HOUSING CONSERVATION UNIT

Ministry of
Municipal Affairs
and Housing
Ontario

THE WEATHERIZE PROJECT

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SUMMARY

A two year research and demonstration project was undertaken by the Ontario Ministry of Municipal Affairs and Housing to demonstrate new techniques, transfer new technology and research critical issues concerning the impact of air tightening on typical houses.

Sixty-five houses in four communities, Peterborough, Sault Ste. Marie, Cambridge and Ottawa, comprising a cross-section of Ontario Housing stock, were air tightened with the aid of fan depressurization. The houses, selected mainly on the basis of two key variables, age and type, are a broadly representative house sample.

Contractors for the air tightening work were selected on the basis of established expertise and their familiarity with the use of depressurization techniques. Each Contractor was responsible to complete a series of tasks on test houses in their locality. These tasks involved obtaining information on the operation and indoor environment of the house, (through an interview with the homeowner); collecting energy consumption data; measuring the houses to calculate total heated volume and above grade envelope area; inspecting each house and detailing building conditions such as moisture problems; and, tightening the houses in a staged manner with each stage tested with fan depressurization.

The work undertaken was evaluated by a variety of follow-up activities from phone surveys, fuel record analysis and field inspections.

Areas of air leakage were identified and evaluated prior to air sealing. The contractor subjectively rated each observed leakage area as "extreme, normal or insignificant". This resulted in 132 different categories of leakage sites. The ten most frequent were interior wall outlets/switches, exterior windows, exterior doors, exterior wall outlets/switches, attic access, ceiling light fixtures, plumbing holes in wall/floor, all floor mouldings, wall/sill plate area and cracks in wall finish. Many potential air leakage points were highly variable from house to house and emphasized the value of investigation in each case prior to air sealing. Some distinct separation can be made in leakage location by age of housing. The older houses tend to leak more often around windows, mouldings and cracked plaster, while sill plates, joist areas and exhaust ductwork are more noticeable in newer houses.

A total of six tests on each of the 65 houses with at least six pressure/flow readings per test were conducted. A number of difficulties arose from assorted field errors, equipment malfunction and variations of test procedures. The greatest source of error was the changing wind conditions over the two or three days per house testing. These errors were further magnified by the "least square" regression analysis used to model the flow/pressure relationship. The staged testing required a degree of precision that fell within the natural error margin of instrumentation. Despite this the bulk of the air tightnesss tests lay within acceptable levels of confidence.

The critical ELA values show a wide variation from 8125 cm^2 to a low of 415 cm^2, or for SLA values a range of 41.0 cm^2/m^2 to 2.0 cm^2/m^2. Houses built after 1945 appear about one-third (1/3) tighter than pre-war housing. Houses built after 1970 appear to be tighter than those built after 1945.

The average percentage reduction ELA for all houses is 36%. Sixty-eight percent of the total sample lies within the 20% to 45% range. Reductions range from a low 9% to a maximum of 70%. Average reductions for each stage of air tightness varied from house to house but each stage of sealing has approximately the following reduction on the tightening process: Openings 12.8%, Cracks 12.2%, Foundations 7.1% and By-pass 4.3%.

The sealing process on the average required three person days (26 hrs.) per house, using 22 tubes of caulking, 39 meters of window and door weatherstripping, 2 sweeps of thresholds, 27 sets of gaskets and an unspecified amount of foam and packing material.

The reductions in leakage area for the entire sample was 28.3 cm^2 per person-hour of work. Weatherstripping doors and windows eliminated about 37.5 cm^2 of ELA per person-hour of effort. Sealing of by-pass routes produced the second greatest reduction of 29.5 cm^2 per person-hour and sealing of cracks and trimwork was the least effective at 21.1 cm^2 per person-hour.

An evaluation of appearance and durability of the materials used was conducted by telephone on two occasions with the majority satisfied with the work carried out and materials used. The primary factor in that comment appears to be an improvement in comfort due to a reduction in drafts. Many had lowered the thermostat settings at night and some indicated the increase in humidity levels as a benefit.

The on site survey established that before sealing was undertaken moisture problems did exist and most were encountered on windows. No significant changes occurred in the overall number of moisture problems after sealing but there is a definite change in the type of problem. In sixteen houses the window moisture problem was eliminated. In a similar number of houses condensation on the innermost panes due to increased humidity levels was encountered. Fourteen houses were identified as having major moisture problems on either window, wall or ceiling surfaces.

Fuel records for a period of one complete year prior to sealing were compared to another complete year following sealing. Thirty-nine houses decreased fuel consumption after sealing on the average of 10.8%. Another twenty houses however indicated an increase on the average of 6.9%. The net fuel reduction for the total sample is 4.8%. Although the data indicates a definite trend towards decrease in fuel consumption following sealing, the number of houses indicating fuel consumption increases cast suspicion on the analytical technique used.

A few simple guidelines should be used in sealing houses to reduce or alleviate the occurrence of moisture problems: Diagnose and remedy moisture problems prior to or in combination with sealing. Disconnect humidifiers and instruct homeowners in methods for reducing moisture inputs in cold weather or increasing the use of ventilation systems. Electrically heated houses should have some means of ventilating the house.

1. INTRODUCTION

The Weatherize Project was a two-year research and demonstration project undertaken by the Ontario Ministry of Municipal Affairs & Housing. The project was initiated in response to general uncertainty and lack of information surrounding air tightness achievements in existing housing stock. The intention was to demonstrate techniques, transfer new technology, and research critical issues concerning the impact of weatherizing on houses.

Sixty-five houses in four communities, comprising a cross-section of the Ontario housing stock, were tested and air sealed in stages by contractors utilizing fan depressurization apparatus and high quality weatherstripping and caulking materials. Work records and house characteristics were analysed to gain further understanding of air leakage and to identify appropriate weatherization techniques.

Concurrent with the weatherizing work, Ministry personnel conducted an educational campaign. Both householders and the weatherization trades were invited to participate in seminars and demonstrations organized during the course of the project.

Specific research objectives were identified as follows:

- Identify the most appropriate house sealing techniques (tools, materials and applications) for use by contractors and householders;

- Identify generic air leakage points for various construction types in Ontario;

- Determine the relative distribution of air leakage throughout different types of housing;

- Develop technical and economic priorities for air tightening various components of houses;

- Determine the range of energy savings and leakage area reductions to be expected from thoroughly caulking and weatherstripping typical Ontario homes;

- Determine if these reductions and savings are likely to vary consistently with age, style or other characteristics of the house being weatherized;

- Determine the impact of air tightening on the ambient indoor humidity levels and on moisture problems;

- Establish a relationship (if possible) between reductions in induced ventilation rates and reductions in space heating energy requirements for various sizes of dwellings; and

- Further the development of technology and standards that can facilitate a high quality, cost-effective approach to air tightness retrofit.

2. **PROJECT DESIGN**

2.1 HOUSE SELECTION

To obtain a representative cross-section of the Ontario housing stock, population and climate, the project was undertaken concurrently in four (4) communities: Peterborough, Sault Ste. Marie, Cambridge and Ottawa. In each community, local municipal and Hydro officials assisted in the selection of approximately fifteen (15) houses, representing the range of local housing types. An additional five houses were selected in the Cambridge area. In total, 65 houses were selected for participation in the study.

Houses were first categorized on the basis of four key variables:

Age	- pre 1920, 1921-45, 1946-60, 1961-70, post 1970;
Construction	- frame, masonry;
Type	- bungalow, two storeys or more, side or backsplit; and
Chimney	- one or more chimneys, no chimneys.

A secondary selection was then undertaken to ensure further variation with the test houses on the basis of:

Orientation	- N/S or E/W;
Heating Fuel	- oil, gas, electric, wood; and
Heating System	- forced air, hydronic, electric.

After pre-selecting a varied housing sample, the project organizers invited householders to a public meeting which outlined the proposed weatherization work and contractural arrangements.

To qualify for participation in the project, a house was to have been occupied by the same owner for at least the previous two years; and during this time period there was not to have been any renovations, weatherizing, insulating or changes to the heating system. Energy consumption records also were to be available for at least the previous two complete heating seasons.

2.2 WORKPLAN FOR CONTRACTORS

Contractors were selected for weatherizing and testing the houses in each community. They were selected on the basis of established expertise in the air tightening of buildings, and a familiarity with the use of depressurization equipment techniques.

Each of the four contractors was responsible for completing a series of tasks on the test houses in their locality.

The detailed task requirements are as outlined in the data collection forms presented in Appendix A1. These requirements deal basically with the following items:

FORM A: INTERVIEW WITH THE HOUSEOWNER

An interview with the houseowner was conducted to obtain information on the history of energy conservation projects, the operation of the house, and the indoor environmental conditions.

FORM B: ENERGY CONSUMPTION RECORDS

At least one full year of energy records, (preferably two years) was collected and itemized on FORM B, including dates, quantities and prices.

FORM C: EXTERIOR MEASUREMENTS

House plans and elevations were drawn on FORM C, and were used to calculate the total heated volume of the house and the above grade envelope area. Area and volume calculations were based upon interior dimensions, and include all parts of the dwelling that were heated to 10°C or higher.

FORM D: HOUSE INSPECTIONS

The dimensions of each building component, as well as quantities of insulation, were recorded on FORM D. Other details, such as observed moisture conditions and ventilation systems were also noted.

AIR SEALING

Each contractor was required to tighten a house using the customary methods and materials. However the houses were to be sealed in a staged process, with a thorough documentation of leakage sites, air flows, and time and material requirements for each stage. The stages for sealing houses are presented in FORMS E, F, G, and H, and correspond to the following areas of a house:

FORM E: OPENINGS

Direct openings to outside from living spaces, such as doors, windows, slots and hatches. (Trim work not included.)

FORM F: CRACKS

Direct leaks into wall and ceiling cavities, such as floor mouldings, door frames, plumbing holes and switchcovers.

FORM G: FOUNDATIONS

Penetrations through or around the basement or crawl space walls, such as sill plates, joints, conduits, and cracks in masonry.

FORM H: BY-PASSES

All other leakage sites including circuitous pathways through floor joists or wall partitions that connect attic and wall cavities with the basement area.

All the air leakage sites identified at each stage were checked off or noted in the forms, and air flows were assessed as insignificant, normal or extreme. The investigation and assessment of leakage sites was conducted with a smoke pencil while depressurizing the house to induce exaggerated rates of infiltration.

The additional 5 houses in the Cambridge area were subjected to a more intensive air sealing application. The contractor in this locality had specialized in the use of foamed-in-place polyurethane foam as a seal for use in basements, attics and behind trimwork throughout the house. The contractor was allocated additional time and money to permit the extensive use of foam sealants on five houses only. It was felt that a comparison of the effectiveness of such an application with the more standard caulking and weatherstripping applied to the remaining 60 houses would be worthwhile.

