The Variation of Airtightness of Wood-Frame Houses Over an 11-Year Period

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ABSTRACT

This paper summarizes the most recent results from an ongoing, multi-year research program to monitor the long-term performance of residential air barrier systems. Airtightness tests were conducted on 17 houses, located in Winnipeg, Canada, ranging in age from 8 to 11 years, for which there was extensive historical data. Eight of the houses used polyethylene air barrier systems and nine used an early version of the airtight drywall approach (ADA). The latest tests were conducted in 1997.

The current results showed that the average airtightness of the eight polyethylene houses was essentially unchanged over the monitoring period. Although three of the houses became somewhat leakier, most of the major leakage occurred at locations not associated with the polyethylene portions of the air barrier. It was concluded that no evidence was found to indicate that polyethylene is unsuited for use as an air barrier material in residential wood-frame construction, particularly given that the polyethylene used in the project houses was of a lower quality than now required by the National Building Code of Canada.

The average leakage rate of the nine ADA houses was found to have degraded slightly, with six of the houses becoming somewhat less airtight. Once again though, most of the major leakage occurred at locations not directly associated with the ADA portions of the envelope. It was concluded that no evidence was found to indicate that the ADA system is unsuited for use in residential wood-frame construction.

INTRODUCTION

One of the most critical parameters affecting building performance is the airtightness of the envelope. A structure with a leaky envelope will suffer from unnecessarily high energy costs, a less comfortable interior environment, and degraded envelope durability resulting from air leakage/moisture deposition problems. Unfortunately, little information is available on the long-term performance of air barrier systems. One of the few research projects that has explored the issue (for houses) was the Flair Homes Energy Demo/CHBA Flair Mark XIV Project in Winnipeg, Canada. Twenty-four houses were constructed between 1985 and 1989 using two different types of air barrier systems: polyethylene and the airtight drywall approach (ADA). Regular airtightness tests were carried out over a three-year period to assess their performance. When the Flair Project was completed in 1989, it provided one of the few long-term assessments of building airtightness. However, even three years is a relatively short time period compared to the expected life of a house. In 1997, an opportunity arose to revisit the Flair houses to see how their airtightness had changed over the decade since the first house was tested. Of the original 24 houses, 17 participated in the present study.

The objectives of the work described in this paper were to evaluate the airtightness of the Flair Project houses after a decade of service and to provide a critical commentary on the durability of their air barrier systems.

DESCRIPTION OF THE 17 HOUSES

The 17 project houses were all detached bungalows with full basements and main floor areas ranging from 60 m^2 to 85 m^2 (646 ft^2 to 915 ft^2). They were all constructed by the same builder and were architecturally extremely similar. Each house was designated as either a "polyethylene" or "ADA" house depending on the dominant air barrier system used. The polyethylene houses used sheet polyethylene with

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joints and penetrations sealed, typically with acoustical sealant. The ADA houses relied on a combination of drywall and strategically placed gaskets to serve as the air barrier. More detailed descriptions can be found in Proskiw (1997).

Significantly, none of the houses used polyethylene manufactured in compliance with Standard CGSB CAN2-51.34, since it was not then available. Material that complies with this standard is more resistant to chemical and physical attack and is generally regarded as being of a higher quality than the type used in earlier construction (including the Flair houses). As well, the ADA houses used a relatively early version of the ADA system. Subsequent versions of the system are believed to have better performance due to the combination of improved materials and better design details. This suggests that the airtightness results discussed here may represent a worst-case scenario since better performance should be possible for both air barrier systems.

Testing and Analysis

Airtightness tests on the 17 houses were carried out in early 1997 in accordance with Standard CAN/CGSB-149.10-M86 (CGSB 1986). The same blower door rig was used for the earlier tests and the 1997 tests. Examinations were also performed on each house to identify the major sources of leakage for comparison to historical data. During the initial monitoring period, regular contact had been maintained with the occupants, and the houses were routinely inspected to note any physical alterations that might have affected their airtightness. Few changes were observed and these were judged to be typical for new houses. The 1997 visits generally found that the houses had not been altered in any way that would be expected to affect their airtightness. Where changes had occurred, such as the addition of a new furnace, every effort was made to configure the house back to its original condition by sealing the new openings. Houses' volumes and envelope areas were unchanged between the earlier and the 1997 tests.

