					
2		1.053	1.171	1.119	0.977	1.047	1.169			1.201		1.195	1.184					
3	1.509		1.539	1.852	1.486		1.689						1.497					
4	1.455		1.311	1.299	1.115		1.415			1.378			1.472					
5	1.118		1.264	1.104	1.144		1.049						1.032					
6	1.205		1.255	1.306	1.187		1.417			1.195			1.229					
Polyethylene Gaskets																		
7	1.166		1.522	2.196						2.058			1.423					
8			1.392	1.740	1.342		1.444			1.477			1.111					
Simplified ADA & SBPO Air Retarder																		
11	1.694*	0.892	0.962	0.881	0.879		1.007						1.074					
12	1.593*	1.120	0.960	0.979	0.878		0.980			1.059			1.246					
13	1.268*	0.836	0.830	0.761	1.043		0.938			1.258			0.886					
14	1.319*	1.136		0.955	0.989		1.155			1.103			1.324					
Polyethylene, Ethafoam Rod & Neoprene Gaskets																		
19	1.049*	0.807	0.842	0.908	0.715		1.038			0.919			1.108					
20	1.126*	0.708	0.815	0.731	1.008		0.797			0.942			0.873					

CHANGE BETWEEN FIRST (POST-STUCCO) TEST AND FINAL TEST

GASKET TYPE & HOUSE NO.	ABSOLUTE CHANGE[2] (ac/hr_{50})	%[2]	NO. OF MONTHS
Polyethylene Gaskets & SBPO Air Retarder			
1	-0.220	-13	36
2	0.132	13	32
3	-0.012	-1	36
4	0.017	1	36
5	-0.086	-8	36
6	0.025	2	36
Polyethylene Gaskets			
7	0.257	22	36
8	-0.478	-30	36
Simplified ADA & SBPO Air Retarder			
11	0.182	20	32
12	0.126	11	32
13	0.049	6	32
14	0.187	16	32
Polyethylene, Ethafoam Rod & Neoprene Gaskets			
19	0.301	37	32
20	0.165	23	32

CHANGE BETWEEN FIRST (POST-STUCCO) TEST AND FINAL SEASONALLY-COINCIDENT TEST

GASKET TYPE & HOUSE NO.	ABSOLUTE CHANGE[2] (ac/hr_{50})	%[2]	NO. OF MONTHS
Polyethylene Gaskets & SBPO Air Retarder			
1	-0.220	-13	36
2	0.065	6	25
3	-0.012	-1	36
4	0.017	1	36
5	-0.086	-8	36
6	0.025	2	36
Polyethylene Gaskets			
7	0.257	22	36
8	-0.478	-30	36
Simplified ADA & SBPO Air Retarder			
11	0.193	22	25
12	0.266	27	25
13	0.125	16	25
14	0.368	39	25
Polyethylene, Ethafoam Rod & Neoprene Gaskets			
19	0.200	22	25
20	0.142	19	25

NOTES:
1. * = No Stucco
2. A -ve indicates the house became more airtight.

TABLE 8
NLA_{10} RESULTS - ADA HOUSES

GASKET TYPE & HOUSE NO.	MAR/86	JUL/86	NOV/86	FEB/87	JUL/87	NOV/87	FEB/88	MAY/88	JUN/88	JUL/88	AUG/88	NOV/88	MAR/89	JUN/89	AUG/89	DEC/89	MAR/90	APR/90
Polyethylene Gaskets & SBPO Air Retarder																		
1	0.577		0.467	0.380			0.477					0.452	0.506					
2		0.410	0.603	0.451	0.400	0.425	0.503			0.515		0.521	0.471					
3	0.513		0.517	0.762	0.564		0.656						0.525					
4	0.585		0.482	0.551	0.437		0.643			0.546			0.566					
5	0.444		0.450	0.432	0.334		0.341						0.318					
6	0.473		0.488	0.613	0.366		0.581			0.456			0.652					
Polyethylene Gaskets																		
7	0.433		0.637	0.981						0.717			0.496					
8	0.857		0.636	0.745	0.620		0.664			0.629			0.379					
Simplified ADA & SBPO Air Retarder																		
11	0.753*	0.345	0.396	0.317	0.282		0.370						0.393					
12	0.835*	0.468	0.419	0.329	0.318		0.405			0.433			0.538					
13	0.569*	0.360	0.314	0.401	0.437		0.403			0.434			0.271					
14	0.754*	0.490		0.516	0.393		0.467			0.425			0.578					
Polyethylene, Ethafoam Rod & Neoprene Gaskets																		
19	0.444*	0.232	0.320	0.347	0.279		0.402			0.381			0.444					
20	0.560*	0.298	0.287	0.208	0.444		0.299			0.391			0.343					