FORM I: AIR TIGHTNESS TESTING

Air tightness tests were conducted on each test house prior to air sealing, and at the completion of each stage of air sealing. The air tightness tests were conducted using fan depressurization apparatus (a door fan), following the procedures outlined in Draft 2 of the Canadian General Standards Board standard "Determination of Airtightness of Buildings by the Fan Depressurization Method" (CGSB 149-GP-10M). Refer to Appendix A2.

An exception to the CGSB standard test procedure was made in the case of intentional ventilation openings such as exhaust ducts, fireplace dampers, and fresh air inlets. Rather than just closing dampers on such intentional openings, the contractor was obliged to temporarily tape and seal these openings prior to testing. In this way, the staged air tightness tests would provide a better indicator of the contractor's ability to eliminate all unintentional openings in the building envelope.

Five air tightness tests were conducted in this manner - an initial test and a test at the completion of each of four stages. A final, sixth test was then conducted in exact accordance with the CGSB standard requirements. This final CGSB test provides a standard air tightness rating of the weatherized houses for use in comparative studies or air infiltration modelling. The ambient conditions, air pressures and air flows for each air tightness tests were recorded on FORM I.

FORM J: REPORT TO THE HOUSEOWNER

A report was prepared to each houseowner upon completion of the air sealing work. The report provided the houseowner with a graphic illustration of the reduction in Equivalent Leakage Area (see Form J). Attached to the report was a fact sheet from the Ministry providing guidelines for controlling Fresh Air and Humidity in a Tighter Home.

FORM K: COMBUSTION AIR SUPPLY REQUIREMENTS

Contractors were required to install a special combustion air intake device if the final air tightness test indicated that a test house was now tighter than the average new house in Ontario, and if the house contained a fossil fuel fired furnace without a fresh air supply system. An Equivalent Leakage Area of 600cm2 (at 10 pascals) was deemed average for new houses. Air inlets were to consist of insulated ducts at least 100mm in diameter and installed to spill into the cold air return plenum, or onto the basement floor one or more meters from the burner.

2.3 FOLLOW-UP EVALUATIONS

A variety of follow-up activities were conducted during the sealing process and over the next two years to evaluate the impact of the weatherizing work on the houses and their occupants. A schedule and brief description of these follow-up activities is outlined below:

November 1981 January 1982	Field Work Air sealing and testing is completed on 65 houses, and the data from FORMS A to J is consolidated.
December 1981 January 1982	Furnace On-Time Recordings Time totalizers were attached to the furnace burners on a subset of houses. Furnance on-time was recorded for a period of several days prior to and following weatherizing work.
January 1982 February 1982	Thermographic Evaluations An AGA 750 infra-red scanner was used in six of the Ottawa houses to evaluate the leak detection techniques and air sealing effectiveness of the weatherizing crew, and to identify reasons why some houses achieved reductions much lower than average.
March 1982 April 1982	Telephone Survey 1 - 37 Houses Houseowners were asked to respond to a 24 point questionnaire that focused on attitudes towards energy conservation and air sealing work, and on changes to the comfort and operation of their home.

May 1982 December 1982	Fuel Consumption Data Analysis Records of fuel consumed over the remainder of the 1981/82 heating season were collected and analysed to determine if changes occurred in consumption per degree day ratios.
November 1982	Telephone Survey 2 - 24 Houses A 27 point questionnaire was completed with all houseowners in houses with previous indications of high moisture input or ventilation problems. Information was collected on the operation of ventilation systems, sources of high humidity, incidence of condensation, and difficulties with chimney draft.
March 1983	On-Site Moisture Inspection Checklist Field inspections were conducted on all test houses for indications of moisture problems. More detailed information was collected on lifestyle, occupancy, humidity levels and ventilation systems. Any recent energy conservation projects in the houses were documented.

3. PROJECT RESULTS

3.1 HOUSE DESCRIPTIONS

Selection criteria used for choosing test houses produced a broadly representative housing sample. Age distribution and style reflected the overall housing stock in Ontario. Thirty-eight percent of the sample was built prior to 1945, another 27% were built between 1946 and 1960, and the remaining 35% after 1961. Table 3.1 presents the distribution of houses by age, number of storeys and locality. The houses were given numbers from one to 65 for research purposes. Table 3.2 provides a detailed breakdown on construction details and heating systems for each house in the sample.

Wall construction was primarily wood frame, with a small component of brick masonry. Most primary heating systems were forced air, some were hydronic systems and a group electric resistance.

Indoor thermostat settings and other details on the operation of sample houses are summarized in Table 3.3. Average day-time temperature settings ranged from 59°F to 72°F, with a mean of 68.6°F (20.3°C). A small minority of houseowners 21 (35.4%) set back thermostats for night-time operation and 7 (10.7%) houseowners turn theirs up for the night.

About half the houseowners had been drying clothes completely indoors. Fifty percent of the houseowners were also employing humidifiers for intermittent or regular humidification of indoor air. Although some houses contained one or more fireplaces, they were seldom used by most occupants. Some houseowners admitted to leaving windows open for additional "fresh" air or cooler sleeping temperatures in bedrooms.

Houseowners were questioned about previous energy conservation activities in their houses. Findings are summarized in Table 3.5. Of 65 houses, 50 houses had attics reinsulated, and 29 houses had reinsulating work completed on the walls. The next most common retrofit was changes in the heating systems in 16 houses.

The initial environmental conditions in each house are summarized in Table 3.4. The number of occupants in the houses ranged from 1 to 8, but 80% of the sample had from 2 to 4 occupants. Most houses had normal or dry winter humidity levels, with only 17 experiencing high indoor humidity according to occupant evaluation. The few cases of high humidity correspond with increased incidence of window fogging and staining or mould growth on window sills. Most houseowners complained of at least one hard-to-heat room, usually the bedrooms. Almost everyone had noticed discomfort from cold drafts. Indoor air quality was not felt to be a problem by any of the houseowners.

TABLE 3.1 DISTRIBUTION OF HOUSES BY AGE, STOREYS AND LOCALITY

HOUSING DISTRIBUTION AGE/STOREYS	NUMBER OF HOUSES	% OF SAMPLE	% OF ONTARIO HOUSING STOCK	NUMBER OF HOUSES PER COMMUNITY			
				SAULT STE. MARIE 1 to 15	PETERBOROUGH 16 to 30	CAMBRIDGE 31 to 50	OTTAWA 50 to 65
AGE							
Pre - 1920	(14)	38	33	1	3	3	7
1921 - 1945	(11)			4	2	4	1
1946 - 1960	(17)	27	31	5	5	4	3
1961 - 1970	(12)			2	4	4	2
Post 1970	(11)	35	36	3	1	5	2
TOTAL	(65)			15	15	20	15
STOREYS							
1 Storey	(21)	32		7	6	5	3
1-1/2 Storeys	(18)	28		3	3	6	6
2 Storeys	(21)	32		4	4	9	4
2-1/2 Storeys	(5)	8		1	2	0	2
TOTAL	(65)			15	15	20	15

TABLE: 3.2 HOUSE CHARACTERISTICS

HOUSE NUMBER	YEAR OF CONSTRUCTION	NO. OF STORIES	WALL CONSTRUCTION	PRIMARY HEATING FUEL	SECONDARY HEATING FUEL	PRIMARY HEATING SYSTEM	SECONDARY HEATING SYSTEM	DOMESTIC HOT WATER	AIR CONDITIONING
SAULT STE. MARIE									
1	PRE 1920	2	WOOD FRAME	GAS	-	FORCED AIR	-	ELECTRIC	-
2	1921-1945	1	WOOD FRAME	GAS	-	FORCED AIR	-	ELECTRIC	-
3	1921-1945	1 1/2	WOOD FRAME	GAS	-	FORCED AIR	-	ELECTRIC	-
4	1921-1945	2	BRICK VENEER	GAS	-	FORCED AIR	-	GAS	-
5	1921-1945	2 1/2	BRICK VENEER	OIL	-	FORCED AIR	-	GAS	-
6	1946-1960	1	BRICK VENEER	OIL	-	FORCED AIR	-	ELECTRIC	-
7	1946-1960	1	WOOD FRAME	GAS	-	FORCED AIR	-	GAS	-
8	1946-1960	1 1/2	WOOD FRAME	OIL	-	FORCED AIR	-	OIL	-
9	1946-1960	2	BRICK VENEER	GAS	-	WATER	-	ELECTRIC	-
10	1961-1970	1	BRICK VENEER	OIL	-	FORCED AIR	-	ELECTRIC	-
11	1961-1970	2	BRICK VENEER	OIL	-	FORCED AIR	-	ELECTRIC	-
12	POST 1970	1	BRICK VENEER	ELECTRIC	-	RADIANT	-	ELECTRIC	-
13	POST 1970	1	BRICK VENEER	ELECTRIC	-	RADIANT	-	ELECTRIC	-
14	POST 1970	1	WOOD FRAME	GAS	-	FORCED AIR	-	GAS	-
15	1946-1960	1 1/2	WOOD FRAME	OIL	-	FORCED AIR	-	ELECTRIC	-
PETERBOROUGH									
16	1946-1960	1 1/2	WOOD FRAME	GAS	-	FORCED AIR	-	ELECTRIC	-
17	1946-1960	1	WOOD FRAME	GAS	-	FORCED AIR	-	GAS	ROOM
18	PRE 1920	2 1/2	WOOD FRAME	OIL	ELECTRIC	FORCED AIR	ELECTRIC HEAT PUMP	GAS & ELECTRIC	CENTRAL
19	PRE 1920	2	MASONRY	OIL	-	FORCED AIR	-	ELECTRIC	-
20	1946-1960	2	WOOD	GAS	-	FORCED AIR	-	GAS	ROOM
21	1961-1970	1	WOOD	GAS	-	FORCED AIR	-	GAS	ROOM
22	POST 1970	1	BRICK VENEER	GAS	ELECTRIC	FORCED AIR	RADIANT	GAS	-
23	1946-1960	1	WOOD	ELECTRIC	ELECTRIC	FORCED AIR	-	ELECTRIC	-
24	1946-1960	1	WOOD	OIL	-	FORCED AIR	-	ELECTRIC	-
25	1946-1960	1 1/2	WOOD	OIL	-	FORCED AIR	-	ELECTRIC	-
26	1961-1970	1 1/2	WOOD	OIL,GAS	-	FORCED AIR	-	ELECTRIC	ROOM

TABLE: 3.2 HOUSE CHARACTERISTICS (Continued)