ANALYSIS

Test results are reported in this paper using the air change rate at 50 pascals (ACH_{50}) and the normalized leakage area at 10 pascals (NLA_{10}). For comparison purposes, the Canadian R-2000 technical standard for energy-efficient houses requires that either the ACH_{50} be less than 1.50 ACH_{50} or that the NLA_{10} not exceed 0.7 cm^2/m^2. These values are often regarded as the unofficial demarcation between "tight" and "loose" construction. Three methods, described below, were used to evaluate changes in airtightness. However, none was deemed capable of providing a definitive statement on the change in airtightness. This assessment was made after consideration of the data, the methods of analysis, and the houses themselves.

Change Between the First and Last Airtightness Tests

The absolute and percentage changes in ACH_{50} and NLA_{10} values were compared using data from the first and last tests conducted on each house. The limitation of this method of analysis is its susceptibility to measurement error, since only two data points are used. Also, it does not distinguish between a slow, gradual degradation in airtightness and a single-event change.

New High

The 1997 ACH_{50} and NLA_{10} test values were compared to the data from earlier tests. If the 1997 results for a house were higher than any of the previous results, this event was noted. The rationale behind this method is that some degree of change can be expected due to normal variations in house airtightness, as well as from measurement error; if a new high value was measured, it could be indicative of a significant change in airtightness.

Statistical Tests

For each house, the earlier data were treated as a data sample with a sample mean and a sample standard deviation. The 1997 results were then compared to the earlier results to see if the 1997 results fell within the confidence interval established for the earlier tests. If the 1997 results did fall within the confidence interval, then it was concluded that they and the earlier results were from the same population, i.e., that the house and, hence, its airtightness had not changed. For each house, the ACH_{50} and NLA_{10} values were analyzed for the original data set and a confidence interval established using the two-sided t-test and a 99% confidence interval. In other words, if the t-test indicated that a change in airtightness had occurred, there was a 1% probability that the conclusion was incorrect.

AIRTIGHTNESS RESULTS

The complete set of ACH_{50} and NLA_{10} data for the 17 houses, dating back to their time of construction, is shown in Tables 1 and 2. Table 3 summarizes the changes in ACH_{50} and NLA_{10} values between the first and the 1997 tests results and gives an overview of the new high and statistical results.

Performance of the Polyethylene Air Barriers

The overall performance of the eight polyethylene air barrier houses is summarized in Figures 1 through 4, which show the absolute and percentage changes in the ACH_{50} and NLA_{10} results, respectively, between the first and last (1997) tests. Note that the houses are rank-ordered in these graphs and the order of the houses changes between graphs. It can be seen that while some of the houses became leakier, the average change in airtightness was effectively negligible. While both the mean and median ACH_{50} values increased very slightly,

TABLE 1
ACH_{50} Results

House	3/86	7/86	11/86	2/87	7/87	11/87	2/88	5/88	7/88	8/88	11/88	3/89	8/89	12/89	1/90	3/90	4/90	1/97	2/97	3/97
2		1.05	1.17	1.12	0.98	1.05	1.17		1.20		1.20	1.18							1.36	
3	1.51		1.54	1.85	1.49		1.69					1.50							1.52	
4	1.46		1.31	1.30	1.12		1.42		1.38			1.47						1.51		
5	1.12		1.26	1.10	1.14		1.05					1.03							1.03	
6	1.21		1.26	1.31	1.19		1.42		1.20			1.23								1.64
7	1.17		1.52	2.20					2.06			1.42						1.05		
9	1.62	1.66	1.74	1.84	1.48	1.68	1.78		1.74		1.73	1.77							1.83	
10	1.28	1.15	1.43	1.39	1.17	1.04	1.03		1.20		1.24	1.19						1.30		
12	1.59[1]	1.12	0.96	0.98	0.88		0.98		1.06			1.25								1.40
13	1.27[1]	0.84	0.83	0.76	1.04		0.94		1.26			0.89						1.33		
15	1.47[1]	1.33	1.26	1.15		1.10			1.22			1.19								1.54
16	1.26[1]	1.29	1.38	1.41		1.52						1.50							1.35	
18	0.49[1]	0.42	0.48	0.48	0.39	0.42	0.43		0.49		0.38	0.44							0.51	
19	1.05[1]	0.81	0.84	0.91	0.72		1.04		0.92			1.11						1.13		
21															1.83[1]				1.77	
22								1.59[1]	0.96					0.94			1.14		0.80	
24										1.39			1.39	1.31		1.29		1.17		

[1] No stucco.