CHANGE BETWEEN FIRST (POST-STUCCO) TEST AND FINAL TEST

GASKET TYPE & HOUSE NO.	ABSOLUTE CHANGE[2] (NLA_{10})	%[2]	NO. OF MONTHS
Polyethylene Gaskets & SBPO Air Retarder			
1	-0.072	-12	36
2	0.061	15	32
3	0.012	2	36
4	-0.019	-3	36
5	-0.126	-28	36
6	0.180	38	36
Polyethylene Gaskets			
7	0.063	14	36
8	-0.478	-56	36
Simplified ADA & SBPO Air Retarder			
11	0.048	14	32
12	0.069	15	32
13	-0.088	-25	32
14	0.088	18	32
Polyethylene, Ethafoam Rod & Neoprene Gaskets			
19	0.212	91	32
20	0.045	15	32

CHANGE BETWEEN FIRST (POST-STUCCO) TEST AND FINAL SEASONALLY-COINCIDENT TEST

GASKET TYPE & HOUSE NO.	ABSOLUTE CHANGE[2] (NLA_{10})	%[2]	NO. OF MONTHS
Polyethylene Gaskets & SBPO Air Retarder			
1	-0.072	-12	36
2	0.020	4	25
3	0.012	2	36
4	-0.019	-3	36
5	-0.126	-28	36
6	0.180	38	36
Polyethylene Gaskets			
7	0.063	14	36
8	-0.478	-56	36
Simplified ADA & SBPO Air Retarder			
11	0.076	19	25
12	0.209	39	25
13	-0.130	-48	25
14	0.062	11	25
Polyethylene, Ethafoam Rod & Neoprene Gaskets			
19	0.097	22	25
20	0.134	39	25

NOTES:
1. * = No Stucco
2. A -ve indicates the house became more airtight.

FIGURE 12(a)

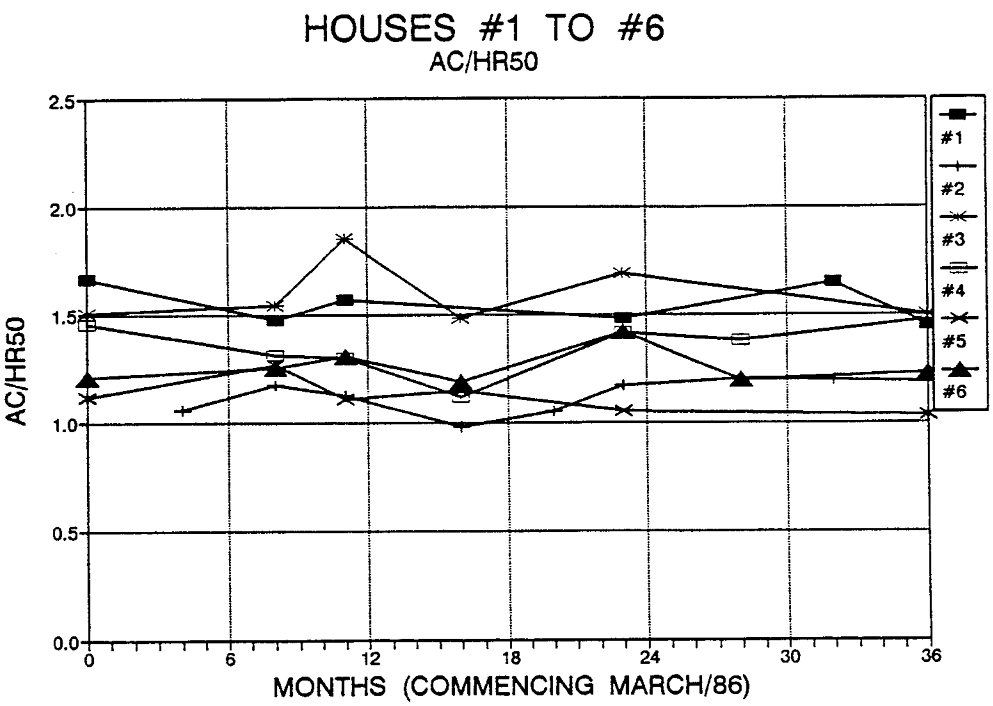


FIGURE 12(b)