HOUSE NUMBER	YEAR OF CONSTRUCTION	NO. OF STORIES	WALL CONSTRUCTION	PRIMARY HEATING FUEL	SECONDARY HEATING FUEL	PRIMARY HEATING SYSTEM	SECONDARY HEATING SYSTEM	DOMESTIC HOT WATER	AIR CONDITIONING
PETERBOROUGH									
27	PRE 1920	2 1/2	WOOD FRAME	OIL	-	FORCED AIR	-	ELECTRIC	-
28	1921-1945	1	WOOD FRAME	ELECTRIC	-	RADIANT	-	ELECTRIC	ROOM
29	1961-1970	1 1/2	WOOD FRAME	GAS	-	FORCED AIR	-	GAS	-
30	1920-1945	2	MASONRY	OIL	-	FORCED AIR	-	ELECTRIC	-
CAMBRIDGE									
31	1946-1960	1	WOOD FRAME	OIL	-	FORCED AIR	-	ELECTRIC	-
32	POST 1970	2	WOOD FRAME	GAS	-	FORCED AIR	-	GAS	-
33	1946-1960	1	WOOD FRAME	ELECTRIC	-	RADIANT	-	ELECTRIC	ROOM
34	PRE 1920	2	WOOD FRAME	GAS	GAS	FORCED AIR	GRAVITY	GAS	-
35	1946-1960	1	WOOD FRAME	OIL	-	GRAVITY	-	ELECTRIC	-
36	PRE 1920	2	WOOD FRAME	GAS	-	FORCED AIR	-	GAS	-
37	POST 1970	2	WOOD FRAME	ELECTRIC	-	RADIANT	-	ELECTRIC	-
38	POST 1970	2	WOOD FRAME	ELECTRIC	-	RADIANT	-	ELECTRIC	-
39	1921-1945	1	WOOD FRAME	OIL	-	FORCED AIR	-	ELECTRIC	-
40	PRE 1920	1 1/2	WOOD FRAME	GAS	-	FORCED AIR	-	ELECTRIC	-
41	1961-1970	1 1/2	WOOD FRAME	ELECTRIC	-	ELECTRIC	-	ELECTRIC	-
42	POST 1970	2	WOOD FRAME	GAS	-	FORCED AIR	-	GAS	-
43	1946-1960	1 1/2	WOOD FRAME	GAS	-	FORCED AIR	-	GAS	CENTRAL
44	1921-1945	2	WOOD FRAME	GAS	-	FORCED AIR	-	ELECTRIC	-
45	1961-1970	1 1/2	WOOD FRAME	GAS	ELECTRIC	FORCED AIR	RADIANT	GAS	-
46	1961-1970	1	WOOD FRAME	ELECTRIC	-	RADIANT	-	ELECTRIC	-
47	1961-1970	1 1/2	WOOD FRAME	GAS	-	FORCED AIR	-	ELECTRIC	-
48	1921-1945	2	WOOD FRAME	OIL	-	FORCED AIR	-	ELECTRIC	-
49	POST 1970	2	WOOD FRAME	GAS	-	FORCED AIR	-	GAS	-
50	1921-1945	1 1/2	WOOD FRAME	GAS	-	GRAVITY	-	GAS	-

TABLE: 3.2 HOUSE CHARACTERISTICS (Continued)

HOUSE NUMBER	YEAR OF CONSTRUCTION	NO. OF STORIES	WALL CONSTRUCTION	PRIMARY HEATING FUEL	SECONDARY HEATING FUEL	PRIMARY HEATING SYSTEM	SECONDARY HEATING SYSTEM	DOMESTIC HOT WATER	AIR CONDITIONING
OTTAWA									
51	PRE 1920	2	WOOD FRAME	GAS	-	FORCED AIR	-	GAS	-
52	PRE 1920	1 1/2	WOOD FRAME	OIL	WOOD	FORCED AIR	RADIANT	ELECTRIC	-
53	PRE 1920	2 1/2	WOOD FRAME	GAS	-	FORCED AIR	-	ELECTRIC	-
54	PRE 1920	2 1/2	WOOD FRAME	OIL	-	FORCED AIR	-	ELECTRIC	-
55	PRE 1920	2	WOOD FRAME	OIL	-	FORCED AIR	-	ELECTRIC	-
56	PRE 1920	1 1/2	WOOD FRAME	OIL	-	FORCED AIR	-	ELECTRIC	-
57	PRE 1920	2	WOOD FRAME	OIL	-	FORCED AIR	-	ELECTRIC	-
58	1921-1945	2	WOOD FRAME	OIL	-	FORCED AIR	-	ELECTRIC	-
59	1946-1960	1 1/2	WOOD FRAME	OIL	-	FORCED AIR	-	ELECTRIC	-
60	1946-1960	2	WOOD FRAME	OIL	-	FORCED AIR	-	ELECTRIC	-
61	1946-1960	1	WOOD FRAME	OIL	-	FORCED AIR	-	ELECTRIC	-
62	1961-1970	1	WOOD FRAME	OIL	-	FORCED AIR	-	ELECTRIC	-
63	1961-1970	1 1/2	WOOD FRAME	OIL	-	FORCED AIR	-	ELECTRIC	ROOM
64	POST 1970	1 1/2	WOOD FRAME	ELECTRIC	-	RADIANT	-	ELECTRIC	-
65	POST 1970	1	WOOD FRAME	ELECTRIC	-	RADIANT	-	ELECTRIC	ROOM

TABLE 3.3 HOUSE OPERATION

HOUSE NUMBER	YEARS OF OCCUPANCY	TEMPERATURE SETTINGS		CLOTHES DRYING IN WINTER	WINTER HUMIDIFICATION	NUMBER OF FIREPLACES		WINDOWS LEFT OPEN IN WINTER	HOT WATER APPLIANCES
		DAY	NIGHT			NUMBER	USE		
SAULT STE. MARIE									
1	>5	70	70	INSIDE	-	-	-	-	CLOTHES WASHER
2	>5	72	72	OUTSIDE	-	-	-	-	CLOTHES WASHER
3	>5	-	-	INSIDE	-	-	-	-	CLOTHES WASHER
4	>5	68	68	INSIDE	-	-	-	-	CLOTHES WASHER
5	>5	68	68	INSIDE	SOME	-	-	-	CLOTHES WASHER
6	>5	70	68	OUTSIDE	SOME	-	-	-	CLOTHES WASHER
7	>5	70	62	INSIDE	SOME	-	-	1 BEDROOM	CLOTHES WASHER
8	>5	68	66	INSIDE	-	-	-	-	CLOTHES WASHER
9	>5	70	68	INSIDE	-	-	-	1 BEDROOMS	CLOTHES WASHER
10	>5	70	70	OUTSIDE	SOME	2	ONCE A WEEK	BEDROOMS	DISH WASHER
11	>5	68	65	OUTSIDE	-	-	-	1BEDROOM	DISH WASHER SAUNA
12	3 MONTHS	68	68	OUTSIDE	SOME	1	ONCE A WEEK	WHOLE HOUSE	CLOTHES WASHER DISH WASHER
13	>5	70	60	OUTSIDE	-	1	ONCE A WEEK	-	CLOTHES WASHER
14	>5	70	70	OUTSIDE	SOME	-	-	-	CLOTHES WASHER
15	2	-	-	INSIDE	REGULAR	1	SELDOM	-	CLOTHES WASHER DISH WASHER
PETERBOROUGH									
16	>5	68	68	OUTSIDE	SOME	-	-	1 BEDROOM	CLOTHES WASHER
17	>5	72	72	OUTSIDE	REGULAR	-	-	-	CLOTHES WASHER
18	3 TO 5	69	69	OUTSIDE	SOME	1	SELDOM	-	CLOTHES WASHER DISH WASHER
19	>5	70	70	INSIDE	REGULAR	-	-	BATHROOM	CLOTHES WASHER DISH WASHER
20	>5	70	66	OUTSIDE	REGULAR	1	SELDOM	-	CLOTHES WASHER

TABLE 3.3 HOUSE OPERATION (Continued)

HOUSE NUMBER	YEARS OF OCCUPANCY	TEMPERATURE SETTINGS		CLOTHES DRYING IN WINTER	WINTER HUMIDIFICATION	NUMBER OF FIREPLACES		WINDOWS LEFT OPEN IN WINTER	HOT WATER APPLIANCES
		DAY	NIGHT			NUMBER	USE		
PETERBOROUGH									
21	>5	62	68	OUTSIDE	REGULAR	-	-	-	CLOTHES WASHER DISH WASHER
22	>5	68	68	OUTSIDE	SOME	-	-	-	CLOTHES WASHER DISH WASHER
23	>5	70	70	OUTSIDE	-	1	SELDOM	-	CLOTHES WASHER DISH WASHER
24	>5	68	68	INSIDE	SOME	-	-	-	CLOTHES WASHER
25	>5	69	69	INSIDE	SOME	1	SELDOM	-	CLOTHES WASHER DISH WASHER
26	2	69	69	OUTSIDE	-	1	SELDOM	-	CLOTHES WASHER
27	>5	64	64	OUTSIDE	REGULAR	-	-	-	CLOTHES WASHER
28	>5	70	70	INSIDE	-	-	-	-	CLOTHES WASHER
29	>5	72	72	OUTSIDE	REGULAR	-	-	-	CLOTHES WASHER DISH WASHER
30	>5	68	64	OUTSIDE	REGULAR	1	SELDOM	-	CLOTHES WASHER
CAMBRIDGE									
31	>5	70	70	OUTSIDE	REGULAR	1	SELDOM	-	CLOTHES WASHER
32	3 TO 5	65	60	INSIDE	REGULAR	-	-	-	CLOTHES WASHER
33	>5	69	69	INSIDE	REGULAR	1	SELDOM	-	CLOTHES WASHER
34	1	65	70	OUTSIDE	-	-	-	-	CLOTHES WASHER
35	>5	69	65	OUTSIDE	REGULAR	1	SELDOM	-	CLOTHES WASHER
36	>5	70	68	INSIDE	REGULAR	-	-	UPSTAIRS	CLOTHES WASHER DISH WASHER
37	3 TO 5	70	65	INSIDE	SOME	-	-	-	CLOTHES WASHER
38	>5	70	70	OUTSIDE	SOME	-	-	-	CLOTHES WASHER
39	>5	70	70	INSIDE	REGULAR	-	-	-	CLOTHES WASHER
40	>5	68	60	OUTSIDE	-	1	SELDOM	BEDROOMS	CLOTHES WASHER
41	>5	68	65	INSIDE	SOME	-	-	-	CLOTHES WASHER

