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An Evaluation of the Effectiveness of Air Leakage Sealing

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ABSTRACT: A field study was carried out to evaluate the effectiveness of air leakage sealing techniques for reducing air infiltration in houses. Presealing and postsealing air leakage tests were performed upon 82 single detached houses. All of the houses were located in Winnipeg or southern Manitoba, a region with an annual degree day value (Celsius) of about 5800. The sample group consisted of 56 conventionally constructed houses of varying size, style, occupancy, and airtightness and 26 nonstandard structures of smaller but identical size and age. This latter group was part of the Flora Place project.

All houses were placed under a negative pressure, and leakage sites were identified using smoke pencils. Windows and doors were weather-stripped and other unintentional openings caulked and sealed using specified materials and techniques.

Based upon the results of the study, the median reduction in airtightness of the conventional structures, defined using the equivalent leakage area at 10 Pa (ELA_{10}), was 31.6% with significant variations occurring both between houses of the same type and between different types of construction. When the houses are examined in groups according to type of construction, it is apparent that the greatest reduction in ELA (36.9%) was achieved in single-story houses. Houses constructed in somewhat more complicated fashion, such as split levels, exhibited less of a reduction. As a group, two-story houses showed the least reduction (24.4%), likely due to the indirect leakage between floors that could not be addressed properly. Within any group, houses with inaccessible air leakage points, such as in finished basement areas, showed the least reduction. The median reduction in the ELA_{10} for the Flora Place houses was 42.5%, again with significant variations between houses despite their near-identical construction.

Using the air leakage test data and a recently developed correlation model, an estimate was made of the naturally occurring air infiltration rates for all the test houses. This analysis indicated that the sealing produced a median reduction in the infiltration rate of 32.8% for the conventional houses and 46.1% for the Flora Place houses. Due to a lack of equipment, tracer gas tests were not conducted to confirm these values.

Note, however, that the results of this study likely are representative of houses constructed only in Manitoba and possibly in Saskatchewan and Alberta. Since houses in the prairie provinces tend to have low air ~~infiltration~~ rates, the effects of air leakage sealing on houses in other parts of the country could be different from those found in this study.

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Air Infiltration in Houses

Air infiltration generally is acknowledged to represent a major component of the total heating load of houses. Depending upon the type of structure and its existing insulation levels, heat loss due to air infiltration may represent as much as 40% of the annual heating cost [*1*]. To the homeowner, this means an unwelcome expense that must be met every year. To the nation, it represents a significant component of the country's total energy needs. As a result, air infiltration represents both an existing liability and a potential opportunity for reducing energy costs. There is evidence [*2*] to support the fact that reducing the air change rate of a new house to less than 0.2 air changes per hour (ACH) may result in the buildup of unacceptable levels of indoor pollutants.

Purpose and Scope

The project described in this report was carried out to determine the effectiveness of air leakage sealing techniques for reducing air infiltration in houses. To quantify these results, presealing and postsealing air leakage tests were performed upon 82 houses, representing a broad cross section of age, style, construction, size, and occupancy. All were located in Winnipeg or southern Manitoba.

Interpretation of Results

Within the course of this project, a considerable volume of data was collected, refined, and subsequently analyzed with the most relevant information ultimately being reported within this document. However, to satisfy the study objectives, it was not considered possible to express these results using a single parameter. Therefore, to assist the reader in interpreting the study results, a few words of explanation are offered at this point.

First, air infiltration and air leakage should be defined. Within this report, air infiltration is used to describe the movement of outdoor air into the interior living space of the house occurring solely due to natural forces, that is, wind action and stack effect. This air, of course, has to be heated to prevent lowering of the interior air temperature. As air infiltrates into the structure, an equal amount must flow outwards from the interior to the outdoors. This air movement is termed air exfiltration. Air leakage, on the other hand, is used to describe the movement of outdoor air into the house due to the action of the depressurization (or pressurization) blower used in an air leakage test. Because many of the tests were

were conducted by pressurizing the houses. The accepted Canadian airtightness testing standard procedure [*3*] requires tests to be performed only under depressurization conditions.