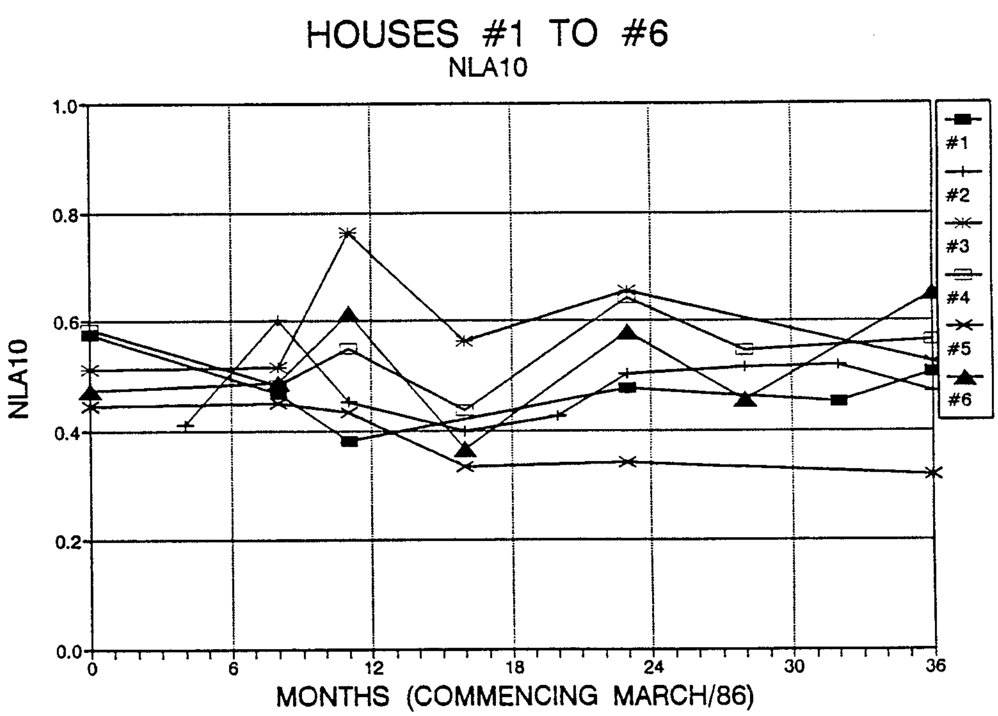


FIGURE 13(a)

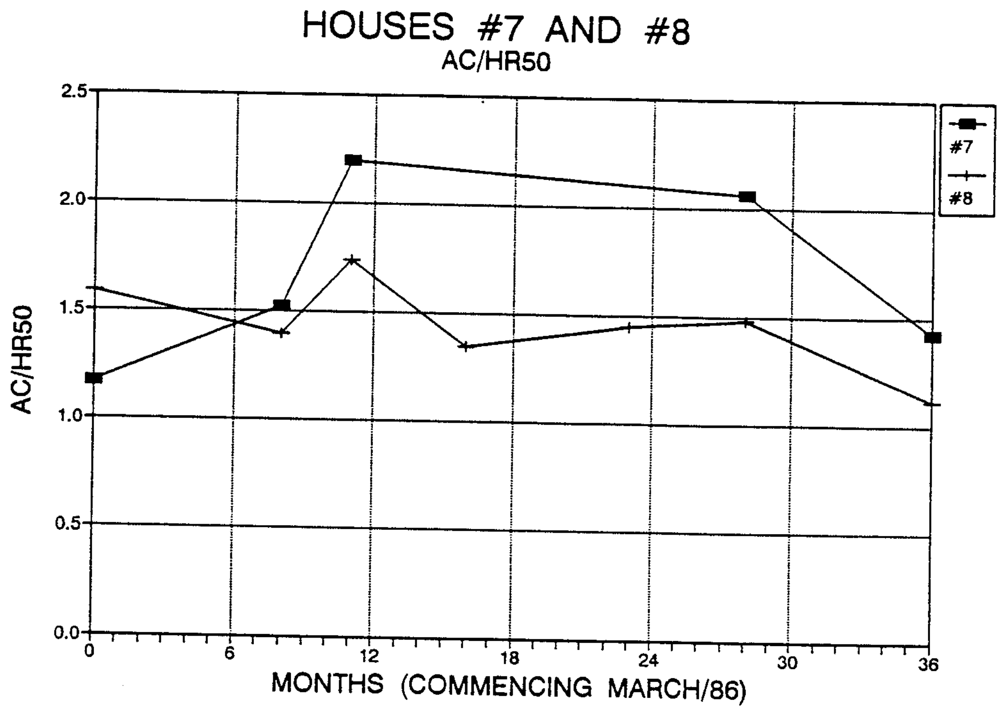


FIGURE 13(b)