TABLE 2
NLA_{10} Results

House	3/86	7/86	11/86	2/87	7/87	11/87	2/88	5/88	7/88	8/88	11/88	3/89	8/89	12/89	1/90	3/90	4/90	1/97	2/97	3/97
2		0.140	0.603	0.451	0.400	0.425	0.503		0.515		0.521	0.471							0.590	
3	0.513		0.517	0.762	0.564		0.656					0.525							0.518	
4	0.585		0.482	0.551	0.437		0.643		0.546			0.566						0.694		
5	0.444		0.450	0.432	0.334		0.341					0.318							0.347	
6	0.473		0.488	0.613	0.366		0.581		0.456			0.652								0.729
7	0.433		0.637	0.981					0.717			0.496						0.380		
9	0.559	0.587	0.566	0.623	0.596	0.641	0.659		0.619		0.613	0.606							0.700	
10	0.588	0.418	0.642	0.805	0.404	0.441	0.392		0.468		0.517	0.644						0.550		
12	0.835[1]	0.468	0.419	0.329	0.318		0.405		0.433			0.538								0.522
13	0.569[1]	0.360	0.314	0.401	0.437		0.403		0.434			0.271						0.535		
15	0.774[1]	0.655	0.597	0.547		0.539			0.659			0.593								0.874
16	0.677[1]	0.675	0.714	0.711		0.777						0.715							0.609	
18	0.259[1]	0.227	0.190	0.192	0.155	0.138	0.171		0.177		0.141	0.177							0.181	
19	0.444[1]	0.232	0.320	0.347	0.279		0.402		0.381			0.444						0.470		
21															0.799[1]				0.649	
22								0.697[1]	0.372					0.361			0.445		0.322	
24										0.572			0.640	0.771		0.581		0.511		

[1] No stucco.