TABLE 3.3 HOUSE OPERATION (Continued)

HOUSE NUMBER	YEARS OF OCCUPANCY	TEMPERATURE SETTINGS		CLOTHES DRYING IN WINTER	WINTER HUMIDIFICATION	NUMBER OF FIREPLACES		WINDOWS LEFT OPEN IN WINTER	HOT WATER APPLIANCES
		DAY	NIGHT			NUMBER	USE		
CAMBRIDGE									
42	>5	70	70	OUTSIDE	REGULAR	-	-	-	CLOTHES WASHER
43	>5	70	68	INSIDE	SOME	-	-	-	CLOTHES WASHER
44	>5	65	65	OUTSIDE	-	-	-	-	CLOTHES WASHER
45	>5	69	69	OUTSIDE	REGULAR	-	-	-	CLOTHES WASHER DISH WASHER
46	3 TO 5	70	70	OUTSIDE	-	-	-	-	CLOTHES WASHER DISH WASHER
47	>5	70	60	OUTSIDE	SOME	1	SELDOM	BEDROOMS	CLOTHES WASHER
48	>5	64	60	OUTSIDE	SOME	2	ONCE A WEEK	BEDROOMS	CLOTHES WASHER
49	2	72	72	OUTSIDE	-	-	-	-	CLOTHES WASHER DISH WASHER
50	>5	72	72	OUTSIDE	SOME	-	-	UPSTAIRS	CLOTHES WASHER DISH WASHER
OTTAWA									
51	>5	70	70	OUTSIDE	REGULAR	1	SELDOM	-	CLOTHES WASHER
52	>5	70	70	OUTSIDE	-	-	-	-	CLOTHES WASHER
53	>5	-	-	OUTSIDE	SOME	1	-	-	CLOTHES WASHR
54	3 TO 5	66	60	OUTSIDE	REGULAR	-	-	BATHROOM	CLOTHES WASHER DISH WASHER
55	>5	71	68	INSIDE	SOME	1	SELDOM	-	CLOTHES WASHER DISH WASHER
56	2	72	68	OUTSIDE	-	-	-	-	CLOTHES WASHER
57	2	65	70	INSIDE	-	-	-	-	-
58	3 TO 5	72	68	INSIDE	SOME	1	SELDOM	-	CLOTHES WASHER DISH WASHER
59	-	59	63	INSIDE	SOME	-	-	-	-
60	>5	62	70	OUTSIDE	-	-	-	-	CLOTHES WASHER
61	>5	65	70	OUTSIDE	-	-	-	-	CLOTHES WASHER DISH WASHER.

TABLE 3.3 **HOUSE OPERATION** (Continued)

HOUSE NUMBER	YEARS OF OCCUPANCY	TEMPERATURE SETTINGS		CLOTHES DRYING IN WINTER	WINTER HUMIDIFICATION	NUMBER OF FIREPLACES		WINDOWS LEFT OPEN IN WINTER	HOT WATER APPLIANCES
		DAY	NIGHT			NUMBER	USE		
OTTAWA									
62	3 TO 5	68	64	INSIDE	SOME	1	SELDOM	-	CLOTHES WASHER DISH WASHER
63	>5	68	65	OUTSIDE	SOME	-	-	-	CLOTHES WASHER DISH WASHER
64	-	68	70	OUTSIDE	-	2	SELDOM	-	CLOTHES WASHER
65	>5	68-70	68-70	OUTSIDE	-	-	-	BEDROOMS	CLOTHES WASHER DISH WASHER

TABLE 3.4 INITIAL ENVIRONMENTAL CONDITIONS

HOUSE NUMBER	NUMBER OF OCCUPANTS	WINTER HUMIDITY LEVEL	INCIDENCE OF WINDOW FOGGING	STAINS OR MOULD ON SILLS	NUMBER OF SMOKERS	HARD TO HEAT ROOMS	COLD DRAFTS	AIR QUALITY	BASEMENT MOISTURE CONDITION
SAULT STE. MARIE									
1	2	DRY	-	-	-	-	-	-	DAMP
2	1	NORMAL	LIGHT	-	1	BEDROOOMS	-	-	WET
3	2	DRY	-	-	1	YES	MANY	-	-
4	2	DRY	-	-	-	BEDROOMS	FEW	-	DRY
5	1	DRY	-	-	-	-	-	-	DRY
6	2	NORMAL	LIGHT	-	1	-	-	-	DAMP
7	2	DRY	-	-	1	-	-	-	-
8	1	NORMAL	-	-	-	-	-	-	DAMP
9	3	NORMAL	LIGHT	-	-	BEDROOMS	FEW	-	WET
10	4	NORMAL	-	-	2	BEDROOMS	-	-	DRY
11	2	HUMID	HEAVY	YES	-	BEDROOMS	FEW	-	DRY
12	4	NORMAL	LIGHT	-	-	YES	FEW	OCCASIONAL	DRY
13	4	HUMID	HEAVY	YES	-	YES	FEW	-	DAMP
14	3	DRY	-	-	-	BEDROOMS	-	-	WET
15	2	NORMAL	LIGHT	-	-	YES	FEW	-	DRY
PETERBOROUGH									
16	2	NORMAL	LIGHT	-	-	BATHROOM	FEW	-	DRY
17	4	NORMAL	HEAVY	YES	-	-	WINDOWS	-	DRY
18	4	NORMAL	LIGHT	BATHROOM	1	SUNPORCH	FEW	-	DRY
19	2	NORMAL	LIGHT	-	1	BEDROOMS	MANY	-	DRY
20	3	NORMAL	LIGHT	YES	1	BEDROOMS	-	-	DAMP
21	2	NORMAL	LIGHT	-	1	LIVING RM.	WINDOWS	-	DRY
22	5-8	DRY	LIGHT	-	1	BEDROOMS & LIVING RM.	FEW	-	DRY
23	4	NORMAL	HEAVY	-	1	CLOSETS	FEW	-	DAMP
24	1	NORMAL	LIGHT	YES	-	LIVING RM.	MANY	-	DAMP
25	2	DRY	-	-	1	-	FEW	-	DRY
26	4	NORMAL	LIGHT	SOME	-	BASEMENT & KITCHEN	MANY	-	DAMP

TABLE 3.4 INITIAL ENVIRONMENTAL CONDITIONS (Continued)

HOUSE NUMBER	NUMBER OF OCCUPANTS	WINTER HUMIDITY LEVEL	INCIDENCE OF WINDOW FOGGING	STAINS OR MOULD ON SILLS	NUMBER OF SMOKERS	HARD TO HEAT ROOMS	COLD DRAFTS	AIR QUALITY	BASEMENT MOISTURE CONDITION
PETERBOROUGH									
27	2	HUMID	HEAVY	-	-	-	FEW	-	DAMP
28	2	DRY TO NORMAL	VERY LIGHT	-	-	-	FEW	-	-
29	2	HUMID	HEAVY	YES	2	-	MANY	-	DRY
30	2	NORMAL	LIGHT	-	1	BEDROOM	-	-	DRY
CAMBRIDGE									
31	2	-	LIGHT	-	-	BEDROOM & BATHROOM	FEW	-	DRY
32	4	DRY TO NORMAL	LIGHT	YES	-	BEDROOM	MANY	-	DRY
33	2	NORMAL	HEAVY	YES	1	-	FEW	OCCASIONAL	-
34	4	DRY	-	-	-	LIVING RM	FEW	-	DRY
35	1	NORMAL	LIGHT	-	1	YES	-	-	DRY
36	2	NORMAL	HEAVY	-	-	YES	FEW	-	DRY
37	3	HUMID	HEAVY	YES	-	-	FEW	-	WET
38	3	DRY TO NORMAL	LIGHT	YES	1	BASEMENT	FEW	-	DRY
39	2	NORMAL	LIGHT	-	1	YES	FEW	OCCASIONAL	DAMP
40	2	NORMAL	LIGHT	YES	-	-	FEW	-	DAMP
41	5-8	NORMAL	LIGHT	YES	1	-	FEW	-	DRY
42	5-8	DRY	-	-	2	BEDROOM	MANY	-	DRY
43	2	NORMAL	LIGHT	-	-	-	FEW	OCCASIONAL	DRY
44	1	HUMID	HEAVY	-	1	-	FEW	-	DRY
45	2	DRY	LIGHT	-	1	YES	FEW	-	DRY
46	4	NORMAL	-	-	1	-	-	-	DRY
47	2	DRY	LIGHT	-	1	OVER GARAGE	FEW	-	DRY
48	3	DRY	-	-	-	LIVING RM.	MANY	-	DRY

TABLE 3.4 INITIAL ENVIRONMENTAL CONDITIONS (Continued)

HOUSE NUMBER	NUMBER OF OCCUPANTS	WINTER HUMIDITY LEVEL	INCIDENCE OF WINDOW FOGGING	STAINS OR MOULD ON SILLS	NUMBER OF SMOKERS	HARD TO HEAT ROOMS	COLD DRAFTS	AIR QUALITY	BASEMENT MOISTURE CONDITION
CAMBRIDGE									
49	4	DRY	-	-	2	-	FEW	OCCASIONAL	DRY
50	2	NORMAL	LIGHT	-	-	BATHROOM	FEW	-	DRY
OTTAWA									
51	5-8	NORMAL	LIGHT	-	2	YES	FEW	-	DRY
52	4	NORMAL	-	-	-	-	FEW	OCCASIONAL	DRY
53	4	DRY	-	-	2	YES	FEW	-	DRY
54	4	NORMAL	-	-	1	YES	FEW	-	DRY
55	2	NORMAL	-	-	-	-	FEW	OCCASIONAL	DRY
56	3	DRY	-	-	1	YES	MANY	OCCASIONAL	DAMP TO WET
57	2	DRY	-	-	1	YES	FEW	-	DRY
58	2	NORMAL	-	-	2	YES	FEW	-	DRY
59	1	NORMAL	-	-	1	YES	FEW	OCCASIONAL	DRY
60	2	NORMAL	-	YES BETWEEN WINDOWS	-	-	-	OCCASIONAL	DAMP
61	2	NORMAL	-	-	2	-	FEW	-	DRY
62	4	NORMAL	LIGHT	YES	2	YES	-	-	DRY
63	3	NORMAL	-	YES	-	YES	-	-	DRY
64	2	NORMAL	-	-	2	-	-	OCCASIONAL	DRY
65	4	HUMID	LIGHT	-	-	BATHROOM	FEW	-	DRY