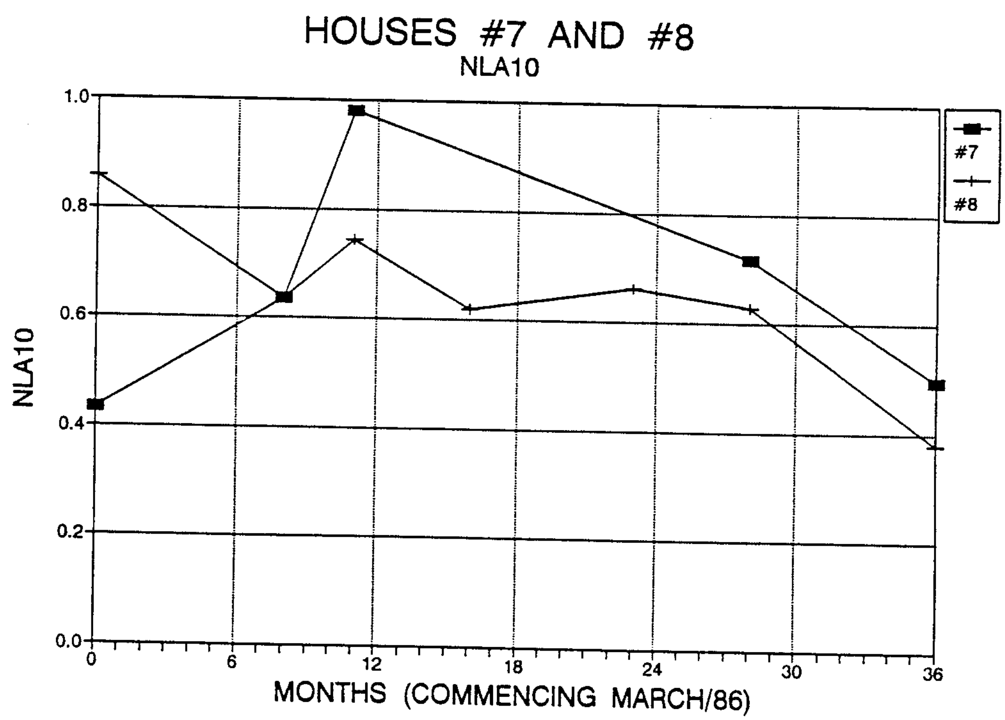


FIGURE 14(a)

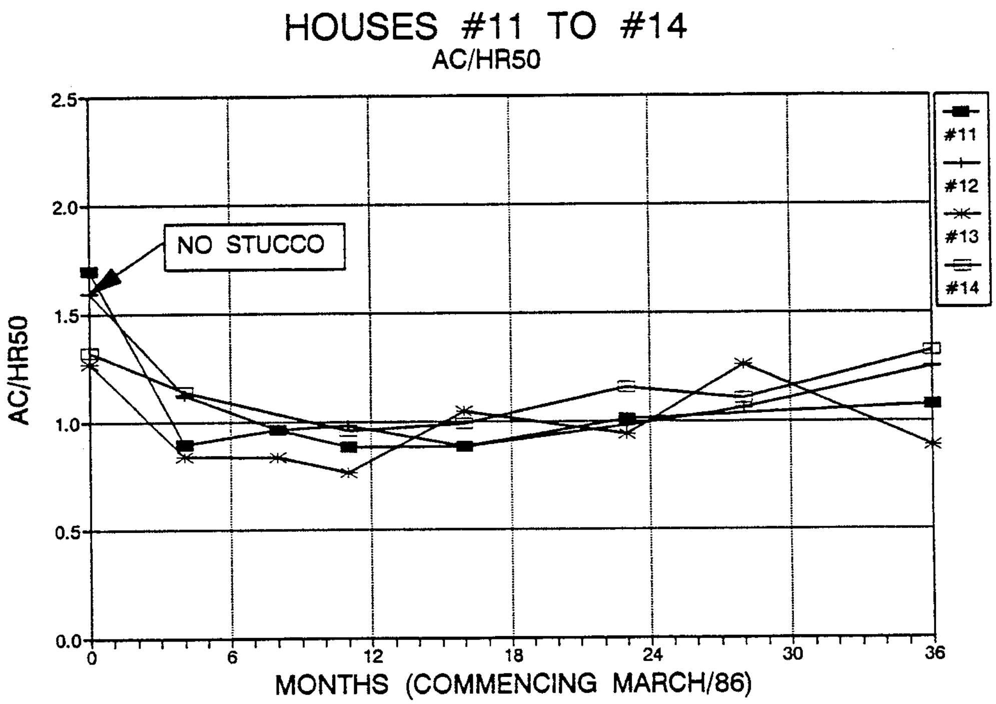


FIGURE 14(b)