Airtightness (or air leakiness) generally is defined in terms of the equivalent leakage area at 10 Pa^3 (ELA$_{10}$). The primary value of such a parameter is that it allows direct and easy comparisons of airtightness to be made between houses since it is determined using standardized and accepted procedures. Prior to introduction of the ELA$_{10}$ parameter, many air leakage test results were reported in terms of the number of ACH at various indoor-to-outdoor pressure differentials (typically 4, 10, or 50 Pa). While these results had the advantage of being easy to understand, they also were very prone to misinterpretation since many laymen thought they described the natural infiltration rate. As a result, considerable confusion has occurred as to the actual air infiltration rate of the typical house. To circumvent this problem, concensus among those involved in air leakage testing in Canada has caused the adoption of the ELA$_{10}$ [*3*] approach to eliminate any misunderstanding. As a result, most air leakage tests, including those in this report, now are reported in terms of the ELA$_{10}$.

It also was recognized, however, that the ELA$_{10}$ does not provide explicit information on the naturally occurring air infiltration rate, defined as the rate of air exchange resulting solely from natural forces and not from the depressurization blower used in the air leakage test. For energy-estimating purposes, knowledge of the air infiltration rate is, of course, essential.

To provide this information, the air leakage test results were used to estimate the natural air infiltration rate using a recently developed correlation model [*4*]. Testing this correlation on 25 houses in Canada and Sweden, this model appears capable of predicting air infiltration rates within ±25% of measured values.

To assist the reader, it is suggested that the air leakage test results, expressed using the ELA$_{10}$, be accepted as a means of comparing the airtightness of houses both within this and other studies. The predicted air infiltration rates, on the other hand, should be used to better appreciate the actual effects of air infiltration produced under natural conditions, acknowledging the accuracy limitations of the infiltration model. The ability of the model to predict an infiltration rate not only is dependent upon a properly conducted air leakage test but is also dependent on the outdoor temperature, wind speed and direction, degree of shielding, and the correct calculation of the conditioned volume within the building envelope.

Fundamentals of Air Infiltration

Causes of Air Infiltration

Air infiltration is caused by pressure differentials which exist across the house envelope and result in the uncontrolled movement of outdoor air into the structure. These pressure differentials can be produced by three different driving forces;

1. Stack effect,
2. Wind action.
3. Exhaust fan/ventilation system operation.

Stack Effect—Since indoor and outdoor air are at different temperatures during the heating season, their densities and resulting buoyancies will be different. In the winter months, these buoyancy differentials create negative indoor-to-outdoor pressure differentials over the lower portions of the house envelope and positive pressure differentials over the upper portions. As a result, the stack effect attempts to induce infiltration across the lower portions of the envelope and exfiltration over the upper portions.

Wind Action—The most obvious effects of wind action are well understood by most people. The wind blowing against a structure creates a pressure force on the windward side and a suction force on the leeward side which, if the walls contain any holes or cracks, causes air infiltration on the windward side and air exfiltration on the leeward side. In practice, the subtle dynamics of wind flow around buildings is considerably more complex. Distortions to these flow patterns caused by turbulence from adjacent structures, trees, etc., can result in air infiltration/exfiltration forces markedly different from those anticipated.

Exhaust Fan/Ventilation System Operation—Mechanical exhaust systems such as bathroom fans and dryer exhausts remove air from the building at high flow rates which may induce air infiltration over the entire house envelope. Because these systems are run intermittently, their contribution to the ELA and the predicted infiltration rate has not been included. Only unintentional openings in the building envelope were included in the air leakage tests.