TABLE: 3.5 RETROFIT HISTORY

HOUSE NUMBER	LOCATION OF PREVIOUS INSULATION MEASURES	NUMBER OF STORM WINDOWS	HEATING SYSTEM CHANGES
SAULT STE. MARIE			
1	-	-	NEW SYSTEM OIL TO GAS 1970
2	WALLS, ATTIC	7	NEW BURNER OIL TO GAS 1972
3	ATTIC	-	-
4	ATTIC	-	NEW BURNER OIL TO GAS 1971
5	-	-	-
6	WALLS, ATTIC	-	-
7	WALLS, ATTIC	-	NEW SYSTEM 1979
8	WALLS, ATTIC CEILING	-	-
9	WALLS, ATTIC CEILING	-	-
10	WALLS, ATTIC	-	-
11	BASEMENT, WALLS	-	-
12	WALLS, ATTIC	-	-
13	WALLS, ATTIC	-	-
14	WALLS, ATTIC	5	-
15	WALLS, ATTIC	12	NEW SYSTEM OIL TO OIL 1968
PETERBOROUGH			
16	WALLS, ATTIC	5	NEW SYSTEM 1979
17	WALLS, ATTIC	-	NEW SYSTEM 1960
18	WALLS, ATTIC	-	HEAT PUMP ADDED IN 1980
19	WALLS, ATTIC	-	-
20	WALLS, ATTIC	-	NEW SYSTEM NEW FURNACE 1979
21	WALLS, ATTIC	-	-
22	ATTIC	-	ELECTRIC HEATER IN THE BASEMENT
23	ATTIC	-	NEW SYSTEM 1978 (HEAT PUMP & FURNACE)
24	ATTIC	-	-
25	ATTIC	-	-
26	WALLS, ATTIC	3	NEW SYSTEM FEB. 1981
27	ATTIC	6	-
28	WALLS, ATTIC	-	NEW SYSTEM ELECTRIC 1980
29	WALLS, ATTIC	-	-
30	WALLS, ATTIC	-	-
CAMBRIDGE			
31	ATTIC, BASEMENT	-	-
32	-	-	-
33	WALLS, ATTIC	2	NEW SYSTEM ELECTRIC 1961
34	ATTIC	-	-
35	ATTIC	-	-
36	WALLS, ATTIC	4	SETBACK THERMOSTAT 1970
37	-	-	-
38	-	-	-

TABLE: 3.5 RETROFIT HISTORY (Continued)

HOUSE NUMBER	LOCATION OF PREVIOUS INSULATION MEASURES	NUMBER OF STORM WINDOWS	HEATING SYSTEM CHANGES
CAMBRIDGE			
39	ATTIC	11	NEW BURNER
40	ATTIC	-	NEW SYSTEM COAL TO GAS 1961
41	-	-	-
42	-	4	-
43	ATTIC	2	-
44	WALLS, ATTIC	7	-
45	-	-	-
46	-	-	-
47	-	-	-
48	ATTIC	5	-
49	-	-	-
50	ATTIC	-	COAL TO GAS 1951
OTTAWA			
51	-	-	-
52	-	-	-
53	ATTIC	-	-
54	ATTIC	-	-
55	ATTIC	-	-
56	ATTIC	-	-
57	ATTIC	-	-
58	ATTIC	-	-
59	WALLS, ATTIC	-	-
60	WALLS, ATTIC	-	-
61	WALLS, ATTIC	-	-
62	WALLS, ATTIC	-	-
63	WALLS, ATTIC	-	-
64	ATTIC	-	-
65	-	-	-

3.2 ASSESSMENT OF AIR LEAKAGE AREAS

Areas of air leakage were identified and evaluated prior to air sealing. Using smoke pencils, the contractors subjectively rated each observed area of air leakage as "extreme", "normal", or "insignificant". This approach resulted in 132 categories of leakage sites and ratings for the total sample, with the observed occurrences in each category ranging from 1 to 48. A complete summary of observed air flow occurrences in the housing sample is contained in Appendix B1.

The ten most frequently observed sites in each rating are listed in Table 3.6. The "insignificant" sites comprise areas where air infiltration occurred, but at such low velocity that air sealing was deemed unjustified. In almost every case however, components frequently rated "insignificant" in some houses were often found to be "normal" or "extreme" in other houses. It is not possible to conclude that any sites could be safely ignored when air sealing these houses. All that is clear is that many potential air leakage points are highly variable from house to house, and would require investigation in each case prior to air sealing. Table 3.6 will provide some insight into the severity of the leakage points.

No significant difference is apparent in the ranking of air leakage sites as either "normal" or "extreme". Both rankings produce approximately the same list, consisting of building components that are present in most houses, and that almost always suffer from high infiltration. Differentiating between "normal" and "extreme" leakage is difficult without some kind of quantitative measurement. A leak can be rated relative to other leaks in the same house, or relative to similar building components in other houses, or relative to some subjective standard used by the contractor. Because of these interpretations, it is difficult to evaluate the leakage assessment ratings by contractors, except in cases where a large difference exists between the number of times a particular component is rated "normal" or rated "extreme".

Table 3.7 lists the number of air flow occurrences, both extreme and normal, for every potential leakage site. The total combined occurrences for each site is also listed, and expressed as a percentage of the 65 unit sample.

Many leakage sites have a disproportionate number of occurrences in one of the two categories. The frames around windows and doors, for example, are rarely found to have "extreme" leakage, but often ranked as "normal". The windows and door units themselves, however, are most often found to be extreme leakage sites, especially in the basement area. Other leaks that are most often described as "extreme", include delivery doors, baseboard heaters, plumbing access hatches, mail slots, ash clean-outs, and partition walls that open into the basement. The variety of leakage sites, and the emphasis placed by contractors on some of these more obscure items, suggests that air sealing applications are best conducted after a fairly comprehensive inspection of a house. There are few areas that can be safely overlooked.

A majority of the building components listed in Table 3.7 existed in all of the sample houses. For these items the percentage figures for observed occurrence in the sample houses are realistic indication of the extent to which those areas can be expected to leak badly in typical houses. Attic hatches and the wall outlets/switches, for example, are common components that also can be guaranteed to leak in virtually all existing conventional housing.

It is interesting to note that partition wall outlets/switches are slightly more of a problem than exterior walls. This phenomenon may be explained by the largely unobstructed passageways connecting partition walls with interfloor cavities and attic spaces. In many cases air can simply follow the wiring holes directly into the attic. Exterior walls on the other hand are tighter due to additional sheathing, and the presence of insulation, firestops, and double plates. Floor mouldings were exhibiting significant leakage in 68% of the housing sample. Presumably they would also be as leaky around partition walls as exterior walls for the same reasons as outlets, although no such divisions were required by the checklists.

Remaining areas showing significant air leakage in a high percentage of the sample included plumbing holes, sill plates, ceiling fixtures and cracks in walls. The combination of different building materials and direct openings to the exterior help to explain leakage observed in these high priority areas.

It is surprising not to find more observed air leakage in the attic spaces of the sample houses. Only the chimney cavity, and open plates on partition walls stand out as significant. However, the identification of air leaks in attic spaces is a difficult task due to poor lighting, and knee-deep insulation. Inaccessible knee wall spaces and cramped working spaces further restricted access to attic air leakage sites. Houses must be pressurized to exaggerate air leakage into attic spaces, and this also posed problems for contractors working in January weather.

Some building components listed in Table 3.7 were only present in a minority of the sample. These items are marked with an asterisk. They often contribute considerable air leakage, but are less important when considered as part of the entire housing sample. Dryer vents, fireplace dampers and stair risers are examples of areas of high leakage that are restricted to particular houses.

TABLE 3.6 TOP TEN LEAKAGE SITES PER RATING

RANK	"INSIGNIFICANT" LEAKAGE SITES	"NORMAL" LEAKAGE SITES
1)	AROUND BATHTUB, SHOWER	EXTERIOR DOORS
2)	MEDICINE CABINETS	INTERIOR WALL OUTLETS/SWITCHES
3)	HEATING DUCTS AND PIPES	EXTERIOR WALL OUTLETS/SWITCHES
4)	BASEMENT WIRING INTO CEILING	LIGHT FIXTURES (CEILING)
5)	CABLE PENETRATIONS	EXTERIOR WINDOWS
6)	WIRING HOLES TO UPSTAIRS	PLUMBING HOLES IN WALL/FLOOR
7)	ALL FLOOR MOULDINGS	ALL FLOOR MOULDINGS
8)	STAIR RISERS	ATTIC ACCESS, HATCH/DOORS
9)	LIGHT FIXTURES (WALL)	CRACKS IN WALL FINISH
10)	PLUMBING UITLITY PENETRATIONS	STAIR RISERS

	"EXTREME" LEAKAGE SITES	SUMMARY OF LEAKAGE SITES FOR ALL 65 HOUSES
1)	EXTERIOR WINDOWS	INTERIOR WALL OUTLETS/SWITCHES
2)	ATTIC ACCESS, HATCH/DOORS	EXTERIOR WINDOWS
3)	EXTERIOR DOORS	EXTERIOR DOORS
4)	WALL/SILL PLATE (JOIST AREA)	EXTERIOR WALL OUTLETS/SWITCHES
5)	INTERIOR WALL OUTLET/SWITCHES	ATTIC ACCESS, HATCH/DOORS
6)	PLUMBING HOLES IN WALL/FLOOR	LIGHT FIXTURES (CEILING)
7)	EXTERIOR WALL OUTLET/SWITCHES	PLUMBING HOLES IN WALL/FLOOR
8)	DRYER VENT	ALL FLOOR MOULDINGS
9)	ALL FLOOR MOULDINGS	WALL/SILL PLATE (JOIST AREA)
10)	LIGHT FIXTURES (CEILING)	CRACKS IN WALL FINISH

TABLE 3.7

OVERALL SUMMARY OF EXTREME-NORMAL AIR FLOW PRIOR TO TIGHTENING IN SIXTY-FIVE (65) DWELLING UNITS

CATEGORY: OVERALL AGE (65 UNITS)	NUMBER OF AIR FLOW OCCURRENCES			
LEAKAGE AREA LOCATIONS	EXTREME	NORMAL	TOTAL	% OF 65 UNIT SAMPLE
WINDOWS - Living area	31	27	58	89
- Basement	26	20	46	71
- Frames	15	41	56	86
DOORS - Living area	22	36	58	89
- Basement	20	5	25	38
- Frames	7	48	55	85
HATCHES - Attic access	26	30	56	86
- Delivery door	7	1	8	12 *
OTHER OPENINGS - Dryer vent	12	17	29	45
- Fireplace damper	3	9	12	18 *
- Mail slot	2	1	3	5 *
- Ash clean out	2	0	2	3 *
- Exhaust into attic	3	11	14	22 *
ELECTRICAL				
- Wall outlets/switches (Interior)	15	45	60	92
- Wall outlets/switches (Exterior)	13	45	58	89
- Ceiling light fixtures	10	43	53	82
- Exterior wiring holes	7	20	27	42
- Cable T.V. penetrations	3	19	22	34
- Light fixture wall	3	20	23	35
- Baseboard heaters	3	0	3	5 *
- Wiring into ceiling (Basement)	2	14	16	25
PLUMBING				
- Holes in wall/floor	15	36	51	78
- Basement utility penetrations	14	30	44	68
- Piping into basement ceiling	10	21	31	48
- Access hatches	4	2	6	9 *
- Piping penetrations (Attic)	3	25	28	43
HEATING				
- Heating ducts and pipes	3	17	20	31