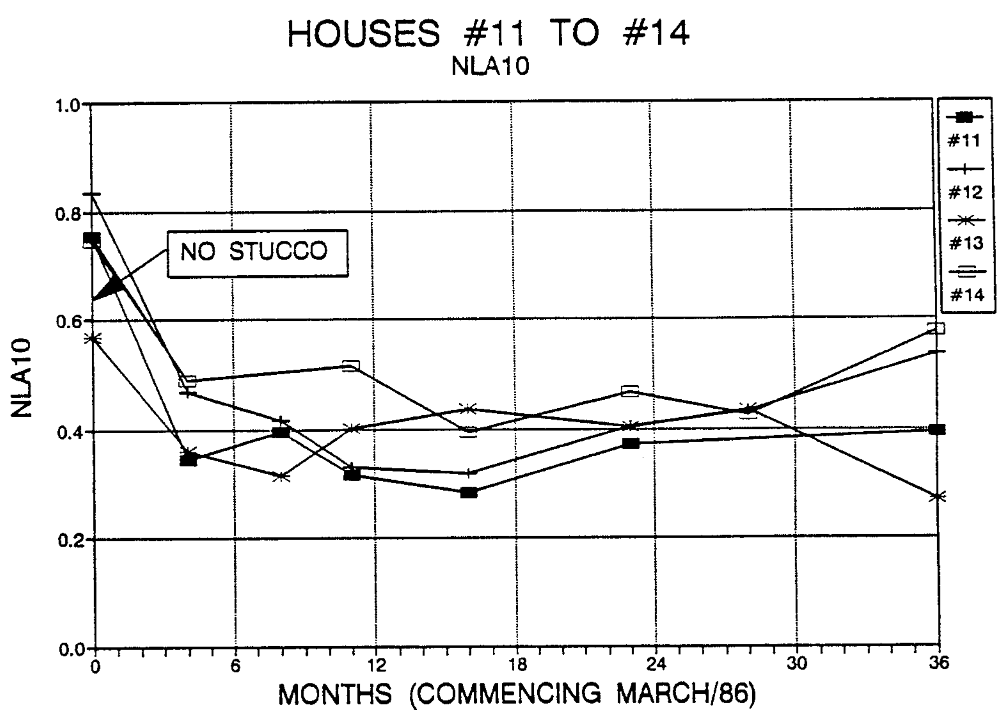


FIGURE 15(a)

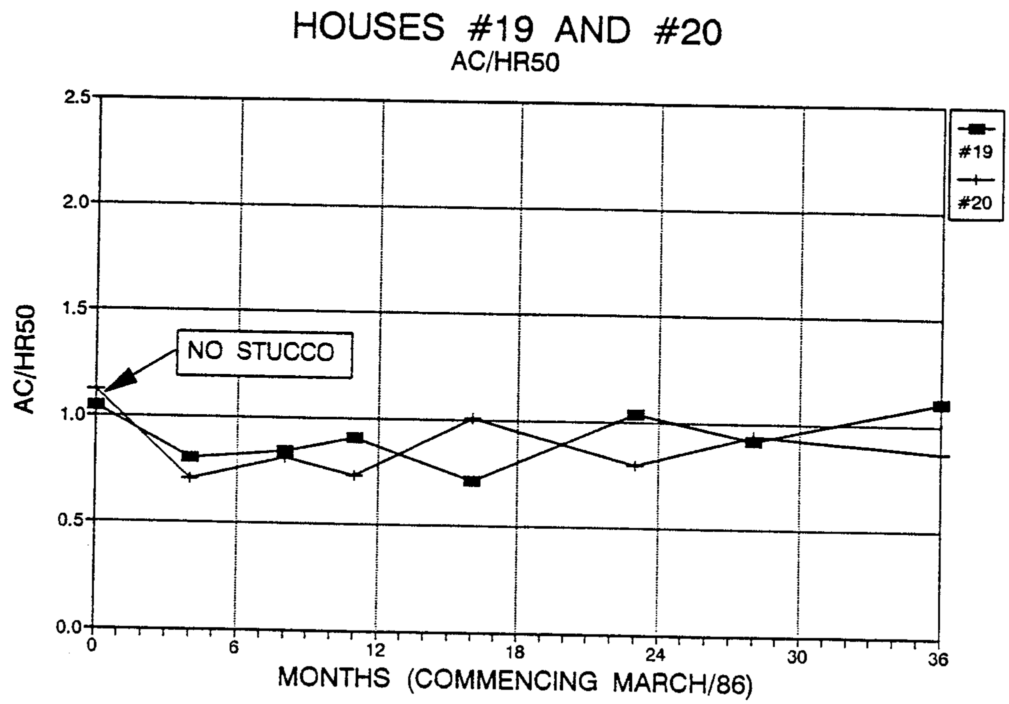


FIGURE 15(b)