The net pressure differential to which a house is exposed to and hence the net air infiltration that it experiences at any time will be the algebraic sum of the three driving forces just described. It is obvious that the pressure differentials and resulting air infiltration rates will vary throughout the year with outside temperature, wind speed and direction, and exhaust fan/ventilation system operation. In general, however, the average indoor-to-outdoor pressure differentials experienced by a house during winter operation generally will be less than 5 Pa [5].

Sources of Air Infiltration/Exfiltration

The locations of the most common sources of air infiltration in a conventional house are shown in Fig. 1 [*6*]. Contrary to popular belief, windows and doors are not the major sources, usually contributing only about 25% of the total. Rather, joints between the main walls and the floor system, electrical outlets on exterior walls, and ceiling penetrations for light fixtures, attic hatches, partition walls, and plumbing fixtures constitute the major infiltration/exfiltration paths.

Most of these cracks, gaps, and holes are "built into" the house during its construction. With lower energy prices, few builders felt the need to take specific measures to control air infiltration.

Effects of Air Infiltration

Uncontrolled air infiltration has several effects upon the operation and use of a house. The first and most obvious is increased heating costs. Any air which enters the building, beyond that required for respiration, furnace operation, and humidity/air pollutant control, represents an additional and unnecessary heating load. In almost all older structures, the quantity of outdoor air delivered by air infiltration exceeds that which is required [*7*], a value generally agreed to be about 0.5 ACH [*8*]. This explains, for example, why most older homes suffer from dry air during the winter months.