* Indicates a limited number of existing leakage area locations in the sample

TABLE 3.7 (Continued)

CATEGORY: OVERALL AGE (65 UNITS)	NUMBER OF AIR FLOW OCCURRENCES			
LEAKAGE AREA LOCATIONS	EXTREME	NORMAL	TOTAL	% OF 65 UNIT SAMPLE
CONSTRUCTION				
- Wall/sill plate	16	25	41	63
- Header joist (Basement)	8	23	31	48
- Floor mouldings	9	35	44	68
- Ceiling mouldings	8	13	21	32
- Beam filled space	5	20	25	38
(Basement)				
- Open wall cavities (partitions)	3	1	4	6 *
- Open wall cavities (exterior)	0	2	2	3 *
(Attic)				
- Open wall activities	1	5	6	9 *
- Open wall cavities (exterior)	1	3	4	6 *
- Floor Cavities	1	0	1	2 *
- Chimney Cavity	4	7	11	17
FINISHES				
- Cracks in walls	10	27	37	57
- Cracks in ceiling	10	16	26	40
- Holes/cracks in basement walls	8	22	30	46
- At bathtub and shower enclosures	6	20	26	40
MISCELLANEOUS				
- Medicine cabinets	3	14	17	26 *
- Stair risers	2	27	29	45
- Floor changes	1	20	21	32
- Additional attachments to house (garage)	4	9	13	20
- Double hung window (pulleys)	1	5	6	9 *
- Attic kneewalls	1	3	4	6 *
- Dropped ceilings	0	4	4	6 *

TABLE 3.8

VARIATIONS IN LEAK LOCATIONS WITH AGE AND STOREYS

HOUSING SAMPLE (STOREYS OR AGE)	MORE FREQUENT LOCATIONS*	LESS FREQUENT LOCATIONS*
1 Storey (21 units)	Attic exhaust Pipes into attic	Sill plate heating Ducts and plates ceiling mouldings wiring into ceiling heating ducts and pipes windows in living areas window pulley holes floor clamps stair risers
1-1/2 Storey (18 units)	Pulley holes floor changes cracks in walls and ceilings tub and shower enclosures	Basement windows Attic exhaust
2 Storey (21 units)	Basement utility penetrations stair risers	Attic hatches attic exhaust Floor changes piping penetrations
2-1/2 Storey (5 units)	Medicine cabinets window pulley holes open wall cavities heating ducts and pipes	(Highly variable)

TABLE 3.8 (Continued)

VARIATIONS IN LEAK LOCATIONS WITH AGE AND STOREYS

HOUSING SAMPLE (STOREYS OR AGE)	MORE FREQUENT LOCATIONS*	LESS FREQUENT LOCATIONS*
Pre - 1920 (14 units)	Windows in living area heating ducts or pipes cracks in walls and ceiling medicine cabinets ceiling mouldings	Sill plate Header joist delivery doors dryer vents
1921 - 1945	windows in living area basement doors dryer vents cable penetrations plumbing access hatches sill plates floor and ceiling mouldings open wall cavities (in basement) window pulley holes knee walls (attic)	exterior wiring holes wall fixtures chimney cavity
1946 - 1960 (17 units)	doors delivery doors ash clean-outs header joist	basement windows dryer vents sill plate stair risers window pulley holes
1961 - 1970 (12 units)	wall outlets/switches dryer vents sill plates header joists chimney cavities cracks in walls and foundation	open wall cabinets wall fixtures attic hatches window pulley holes
Post 1970 (11 units)	attic exhaust duct dryer vents wall cabinets open to attic	windows in living area basement doors and frames plumbing holes in wall or floor heating ducts or pipes ceiling mouldings

Breaking down the housing sample into a number of smaller samples, based upon age or number of storeys, produces some interesting variations in the frequency of occurrence of various leakage locations. A complete summary of "extreme" and "normal" observed air leakage sites in various categories of housing is contained in Appendix B1. The most significant variations in leakage locations for different types of housing are summarized in Table 3.8.

In many cases the differences in leak locations are a direct result of the differences in the style of housing. For example, one storey houses will leak less around stair risers and heating ducts since these items are less plentiful in a bungalow. An increase in pulley holes and wall penetrations is apparent as houses become taller. Attic leakage sites appear more prevelant in the shorter houses.

A more distinct separation can be made in leak locations by age of housing. The older houses tend to leak more often around windows, attachments to the houses, mouldings, and cracked plaster. Sill plates and joist areas and leaks around exhaust ventilation ducts are more noticeable in the newer housing.

3.3 FAN TEST DATA DISCREPANCIES

Fan depressurization tests were conducted on each house before weatherizing, at the completion of each stage, and at the overall completion (to provide a CGSB standard test). This amounted to a total of six tests for each of the 65 houses, with at least six pressure/flow readings per test; a substantial quantity of data for analysis.

As might be expected, a number of difficulties arose from assorted field errors, equipment malfunction and variations of test procedure. Probably the greatest source of error was the changing wind conditions over the two or three days of testing on each house. Most contractors employed a single outdoor pressure tap. It has since been demonstrated that a much more effective technique is to mount pressure taps on each of the four faces of a house to average the variable wind pressures. Even the use of pressure averaging tubes would still have been inadequate in the more gusty weather. Because the houses were occupied, it was unrealistic to consider delaying consecutive stages of weatherizing until winds calmed.

The errors from wind effects on house pressure are further magnified by the "Least square" regression analysis used to model the flow/pressure relationship in the house. Wind error is most significant at the lower pressure points of 10, 15, and 20 pascals, the very points which have the greatest impact on a least squares regression fit. Because testing on windy days was inevitable it may have been better, in hindsight, to avoid all measurements with house pressures below 20 pascals. Another alternative would be to calculate the standard error of each point on a test, apply an accuracy qualification on all of the data, but weighted to avoid even small errors at the lower pressures.

Contractors were often attempting to measure differences in air tightness of only two or three percentage points between any two consecutive stages of air sealing. Unfortunately this kind of precision fell within the natural error margin of instrumentation. On a few occasions the air leakage rate of houses would actually appear to increase after air sealing, to the great frustration of weatherizers. Improved techniques for measuring air flow through depressurization equipment could have greatly reduced error margins and alleviated many of the data discrepancies.

At the time of testing (1981/82) the high air flow requirements of the older and leakier houses in the sample made necessary the use of calibrated fans. With a calibrated fan, air flows vary directly with fan speed (rpm). Small errors in reading the tachometer can produce large variations in the air flow and air tightness. Improvements in fan technology since have produced high flow fans that measure air flows as a square root of the air pressure difference across the fan's venturi nozzle or orifice. With this type of equipment, operator error is likely to be much less significant, and much of the data discrepancy encountered by the current study could be avoided.

Equipment used by the contractor working in the Cambridge community suffered from special problems attributed to a low battery and to erratic behaviour of the computer used to calculate flows. Recalculation of air flow values using fan characteristics and raw measurements produced an acceptable set of readings for most houses. However the high percentage error in these tests, at low house pressures, destroyed much confidence in the flow exponents. Rather than reject the fan tests, it was decided to simply compare all of the single point readings at 50 Pascals at each stage of tightening. Calculations of the air tightness parameters was then completed by assuming an average flow exponent (u) of 0.65. This "OPTIONAL TEST" analysis was employed for virtually all the Cambridge test data.

For Sault Ste. Marie, the original flow measurements were exceptionally free of error, and therefore suspect. It was learned that the contractor took flow readings at house pressures well above the specified range. Air leakage profiles were developed using these air flows. Data submitted by the contractor included lower house pressures and lower flow values, taken from the resulting curves. For these houses, the original field data was reanalysed and a more realistic set of values determined.

Detailed statistical analyses were undertaken on the raw data after the above corrections; some further test rejections seem justified for occasional tests throughout the entire sample of 65 houses. Rejections of test points were necessary when the air flow/pressure ratio lay outside the theoretical limits of possibility (i.e. $0.5>n>1.0$). In other cases analysis of variance factors for the best fit of specific test data resulted in unacceptable large values. The error analysis was completed on each air tightness test in accordance with CGSB calculations for standard error. All flow/pressure readings with greater than 5% error from the regression fit were rejected and the data reanalysed.

In the case of one house, the changing slope of the air flow/pressure curve generated a higher air flow constant (C) after the weatherizing than existed originally. Despite various discrepancies and errors with the data, the bulk of air tightness tests submitted by contractors lay within acceptable levels of confidence. Two of the test houses, numbers 8 and 26, were completely rejected from the fan test data analysis due to major errors. Excluding these two houses, and the Cambridge tests, the correlation coefficients for the best fit equation were above 0.98 in 77% of the tests, and the overall test results were generally of high quality. In these cases where the correlation was below 0.98, the OPTIONAL TEST analysis was substituted for the CGSB procedure.

3.4 MODELLING AIR FLOW AND PRESSURE DATA

CHOICE OF AN EQUATION

Airflows always increase with pressure differences. However the precise relationship between air flow and pressure can vary from house to house, or even for the same house after reductions in leakage area. The relationship is not constant because leakage sites can be more or less efficient depending upon the particular shape and size of the air passageway. Thin, small leaks, typical of tighter housing, are thought to be characterized by efficient or 'laminar' air flows; conversely, the larger cracks and holes in the leakier houses are less efficient or 'turbulent', and do not respond as quickly to increasing pressure differences.