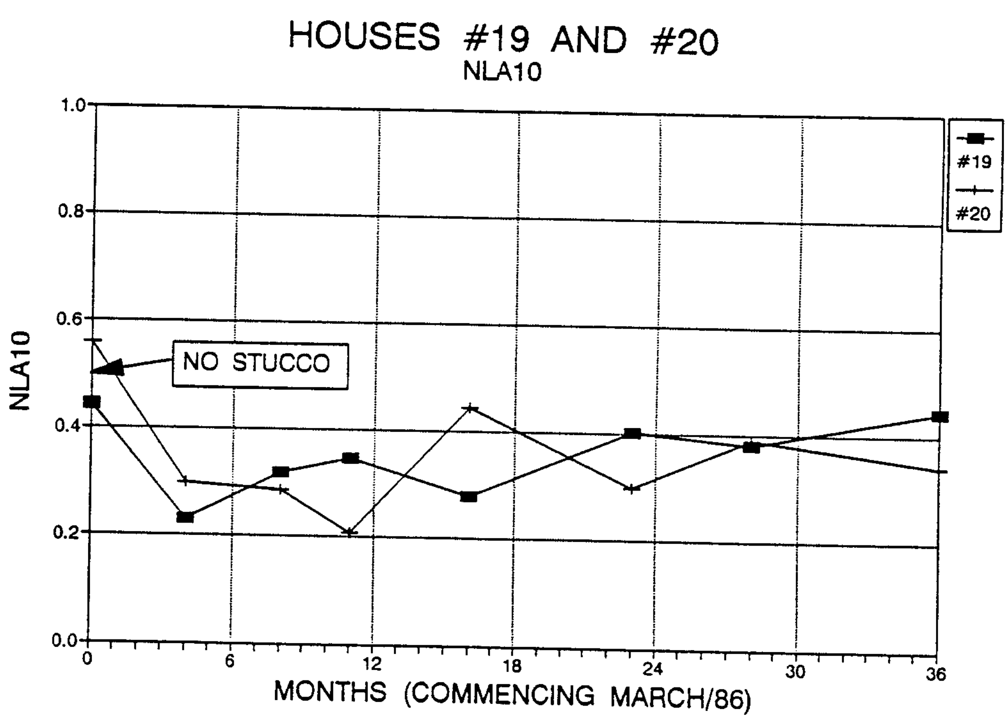


TABLE 9
STATISTICAL ANALYSES - ADA AIR BARRIER HOUSES

ac/hr_{50} DATA

GASKET TYPE AND HOUSE NO.	α	β	n	t-STATISTIC	PROBABILITY (P)	NULL HYPOTHESIS (H_o)	COEFFICIENT OF DETERMINATION (r^2)
Polyethylene Gaskets, SBPO Air Retarder							
1	1.590	-0.00225	6	0.718	0.257	ACCEPT	0.114
2	1.047	0.00389	9	-1.672	0.069	ACCEPT	0.285
3	1.611	-0.00096	6	0.167	0.438	ACCEPT	0.007
4	1.309	0.00230	7	-0.536	0.308	ACCEPT	0.054
5	1.184	-0.00416	6	1.629	0.089	ACCEPT	0.399
6	1.248	0.00048	7	-0.162	0.439	ACCEPT	0.005
Polyethylene Gaskets							
7	1.555	0.00713	5	-0.434	0.347	ACCEPT	0.007
8	1.624	-0.01042	7	1.940	0.055	ACCEPT	0.430
Simplified ADA & SBPO Air Retarder							
11	0.857	0.00561	6	-2.861	0.023	REJECT	0.672
12	0.941	0.00504	7	-1.218	0.139	ACCEPT	0.229
13	0.805	0.00723	7	-1.283	0.125	ACCEPT	0.248
14	0.968	0.00726	6	-1.679	0.084	ACCEPT	0.414
Polyethylene, Ethafoam Rod & Neoprene Gaskets							
19	0.751	0.00856	7	-2.408	0.031	REJECT	0.537
20	0.751	0.00493	7	-1.362	0.116	ACCEPT	0.271

NLA_{10} DATA

GASKET TYPE AND HOUSE NO.	α	β	n	t-STATISTIC	PROBABILITY (P)	NULL HYPOTHESIS (H_o)	COEFFICIENT OF DETERMINATION (r^2)
Polyethylene Gaskets, SBPO Air Retarder							
1	0.492	-0.00085	6	0.382	0.361	ACCEPT	0.035
2	0.459	0.00095	9	-0.430	0.340	ACCEPT	0.026
3	0.587	0.00015	6	-0.037	0.486	ACCEPT	0.000
4	0.526	0.00104	7	-0.434	0.341	ACCEPT	0.036
5	0.452	-0.00421	6	3.407	0.014	ACCEPT	0.744
6	0.464	0.00311	7	-0.926	0.199	ACCEPT	0.146
Polyethylene Gaskets							
7	0.660	-0.00041	5	0.050	0.482	ACCEPT	0.001
8	0.821	-0.00998	7	3.626	0.008	ACCEPT	0.725
Simplified ADA & SBPO Air Retarder							
11	0.330	0.00127	6	-0.699	0.262	ACCEPT	0.109
12	0.362	0.00297	7	-1.119	0.144	ACCEPT	0.200
13	0.388	-0.00076	7	0.319	0.382	ACCEPT	0.020
14	0.451	0.00139	6	-0.507	0.319	ACCEPT	0.060
Polyethylene, Ethafoam Rod & Neoprene Gaskets							
19	0.245	0.00549	7	-3.873	0.006	REJECT	0.750
20	0.275	0.00274	7	-1.012	0.179	ACCEPT	0.170

NOTES:

1. See text for descriptions of α and β.
2. Number of data points = n.
3. "Probability" gives the probability that the observed difference between β and the assumed value of zero could be greater than or equal to that observed.
4. Null hypothesis rejected if P less than or equal to 0.05 (5%) and β is positive (i.e. airtightness increasing with time).