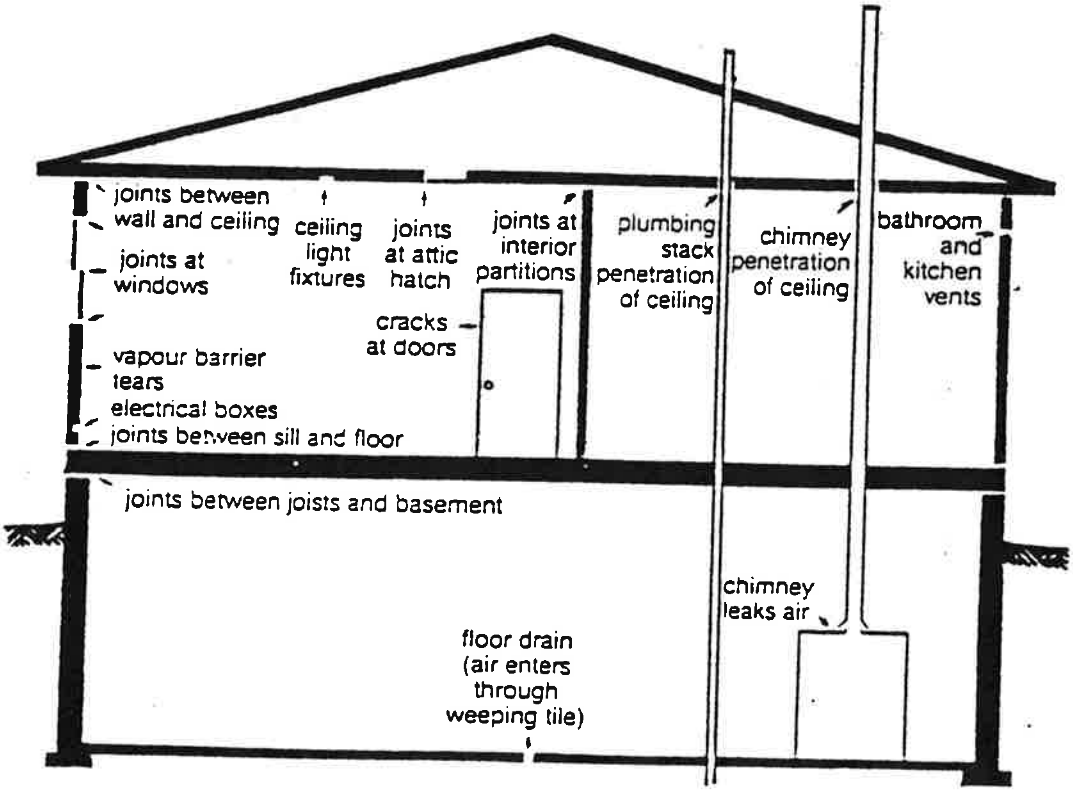

FIG. 1—*Air infiltration locations in a conventional house.*

Air infiltration also can affect the comfort level of the house, as uncontrolled drafts can cause discomfort and chills. Cold drafts also can increase the heating bill beyond that actually necessary to warm outdoor air by causing the occupants to become "thermostat jockies," pushing up the thermostat setting whenever they feel a chill. In extreme cases, air infiltration coupled with a poorly balanced heating system can cause some rooms of a house to become virtually uninhabitable during the winter months. For these reasons, many homeowners regard the degradation of indoor comfort levels as the most serious consequence of air infiltration.

The movement of warm, moisture-laden air outwards through the building shell due to exfiltration forces is responsible for the third major effect. As this air exfiltrates through the (colder) shell, its temperature drops, and condensation can occur [*9*]. If this moisture is not removed by evaporation or sublimation, it may lead to wetting of insulation and structural elements. Many of the insulations found in older houses are vulnerable to moisture damage, which may cause settling and reduction in their effective thermal resistance [*9*]. If the moisture content of wood is raised above approximately 20% for extended periods of time (roughly two months) and appropriate temperatures are maintained, wood rot also may occur. Interior finished surfaces, particularly ceilings, also are vulnerable to moisture damage. Ceiling staining caused by moisture accumulation in the attic is common in some houses, and, in extreme cases, complete collapse of large sections of the ceiling can occur within a few years [*9*].

Although some sources have suggested that many existing homes, even after having been air sealed, are supplied with sufficient outside air for ventilation and combustion purposes through infiltration [*7*], this mechanism should not be relied upon to supply air required for these purposes. A study [*10*] of 100 homes across Canada with suspected venting problems revealed that about 40% actually did have problems that required some form of remedial measures. It is possible that these problems could be aggravated if homes are sealed without addressing ventilation and combustion air supply.

In view of the experience level that some air sealing contractors have achieved during the past four or five years, it is recommended that every major combustion appliance be equipped with its own outside air supply, regardless of the amount of air sealing undertaken. An ever-widening range of products is now available [*11*], and a committee, under the sponsorship of the Canadian General Standards Board (CGSB), has been formed which has been given the responsibility of developing a procedure to permit a contractor to determine what additional ventilation air quantities, if any, are required after a house has been air sealed.[4]

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[4] Private communication, Bruce Fulcher, ENER-CORP Management, Ltd., April 1964.

Description of the Air Leakage Testing Program

Overview

To evaluate the effectiveness of anti-air infiltration measures, presealing and postsealing air leakage tests were performed upon 82 houses in the Winnipeg or southern Manitoba areas.

Houses were selected from customers obtained in the normal course of business. These customers could be characterized as either homeowners who perceived the need for air sealing or who were convinced of its merits by an energy consultant.

In general these measures included:

1. Weatherstripping of:
   (*a*) Exterior doors.
   (*b*) Windows.
2. Caulking and sealing of:
   (*a*) Exterior doors.
   (*b*) Windows.
   (*c*) Electrical plugs and switches on exterior walls.
   (*d*) Ceiling lights and electrical openings in the attic.
   (*e*) Plumbing stacks, vents, and ducts passing through attics.
   (*f*) Fireplace and furnace chimneys in the attic.
   (*g*) Cracks along interior partitions.
   (*h*) Attic hatch.
   (*i*) Cracks between concrete walls and subfloor.
   (*j*) Floor joist area.
   (*k*) Perimeter or milk, mail, and coal chutes.
   (*l*) General cracks and openings in walls (not including basement walls).

After completion, a second air leakage test was performed.