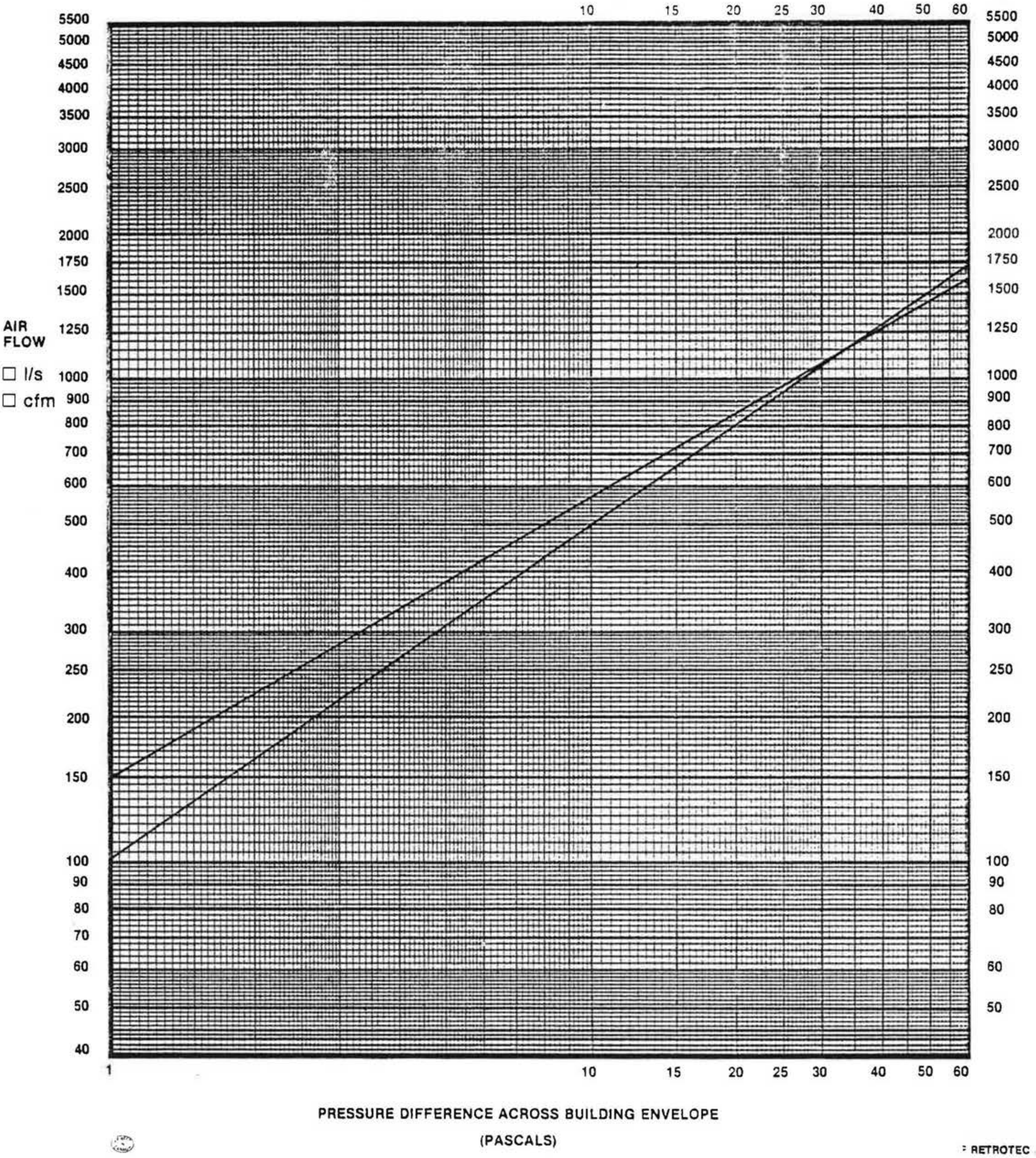
Various equations can be developed to model this relationship, since all houses contain some combination of laminar and turbulent air flow. The equations are essential to developing accurate leakage parameters. Fitting data to an equation smoothes out the single point errors and permits extrapolation to pressures that may be too low or too high for field test purposes.

The choice of an appropriate equation is of special significance for modelling air leakage rates in the air tightening project. Minor variations in the flow/pressure curve for a house can easily obscure the effect of air sealing applications. If, for example, the air sealing work reduces only the turbulent flow in a house, the tighter house will thereafter experience a steeper air flow/pressure curve. Such a change in slope will exaggerate the reductions in air flow at low pressures. At higher pressures the two 'flow/pressure' curves will actually cross each other, and the tighter house will suddenly become "leakier". An example of this phenomenon, extracted from the air tightening data, is presented in Figure 3.1.

The opposite can also occur, where air sealing is concentrated on the thin cracks and several large holes are overlooked. The curves will cross at the lowest pressures and the tighter house will again appear 'leakier'. The more common event is for air sealing to seal predominantly the largest leaks and leave the house with a steeper curve after air tightening as in Figure 3.1.

FIGURE 3.1

EXAMPLE OF AIR LEAKAGE PROFILES CROSSING DUE TO EFFECTS OF WEATHERIZING HOUSE NUMBER 63



Contractors involved in sealing the houses became aware of this problem when calculating reductions in air leakage for this Project. Two common parameters used in describing house tightness are the Equivalent Leakage Area (ELA) and the Air Change per Hour (ACPH). The ELA is typically calculated at 4 pascals (USA) pressure difference or at 10 pascals (CGSB standard), whereas the ACPH is calculated at 50 pascals (internationally). Because of the changing slope of the air leakage curves in houses undergoing air tightening, reductions appeared greater when based on ELA measurements as opposed to ACHP. Contractors were quickly converted to the new CGSB ratings that employ ELA values.

On average the flow exponent for Test 1 was 0.621 which increased to 0.666 in Test 5. In total, 92% of the houses had flow exponents increase after air tightening, and only 8% decreased.

To minimize problems from changing slopes in flow/pressure models it would be preferable if contractors took flow measurements at exactly the same pressure readings before and after air sealing. It would also be preferable to record additional flows at the lower house pressures (e.g: 15, 17, 20, 22, 25, 28) since these measurements are more critical in determining the slope of a regression fit. And finally it may be worth considering a procedure for averaging the reductions at different pressure differences in cases where houses undergo significant air tightening.

In reality it is obviously not possible for houses to become leakier after air sealing. The constants within an equation are possibly functions of pressure difference, which makes a single power law equation inadequate. Nevertheless, it was possible to achieve a reasonably good fit using a single equation to model the test data. In fact, two different models were employed to analyse the test data. The first model assumes that the total air flow is given by the expression Q=C*Pn

where
Q = air flow in litres per second
P = pressure difference in pascals
C = empirically derived constant
n = flow exponent

This model assumes that all flow is through an equivalent orifice within which the flow is usually in transition between laminar and turbulent so that the flow exponent "n" lies between 0.5 and 1.0. These values are the boundaries defined by turbulent and laminar flow respectively. Published results of tests which utilized this model indicate that "n" has a value typically in the 0.65 to 0.70 range.

The second model assumes that the total flow is the sum of the flows through orifices which are either laminar or turbulent and no leaks are in a transitional flow regime. This model can be expressed as:

$$Q = A\Delta P + B\Delta P^{.5}$$

The first part of the expression relates to the portion of the flow which is laminar and the latter to that which is turbulent.

The values of the parameters C, n, A, and B were determined using a "least squares" method applied to the series of air flows at different pressure differences at each of the six stages of air tightness on each of the 65 houses.

Further statistical analysis performed in an attempt to identify the relative performance of the two models. These results may be of interest to researchers in this field, and are presented in Appendix B2. For practical purposes there is no significant difference in the air leakage results estimated by the two models. The results obtained using the simpler model ($Q = C*\Delta P^n$) are presented throughout this report, to facilitate comparisons with other published results.

3.5 AIR TIGHTNESS TEST VALUES AND REDUCTIONS IN LEAKAGE AREAS

A summary of the air tightness test data is presented in Table 3.9, along with key variables on each housing including age, number of stories, space heating, fuel type, heated volume and above-grade envelope area.

Test data presents leakage parameters for each house as measured before air tightening (Test 1), and after air tightening (Test 5).

The "C" and "n" values refer to the constant anf flow exponent in the equation for modelling air flow and pressure: $Q = C*\Delta P^n$.

The ELA is the Equivalent Leakage Area calculated at 10 pascals pressure difference and corrected for variations in air temperature and atmospheric pressure (further explanation in Appendix A2).

The SLA is the Specific Leakage Area, which is the ELA normalized for variations in house size. This produces and ELA in square centimeters per meter squared of above-grade envelope area (cm^2/m^2). The percentage reduction in air tightness is based on the change in leakage areas from Test 1 to Test 5.

A complete listing of results for each test on each house appears in Appendix B3.

3.5.1 AIR TIGHTNESS VALUES FOR TEST 1 (PRE-WEATHERIZING)

The Initial ELA values show a wide variation, from 8125 cm^2 for house 56, to a low of 415 cm^2 for house 65, a factor of twenty.

The wide variations in ELA cannot be explained on the basis of building size alone, since the SLA values actuall experience similar variations, ranging from 41.0 cm^2/m^2 to 2.0 cm^2/m^2, a factor of twenty-one. An attempt to correlate Test 1 ELA and building volume, based upon all 65 houses, produced a negative correlation (-0.11). Clearly the building size is completely independent of the original air tightness. Since both large and small houses in the study were of conventional construction, there is also an implied independence of air leakage from crack length along baseboards and sill plates - a factor often used to estimate the air tightness of housing in lieu of fan test data.

An attempt was made to correlate air tightness with other variables than size. The mean original SLA and ELA for housing categories are summarized in Table 3.10.

The one-and-a-half storey houses appear to be slightly more leaky than the one storey and two storey houses. This may indicate that the more complex half storey construction produces more effective crack length in a house. However, there is also a higher proportion of electrically heated houses in the bungalow category. The two-and-a-half storey houses have surprisingly low SLA values, but the small sample size of only five houses precludes much confidence in this value. The ELA values for two-and-a-half storey houses are much larger than all others, which indicates that it is the exceptionally large wall areas on these tall houses that contribute to lower SLA values.

A more definite relationship is apparent in the Specific Leakage Areas for houses of different age brackets. Houses built after 1945 appear about one-third tighter than pre-war housing, and houses built after 1970 appear half again as tight. The "newer is tighter" relationship does not hold for all the houses, however. It is interesting to postulate why the pre-1920 houses are tighter than houses built 1921-45, or why the 1946-60 group is tighter than the 1961-70 housing. In both cases it is plausible to assume that variations in style and climate may have skewed the samples.

The local climatic conditions are also an apparent factor in determining SLA values. Signficant increases are apparent as the communities move south from Sault Ste. Marie, to Ottawa, Peterborough and Cambridge. The respective degree days for these communities are 5180, 4673, 4520, 4110 (°C).