TABLE 10

ANALYSIS SUMMARY

ADA AIR BARRIER HOUSES

GASKET TYPE & HOUSE NO.	TOTAL MONITORING PERIOD (MONTHS)	EVIDENCE OF AIR BARRIER DEGRADATION?			
		ANALYSIS METHOD			
		1	2	3	4
Polyethylene Gaskets and SBPO Air Retarder					
1	36	NO	NO	NO	NO
2	32	NO	NO	NO	NO
3	36	NO	NO	NO	NO
4	36	NO	NO	NO	NO
5	36	NO	NO	NO	NO
6	36	POSSIBLE	POSSIBLE	POSSIBLE	NO
Polyethylene Gaskets					
7	36	NO	NO	NO	NO
8	36	NO	NO	NO	NO
Simplified ADA					
11	32	NO	NO	NO	POSSIBLE
12	32	NO	NO	POSSIBLE	NO
13	32	NO	NO	NO	NO
14	32	NO	NO	POSSIBLE	NO
Polyethylene, Ethafoam Rod and Neoprene Gaskets					
19	32	POSSIBLE	POSSIBLE	NO	POSSIBLE
20	32	NO	NO	POSSIBLE	NO

ANALYSIS METHOD:

1. Visual examination.
2. Variation between first and last airtightness tests.
3. Variation between first and last seasonally coincident airtightness tests (see note 1).
4. Statistical tests.

NOTES

1. Monitoring period for Analysis Method 3 may be less than Total Monitoring Period, see Tables 7 and 8.

It was concluded that no indication was found of significant airtightness degradation in the six ADA houses constructed with polyethylene gaskets and an SBPO air retarder over their 32 to 36 monitoring periods.

5.3 POLYETHYLENE GASKETS

5.3.1. Description

Houses #7 and #8 used the same gasket schedule as #1 to #6 but were not constructed with the SBPO air retarder on the exterior walls.

5.3.2. Measured Airtightness

Air leakage rates in Houses #7 and #8 were slightly greater than those in #1 to #6, typically with airtightness rates close to the maximum permitted for R-2000 houses. These two houses also had the largest standard deviations of airtightness rates for the project house groups. Despite these variations, no evidence was found of a permanent change in airtightness. Pre-stucco data was not available. Leakage locations were similar to those in Houses #1 to #6 with electrical outlets and switches, particularly on exterior walls, being most commonly identified. Some indication was found of increased leakage in the bottom plate area of the exterior walls.

Based on the results, it was concluded that no indication was found of airtightness degradation in the two ADA houses constructed with polyethylene gaskets, over their 36 month monitoring periods.

5.4 SIMPLIFIED ADA AND SBPO AIR RETARDER

5.4.1. Description

Houses #11 through #14 used a simplified ADA technique designed to permit small amounts of intentional envelope leakage (i.e. a quasi-dynamic wall approach). Gaskets, in this case ethafoam backer rod, were used around major penetrations such as doors and windows, while gaskets and covers were installed around electrical outlets. A SBPO air retarder was carefully taped in place over the exterior insulated sheathing.

5.4.2 Measured Airtightness

Airtightness levels measured prior to the application of stucco were found to be close to, or slightly above, the R-2000 Standard. Once the stucco was applied, the tests were repeated and average reductions of 31% and 43% were found in the ac/hr_{50} and NLA_{10} results respectively. Over the next 32 months, airtightness levels fluctuated and Houses #11, #12 and #14 displayed some evidence of increasing leakiness. The ac/hr_{50} values increased for three of the four houses between the first and last tests and for all four between the first and last seasonally coincident tests. Similar patterns were displayed for NLA_{10} values for Houses #11 and #12. Also, the null hypothesis for the ac/hr_{50} data for House #11 was rejected and the corresponding coefficients of determination were judged to display indication of increasing leakage. These changes, although observable, were not catastrophic and would only be significant if they persisted over an extended period of time.

Air leakage was consistently found at exterior wall outlets and switches and to a lesser extent on interior partitions - similar to that in the other ADA houses. Interestingly, leakage was not noted in the bottom plate area of the exterior walls, either at the beginning or end of the monitoring period.