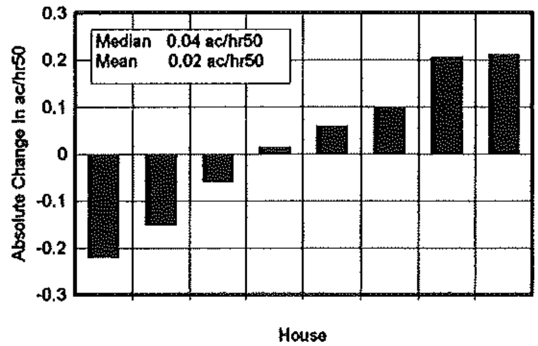

Figure 1 *Absolute changes in ACH_{50}, poly houses.*

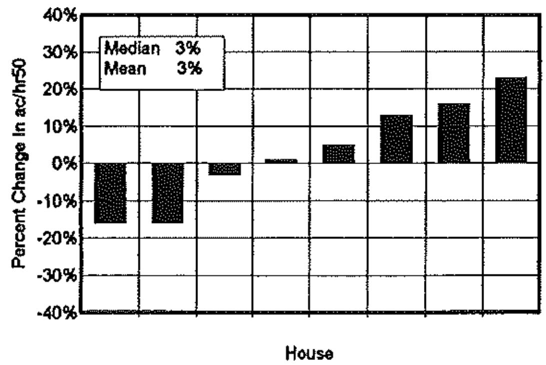

Figure 2 *Percent changes in ACH_{50}, poly houses.*

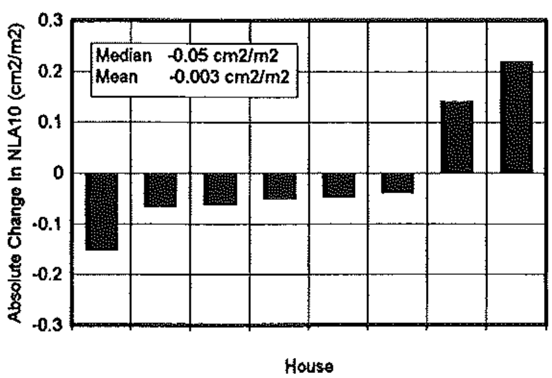

Figure 3 *Absolute changes in NLA_{10}, poly houses.*

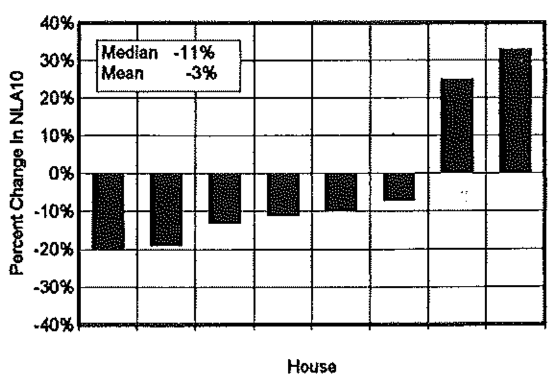

Figure 4 *Percent changes in NLA_{10}, poly houses.*

the corresponding NLA_{10} values decreased by a slightly larger amount. Perhaps more importantly, there was no evidence of any catastrophic failures of the air barrier systems.

Examining the ACH_{50} results, the house that suffered the greatest percentage degradation in airtightness was #18, with a 23% increase. However, the NLA_{10} for this house actually decreased by 20%. Using the NLA_{10} data, the worst-case house was #15 whose NLA_{10} increased by 33% while its ACH_{50} increased by 16%. Yet the absolute magnitude of the changes for house #15 were still rather modest: only 0.21 ACH_{50} and 0.22 cm^2/m^2.

With respect to the new highs, summarized in Table 3, three of the eight houses established new high ACH_{50} or NLA_{10} values in the 1997 tests. Likewise for the t-tests, three of the seven houses failed the test, i.e., the 1997 results did not fit within the earlier data constraints (ignoring #21 for which there was insufficient data and ignoring the two houses that "failed" the t-test because they became more airtight). However, this is a very rigorous test in which a "failure" is not necessarily indicative of a noteworthy degradation in airtightness, at least from a practical perspective.

While these results are encouraging, closer examination suggests that an even more positive interpretation may be warranted. For six of the eight polyethylene houses, including two of the three homes that became leakier, the major leakage locations were found to be at areas that were both easily accessible for repairs and were not specifically part of the "polyethylene portion" of the house's air barrier system. For example, significant leakage was found in several houses at the floor drains, around duct penetrations, or through aged weatherstripping. Presumably, some of the increase in leakage can be attributable to these locations, which suggests there was even less evidence of degradation of the polyethylene portion of the air barrier system. Examining the houses that became leakier, house #9 (which used 4 mil, unsealed polyethylene) had its major leaks at these accessible, nonpolyethylene locations. House #15 was similar, with about one-half of its total leakage occurring through the ductwork originally installed for an air-to-air heat pump located in the basement. When the duct-

TABLE 3

Change[1] in Airtightness Between the First Tests and 1997 Tests, New Highs, and Statistical (t-Test) Results

House	Air Barrier System	Monitoring Period (years)	ACH_{50} Absolute Change	ACH_{50} Percent Change	NLA_{10} (cm^2/m^2) Absolute Change	NLA_{10} (cm^2/m^2) Percent Change	New High? ACH_{50}	New High? NLA_{10}	t-Test Pass/Fail[2] ACH_{50}	t-Test Pass/Fail[2] NLA_{10}
2	ADA	10.8	0.30	29%	0.180	44%	yes	no	fail	fail
3	ADA	10.9	0.01	1%	0.005	1%	no	no	pass	pass
4	ADA	10.8	0.06	4%	0.109	19%	yes	yes	pass	fail
5	ADA	10.9	−0.09	−8%	−0.097	−22%	no	no	pass	pass
6	ADA	11.0	0.43	36%	0.256	54%	yes	yes	fail	fail
7	ADA	10.8	−0.12	−10%	−0.053	−12%	no	no	pass	pass
9	polyethylene	10.9	0.21	13%	0.141	25%	no	yes	fail	fail
10	polyethylene	10.8	0.01	1%	−0.038	−7%	no	no	pass	pass
12	ADA	10.7	0.28	25%	0.054	12%	yes	no	fail	pass
13	ADA	10.5	0.50	60%	0.175	48%	yes	yes	fail	fail
15	polyethylene	10.7	0.21	16%	0.219	33%	yes	yes	fail	fail
16	polyethylene	10.6	0.06	5%	−0.066	−10%	no	no	pass	fail[4]
18	polyethylene	10.6	0.10	23%	−0.047	−20%	yes	no	fail	pass
19	ADA	10.5	0.33	40%	0.238	103%	yes	yes	fail	fail
21[3]	polyethylene	7.1	−0.06	−3%	−0.151	−19%	no	no	n/a	n/a
22	polyethylene	8.6	−0.15	−16%	−0.050	−13%	no	no	pass	pass
24	polyethylene	8.4	−0.22	−16%	-0.061	−11%	no	no	fail[4]	pass