Air Leakage Test Procedure

The procedure used for conducting the air leakage tests was based upon the draft of a standard specification currently being developed by the CGSB [*3*]. At the time of writing, the standard was in its eighth draft and will be identified on finalization as CAN2-149.10-M84, "Determination of the Equivalent Leakage Area of Buildings by the Fan Depressurization Method."

By depressurizing the house, a negative indoor-to-outdoor pressure differential was created which induced air leakage into the structure. The air leakage test consisted of subjecting the house to a number of different pressure differentials while measuring the rate at which air is exhausted according to the prescribed test procedure [*3*]. Using these data, a characteristic air leakage curve was calculated which described the leakage at any pressure differential. In this manner, changes in the airtightness of the house can be determined by conducting identical leakage tests before and after implementation of any antiinfiltration measures.

It should be noted that the air leakage tests were not always performed in strict conformance with the draft standard [3] largely because many of the tests were carried out prior to release of the draft and because of changes between subsequent drafts. The primary deviation from the draft standard procedure was in the inability of the depressurization apparatus to achieve an induced pressure differential of 50 Pa in some very leaky homes.

Tests in which the flow exponents fell outside of the range of 0.50 to 1.00 and the correlation coefficient was less than 0.9800 were rejected.

Air Leakage Test Results

Data Presentation

Air leakage test results are frequently reported using several different parameters. The one that is most commonly used in Canada and the one that was adopted for this report, as previously explained, is the ELA_{10}.

The ELA_{10} is the size of the equivalent hole, in units of square metres, which would produce the same net leakage as the randomly distributed leakage paths normally found in a house. It is calculated at a pressure differential 10 Pa and is independent of the size of the house.

Air Leakage Test Results—Conventional Houses

Results are separated for the 26 Flora Place units and the remaining 56 conventional houses. A summary of the air leakage test results for the 56 conventional houses is shown in Table 1. A further breakdown of the data, based upon type of house, is given in Table 2. Notice that the ELA_{10}s given in Table 2 are median values.

As is evident from Tables 1 and 2, considerable variation was encountered in both the initial air leakiness of the structures and in the effectiveness of the sealing. However, based upon the 56 houses studied, the median reduction in the ELA_{10} due to the air leakage sealing was 31.6%.

Air Leakage Test Results—Flora Place Houses

A summary of the air leakage test results for the 26 Flora Place houses is shown in Table 3. Once again, considerable variations were encountered in the airtightness of the structures and in the effectiveness of the sealing. This is a rather interesting result since the houses were virtually identical in size, construction, and age. The median reduction in the ELA_{10} due to the air leakage sealing was 42.5% for the 26 houses.

TABLE 1—*Summary of presealing and postsealing air leakage tests—conventional houses.*