Three of the four houses displayed some evidence of nominal degradation in airtightness over their 32 month monitoring periods. Although the observed degradation was not catastrophic, it could become significant if it were to continue for an extended period.

5.5 ETHAFOAM ROD, POLYETHYLENE AND NEOPRENE GASKETS

5.5.1 Description

Houses #19 and #20 used three types of gaskets: closed celled polyethylene sill plate gaskets, primarily in the floor system/foundation area; neoprene gaskets at selected locations between the drywall and the bottom plate and ethafoam backer rod around major penetrations. Electrical outlets on exterior walls were sealed with poly-pan gaskets and foam covers.

5.5.2 Measured Airtightness

Prior to the application of stucco, airtightness levels averaged about two-thirds that permitted by the R-2000 Program. Average ac/hr_{50} and NLA_{10} values dropped by 30% and 47% respectively once the stucco was applied, after which both houses become leakier. This was most evident in House #19, in fact the null hypotheses for both the ac/hr_{50} and NLA_{10} data were rejected and the coefficients of determination also showed evidence of increasing leakiness. As was the case with Houses #11 to #14, the magnitude of the observed changes was not serious in terms of their absolute magnitude. Air leakage locations were consistent with the other ADA houses; exterior wall electrical outlets and switches were routinely identified as leakage sources, particularly during the early airtightness tests.

In summary, two of the four ADA houses constructed with multiple gasket types displayed some evidence of nominal degradation in airtightness over their 32 month monitoring period. Although the observed degradation was not catastrophic, it could become significant if it were to continue for an extended period.

5.6 COMMENTARY

The 14 houses constructed with the ADA air barrier system used a variety of gasket types to seal major envelope joints and penetrations. Gasket types were predominately of the closed-cell variety, which is no longer considered to be the most suitable for ADA applications. Monitoring periods ranged from 32 to 36 months and environmental conditions included (airport-measured) wind gusts of up to 96 km/hr.

Six of the fourteen ADA houses displayed possible, albeit slight, evidence of airtightness degradation while the remaining eight displayed no significant change in leakage. However, the magnitude of the observed changes was small considering the air leakage rates at the end of the monitoring period were still below those permitted for R-2000 construction. If the observed changes were indicative of a trend, then a further commentary on the ADA system may be in order, at least for the versions of the system investigated. For this reason, further monitoring of the structures is recommended. However, based on the results to date, it was concluded that no evidence was found to indicate that the ADA system is unsuited for use in residential construction.

Also, initial airtightness levels were less than the maximum permitted for R-2000 construction, demonstrating the capability of the ADA system to achieve low levels of envelope leakage.

Finally, stucco significantly improved the airtightness of the six houses for which pre-and-post stucco data was available. This indicates that leakage sites existed in the wall system air barriers which the stucco was subsequently able to seal.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 AIR BARRIER PERFORMANCE RELATIVE TO THE R-2000 STANDARD

- Both the polyethylene and ADA air barrier systems were able to meet the airtightness requirements of the R-2000 Standard. The tightest building envelopes were those constructed with the double wall technique and polyethylene air barrier systems.

6.2 STABILITY OF THE POLYETHYLENE AIR BARRIER SYSTEM

- Two of the ten, stucco-covered houses constructed with the polyethylene air barrier system demonstrated possible, albeit slight, evidence of airtightness degradation over monitoring periods which ranged up to 36 months. However, the changes in airtightness were small and not judged to be of practical significance. All but one of the houses were able to meet the R-2000 airtightness requirements at the end of their respective monitoring periods. As a result, it was concluded that no evidence was found to indicate polyethylene is unsuited for use as an air barrier material in residential construction.

6.3 STABILITY OF THE ADA AIR BARRIER SYSTEM

- Six of the 14 houses constructed with (an early version of) the ADA air barrier system displayed possible, but also slight, evidence of airtightness degradation over monitoring periods which ranged up to 36 months. However, the magnitude of the observed changes was small and not judged to be of practical significance. All fourteen houses were able to meet the airtightness requirements of the R-2000 Standard at the end of their monitoring period. Based on these results, it was concluded that no evidence was found to indicate that the ADA system is unsuited for use in residential construction. However, further monitoring is recommended to increase confidence in these conclusions.

6.4 IMPACT OF STUCCO UPON AIRTIGHTNESS

- Stucco produced significant reductions in airtightness for most of the polyethylene and ADA air barrier system houses. The exceptions were the two double wall houses with very low leakage rates upon which the stucco had only a minor impact.

6.5 RECOMMENDATIONS

- Continued airtightness monitoring of the houses is recommended to provide longer term data and improve confidence in the conclusions reached to date. A suitable testing schedule would be once per year, preferably during March to coincide with the initial test dates of this study.

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