1 A -ve indicates the house became more airtight.
2 "Pass" means the 1997 results were within the statistical limits established during the earlier tests.
3 Initial test conducted without stucco.
4 The house failed the t-test only because it became more airtight over the monitoring period.

work was sealed, the measured airtightness dropped to about one-half that permitted for R-2000 homes. The final house, #18, may have become leakier, but one needs only to examine the data in Tables 1 and 2 to appreciate the significance of this "degradation." The house was built tight and remained tight. Its "degradation" in airtightness can be interpreted more as a limitation of the analytical methodology than its air barrier. And, as noted, none of these houses used polyethylene manufactured in accordance with Standard CGSB 51.34, which is now required by the 1995 National Building Code of Canada.

It was also found that the acoustical sealant used to seal the polyethylene was still accessible at the basement header location in three of the houses. Closer examination showed that in all three cases, it was still soft and pliable and appeared to be completely functional after an average of 11 years of use. This is a significant observation because of the critical role that acoustical sealant serves in the polyethylene air barrier system.

However, a word of caution should be noted about these results. All of the project houses used stucco as the exterior surface on three of the four walls. Although stucco is not intended to serve as part of the air barrier system, its ability to improve the airtightness of wood-frame construction is well established. It is unknown how well the polyethylene (or ADA houses) would have performed had a more air-permeable cladding system been used.

Performance of the ADA Air Barriers

The performance of the ADA houses for the first and last (1997) airtightness tests is summarized in Figures 5 through 8. Overall, they did not perform quite as well as the polyethylene homes. Both the mean and median ACH_{50} values increased slightly, although the absolute magnitude of the increases was generally modest. The NLA_{10} results behaved in much the same manner. Although a few of the houses displayed large percentage increases in their leakage rates, none were judged as having demonstrated catastrophic failures of the air barrier systems. The few houses with large percentage increases are perhaps best described as being worthy candidates for future monitoring to see if the 1997 results were an aberration or indicative of a trend. With respect to the new highs, summarized in Table 3, six of the nine ADA houses established new highs in the 1997 tests for either their ACH_{50} or NLA_{10} values. Likewise, using the t-tests, six of the nine displayed failures, indicating that house airtightness had changed between the early tests and the 1997 tests. Again, however, this is a very rigorous statistical test.

For the seven ADA houses that became leakier, all or most of the major air leakage occurred at accessible locations that were not part of the "ADA portion" of the overall air barrier system. House #2, which showed a modest increase, had one very large leak through the rough opening around a basement window. This site had been noted during the 1989 airtightness test. House #4 had only a slight increase in its ACH_{50} and NLA_{10} values with some accessible, non-ADA sites noted. House #6 had very noticeable floor drain leakage, not present in the 1989 test, and also had a new, uncovered sump pit added although the leakage rate through it could not be readily assessed. House #12 had a modest increase relative to the first test in 1986 but was effectively unchanged relative to the 1989 results. Also, a natural gas furnace was added during this period and a new vent penetration installed through the floor header, which was a major source of leakage. Houses #13 and #19 showed the largest increases in leakage of any of the 17 project houses relative to their first tests. However, in both cases, the 1997 results were similar to at least one of the prior airtightness test results. Also, #19 was virtually unchanged relative to the last test conducted in 1989.