House Number	House Type (No. of Stories)	Year of Construction	ELA_{10}, m^2		Percentage Reduction in ELA_{10}
			Presealing	Postsealing	
1	2	1902	0.07926	0.05526	30.3
2	split level	1926	0.06008	0.04388	27.0
3	2	1925	0.09482	0.07815	17.6
4	2	1916	0.11522	0.10028	13.0
5	1½	1954	0.06346	0.05280	16.8
6	1	1952	0.09517	0.06686	29.7
7	1½	1920	0.12973	0.09581	26.1
8	1½	1948	0.08703	0.06228	28.4
9	1	1955	0.12382	0.08115	34.5
10	split level	1960	0.09138	0.06184	32.3
11	1	1947	0.05473	0.05124	6.4
12	1	1976	0.06196	0.03597	41.9
13	1	1964	0.10304	0.05720	44.5
14	1	1958	0.07486	0.04413	41.1
15	1	1975	0.08843	0.06419	27.4
16	1½	1950	0.04876	0.04070	16.5
17	1	1951	0.14112	0.05475	61.2
18	1	1976	0.06748	0.04280	36.6
19	1	1953	0.09126	0.05345	41.4
20	1	1969	0.09032	0.04803	46.8
21	2	1923	0.14578	0.12032	17.5
22	1	1927	0.19256	0.14243	26.0
23	split level	1973	0.09076	0.06227	31.4
24	2	1970	0.08979	0.05089	43.3
25	split level	1977	0.09755	0.05183	46.8
26	1	1940	0.10971	0.05936	45.9
27	1	1932	0.06247	0.03838	38.6
28	split level	1974	0.04004	0.03619	9.6
29	1	1946	0.04438	0.03178	28.4
30	1½	1947	0.09205	0.06680	27.4
31	1	1966	0.04614	0.01980	57.1
32	split level	1975	0.08016	0.03834	52.2
33	1	1954	0.05668	0.04272	24.6
34	1	1962	0.04440	0.03481	21.6
35	1	1922	0.09711	0.06105	37.1
36	2	1940	0.12632	0.09555	24.4
37	split level	1962	0.10348	0.08031	22.4
38	1½	1953	0.12560	0.05143	59.1
39	split level	1974	0.06718	0.05275	21.5
40	1	1968	0.05869	0.03984	32.1
41	1	1946	0.13322	0.08542	35.9
42	2½	1925	0.25560	0.13084	45.8
43	2	1902	0.26276	0.19217	26.9
44	1½	1950	0.07642	0.04904	27.6
45	2½	1926	0.17859	0.14270	20.2
46	1	1976	0.05120	0.03600	28.0
47	1	1951	0.07973	0.04339	32.6
48	2½	1930	0.30209	0.17236	42.9
49	split level	1980	0.12155	0.10335	15.0
50	split level	1968	0.06501	0.04049	37.7
51	1	1962	0.04621	0.03762	18.6
52	1	1957	0.08765	0.03694	57.9
53	1	1960	0.11005	0.06638	39.7
54	1	1973	0.10964	0.06826	37.8
55	1	1962	0.06513	0.04092	37.1
56	2½	1930	0.25105	0.17340	31.7

TABLE 2—*Equivalent leakage areas [ELA$_{10}$] conventional houses.*

House Type	Sample Size	Median ELA$_{10}$, m^2		Median Percentage Reduction, %
		Presealing	Postsealing[a]	
1 story	28	0.08369	0.05281	36.9%
Split levels	10	0.08546	0.06051	29.2%
1½ story	7	0.08703	0.06318	27.4%
2 story	7	0.11522	0.08714	24.4%
2½ story	4	0.25483	0.15978	37.3%
All houses	56	0.09054	0.06193	31.6%

[a] Calculated by subtracting the median value of the percentage reductions recorded for the individual houses from the median presealing ELA$_{10}$.

TABLE 3—*Summary of presealing and postsealing air leakage tests—Flora Place houses.*[a]

House Number	ELA$_{10}$, m^2		Percentage Reduction, %
	Presealing	Postsealing	
57	0.03088	0.02244	26.9
58	0.03135	0.01789	42.1
59	0.05402	0.02924	45.5
60	0.04097	0.02581	36.2
61	0.06623	0.02414	63.6
62	0.05450	0.03085	41.3
63	0.04564	0.02850	26.9
64	0.04104	0.01837	55.1
65	0.04683	0.03004	35.8
66	0.03848	0.02869	25.1
67	0.03637	0.02698	44.5
68	0.04656	0.02993	36.8
69	0.04048	0.01984	27.2
70	0.04589	0.02490	45.2
71	0.03672	0.01536	58.4
72	0.04172	0.02357	43.6
73	0.05532	0.02358	57.4
74	0.02849	0.02011	29.4
75	0.04232	0.02651	50.2
76	0.04314	0.02594	39.3
77	0.04787	0.02803	44.2
78	0.03922	0.02243	42.8
79	0.03612	0.02146	40.6
80	0.03471	0.02088	39.9
81	0.04047	0.02087	48.7
82	0.07182	0.02162	69.8

[a] All single story with no basement, constructed in 1940.

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