The project houses used a relatively early version of the airtight drywall approach. Since their construction, improved gasket types and construction details have been developed for the ADA system. The possible beneficial influence of stucco also applies to the ADA houses.

CONCLUSIONS

The average airtightness of the eight project houses constructed with polyethylene air barriers was unchanged over monitoring periods that ranged from 8 to 11 years. Although three of the houses became somewhat leakier, most of the major leakage was found to be occurring at locations not directly associated with the polyethylene portions of the air barrier. No evidence was found to suggest that polyethylene is unsuited for use as an air barrier material in residential wood-frame construction, particularly given that the polyethylene used in the project houses did not conform to contemporary product standards (Standard CGSB 51.34).

The average leakage rates of the nine project houses constructed using an early version of the airtight drywall approach degraded slightly over their 11-year monitoring period. Six of the houses became somewhat leakier, relative to the post-construction condition, but most of the major leakage identified in the 1997 tests occurred at locations not directly associated with the ADA portions of the air barrier. No evidence was found to indicate that the ADA system is unsuited for use in residential wood-frame construction.

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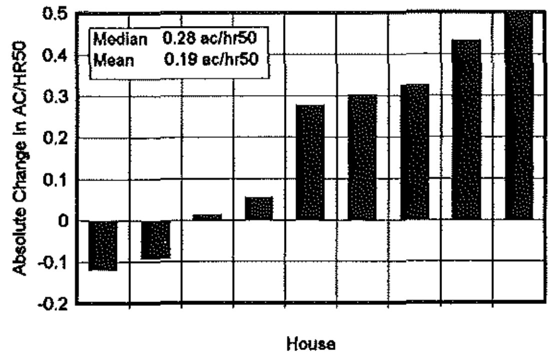

Figure 5 *Absolute changes in ACH_{50}, ADA houses.*

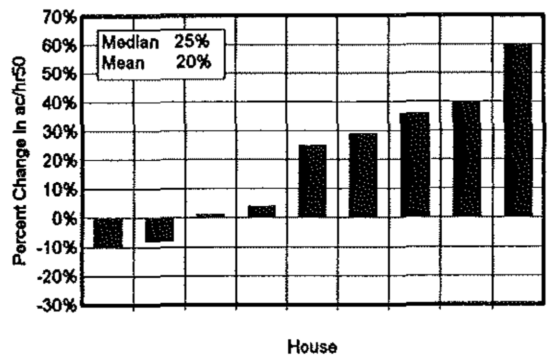

Figure 6 *Percent changes in ACH_{50}, ADA houses.*

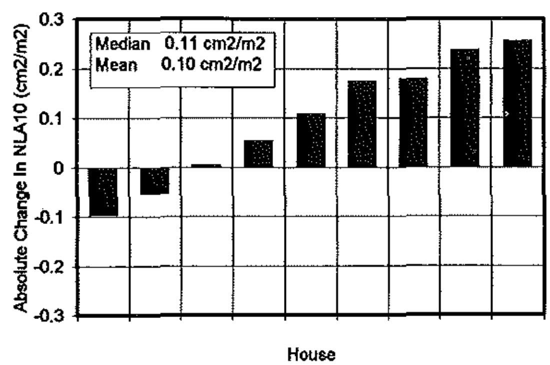

Figure 7 *Absolute changes in NLA_{10}, ADA houses.*

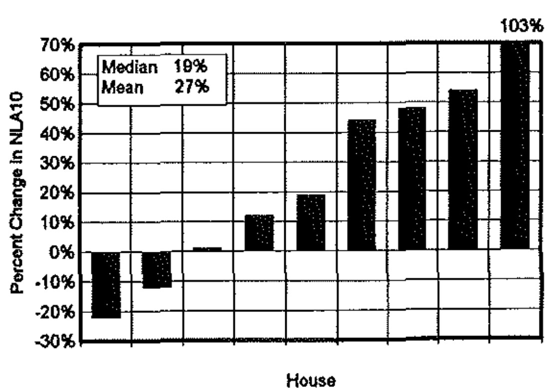

Figure 8 *Percent changes in NLA_{10}, ADA houses.*