TABLE 3.9

AIR TIGHTNESS TEST DATA AND OVERALL REDUCTIONS IN ELA

HOUSE NO.	AGE CATEGORY	NO. OF STORIES	HEATING SYSTEM	VOLUME (m^3)	ENVELOPE AREA (m^2)	TEST NO.	C	N	ELA_{10} (cm^2)	SLA (cm^2/m^2)	ELA Reductions
1	PRE 1920	2	GAS	341	211	1	151.76	0.577	2337	11.08	-
						5	60.58	0.720	1298	6.15	44.46%
2	1921 1945	1	GAS	322	162	1			1548	9.56	-
						5			995	6.14	35.72%
3	1921 1945	1.5	GAS	237	184	1	84.42	1.00	1552	8.43	-
						5	51.81	0.642	927	5.04	40.27%
4	1921 1945	2	GAS	480	263	1			2003	7.62	-
						5			1286	4.89	35.80%
5	1921 1945	2.5	OIL	521	286	1			1490	5.21	-
						5			1151	4.02	22.75%
6	1946 1960	1	OIL	446	204	1	32.28	0.655	595	2.92	-
						5	22.51	0.655	415	2.03	30.25%
7	1946 1960	1	GAS	182	157	1	68.90	0.706	1428	9.10	-
						5	49.28	0.691	986	6.28	30.95%
8	1946 1960	1.5	OIL	374	190	1	38.60	0.660	NA	NA	-
						5	49.28	0.691	NA	NA	NA
9	1946 1960	2	GAS	523	303	1	113.32	0.626	1955	6.45	-
						5	71.60	0.643	1284	4.24	34.32%
10	1961 1970	1	OIL	529	237	1	66.35	0.635	1169	4.93	-
						5	41.27	0.677	800	3.38	31.57%
11	1961 1970	2	OIL	463	228	1	28.48	0.688	541	2.37	-
						5	15.25	0.731	335	1.47	38.08%
12	POST 1970	1	ELEC	422	267	1	64.13	0.639	1138	4.26	-
						5	43.98	0.663	825	3.09	27.50%
13	POST 1970	1	ELEC	585	296	1	35.10	0.701	719	2.43	-
						5	20.61	0.768	493	1.67	31.43%

TABLE 3.9 (Continued)

AIR TIGHTNESS TEST DATA AND OVERALL REDUCTIONS IN ELA

HOUSE NO.	AGE CATEGORY	NO. OF STORIES	HEATING SYSTEM	VOLUME (m^3)	ENVELOPE AREA (m^2)	TEST NO.	C	N	ELA_{10} (cm^2)	SLA (cm^2/m^2)	ELA Reductions
14	POST 1970	1	GAS	412	197	1	40.40	0.617	682	3.46	-
						5	32.46	0.623	556	2.82	18.48%
15	1946 1960	1.5	OIL	498	244	1	88.55	0.689	1765	7.23	-
						4	118.66	0.583	1474	6.04	16.49%
16	1921 1945	1.5	GAS	309	167	1	208.11	0.557	3063	18.34	-
						5	158.80	0.569	2550	15.27	16.75%
17	1921 1945	1.0	GAS	305	170	1	203.83	0.568	3078	18.11	-
						5	214.23	0.484	2664	15.67	13.45%
18	PRE 1920	2.5	OIL	529	403	1	253.82	0.536	3554	8.82	-
						5	198.00	0.564	2959	7.34	16.74%
19	PRE 1920	2	OIL	396	246	1	283.71	0.503	3684	14.98	-
						3	176.36	0.617	2981	12.12	19.08%
20	1961 1970	2	GAS	457	237	1	191.58	0.589	3030	12.78	-
						5	103.52	0.703	2129	8.98	29.74%
21	1961 1970	1	GAS	373	187	1	127.34	0.564	1903	10.18	-
						5	90.46	0.601	1471	7.87	22.70%
22	POST 1970	1	GAS	394	204	1	195.26	0.524	2662	13.05	-
						5	94.97	0.628	1645	8.06	38.20%
23	1946 1960	1	ELEC	389	210	1	246.37	0.520	3324	15.83	-
						5	129.01	0.641	2304	10.97	30.69%
24	1946 1960	1	OIL	284	158	1	153.12	0.537	2150	13.61	-
						5	77.32	0.624	1328	8.41	38.23%
25	1946 1960	2	OIL	470	252	1	187.16	0.554	2737	10.86	-
						5	98.71	0.687	1957	7.77	28.50%
26	1961 1970	1.5	OIL	366	235	1	89.71	0.619	NA	NA	-
						5	31.90	0.891	NA	NA	NA

TABLE 3.9 (Continued)

AIR TIGHTNESS TEST DATA AND OVERALL REDUCTIONS IN ELA

HOUSE NO.	AGE CATEGORY	NO. OF STORIES	HEATING SYSTEM	VOLUME (m^3)	ENVELOPE AREA (m^2)	TEST NO.	C	N	ELA_{10} (cm^2)	SLA (cm^2/m^2)	ELA Reductions
27	PRE 1920	2.5	OIL	425	257	1	109.11	0.681	2135	8.31	-
						4	79.80	0.712	1678	6.53	21.41%
28	1921 1945	1	ELEC	290	164	1	179.35	0.624	3076	18.76	-
						5	102.72	0.694	2069	12.62	32.74%
29	1961 1970	1.5	GAS	447	296	1	257.22	0.571	3904	13.19	-
						4	142.48	0.664	2678	9.05	31.40%
30	1921 1945	2	OIL	384	232	1	79.28	0.637	1403	6.05	-
						4	30.76	0.787	768	3.31	45.26%
31	1946 1960	1	OIL	280	136	1			940	6.91	-
						5			503	3.70	46.49%
32	POST 1970	2	GAS	502	179	1	154.91	0.530	2142	11.97	-
						5	86.86	0.636	1531	8.55	28.52%
33	1946 1960	1	ELEC	420	160	1			1563	9.77	-
						4			420	2.63	73.13%
34	PRE 1920	2	GAS	675	250	1	147.69	0.65	2691	10.76	-
						4			2019	8.08	24.97%
35	1946 1960	1	OIL	360	157	1			1297	8.26	-
						5			774	4.93	40.32%
36	PRE 1920	2	GAS	595	250	1	174.31	0.525	2383	9.53	-
						5			1927	7.71	19.14%
37	POST 1970	2	ELEC	455	192	1			618	3.22	-
						5			232	1.21	62.46%
38	POST 1970	2	ELEC	462	195	1			970	4.97	-
						4			487	2.50	49.79%
39	1921 1945	1	OIL	224	80	1	81.55	0.65	1486	18.58	-
						4			880	11.00	40.78%

TABLE 3.9 (Continued)

AIR TIGHTNESS TEST DATA AND OVERALL REDUCTIONS IN ELA

HOUSE NO.	AGE CATEGORY	NO. OF STORIES	HEATING SYSTEM	VOLUME (m^3)	ENVELOPE AREA (m^2)	TEST NO.	C	N	ELA_{10} (cm^2)	SLA (cm^2/m^2)	ELA Reductions
40	PRE 1920	1.5	GAS	440	196	1			2844	14.51	-
						5			1732	8.84	39.10%
41	1961 1970	1.5	ELEC	416	147	1			1115	7.59	-
						5			585	3.98	47.53%
42	POST 1970	2	GAS	480	192	1			1446	7.53	-
						5			880	4.58	39.14%
43	1946 1960	1.5	GAS	411	167	1			1272	7.62	-
						4			1016	6.08	20.13%
44	1921 1945	2	GAS	308	165	1			838	5.08	-
						5			371	2.25	55.73%
45	1961 1970	1.5	ELEC	530	223	1			1706	7.65	-
						5			759	3.40	55.51%
46	1961 1970	2	ELEC	460	165	1			1828	11.08	-
						5			1029	6.24	43.71%
47	1961 1970	1.5	GAS	475	192	1			1781	9.28	-
						5			1486	7.74	16.56%
48	1921 1945	1.5	OIL	540	237	1			2848	12.02	-
						5			1804	7.61	36.66%
49	POST 1970	2	GAS	440	192	1			1471	7.66	-
						5			616	3.21	58.12%
50	1921 1945	1.5	GAS	420	165	1			2655	16.09	-
						5			1519	9.21	42.79%
51	PRE 1920	2	GAS	311	220	1	102.99	0.747	2345	10.66	-
						5	64.84	0.794	1647	7.49	29.77%
52	PRE 1920	1.5	OIL	319	202	1	27.96	0.835	780	3.86	-
						4	27.35	0.803	709	3.51	9.10%

TABLE 3.9 (Continued)

AIR TIGHTNESS TEST DATA AND OVERALL REDUCTIONS IN ELA

HOUSE NO.	AGE CATEGORY	NO. OF STORIES	HEATING SYSTEM	VOLUME (m^3)	ENVELOPE AREA (m^2)	TEST NO.	C	N	ELA_{10} (cm^2)	SLA (cm^2/m^2)	ELA Reductions
53	PRE 1920	2.5	GAS	463	303	1	139.34	0.635	2453	8.10	-
						5	49.67	0.888	1565	5.17	36.20%
54	PRE 1920	2.5	OIL	483	304	1	161.80	0.651	2953	9.71	-
						5	55.86	0.875	1710	5.63	42.09%
55	PRE 1920	1	OIL	378	257	1	135.19	0.628	2342	9.11	-
						5	72.93	0.748	1666	6.48	28.86%
56	PRE 1920	1.5	OIL	290	197	1	520.15	0.583	8125	41.24	-
						5			2479	12.58	69.49%
57	PRE 1920	1	OIL	232	192	1	194.77	0.504	2535	13.20	-
						4	84.87	0.679	1653	8.61	34.79%
58	1946 1960	1.5	OIL	456	236	1	110.45	0.642	1974	8.36	-
						5	32.33	0.896	1038	4.40	47.42%
59	1946 1960	1.5	OIL	301	176	1	131.36	0.629	2279	12.95	-
						4	58.26	0.786	1450	8.24	36.36%
60	1946 1960	1	OIL	447	212	1	32.09	0.736	712	3.36	-
						5	19.82	0.842	561	2.65	21.21%
61	1946 1960	1	OIL	459	254	1	187.22	0.548	2694	10.61	-
						5	119.95	0.607	1980	7.80	26.50%
62	1961 1970	1	OIL	635	284	1	187.65	0.709	3914	13.78	-
						5	71.74	0.815	1911	6.73	51.18%
63	1961 1970	1.5	OIL	380	344	1	116.53	0.656	2153	6.26	-
						5	67.57	0.769	1619	4.71	24.80%
64	POST 1970	1.5	ELEC	634	375	1	157.79	0.591	2507	6.69	-
						5	74.48	0.682	1459	3.89	41.80%
65	POST 1970	1	ELEC	330	184	1	15.72	0.811	415	2.26	-
						5	7.62	0.941	271	1.47	34.70%

3.5.2 AIR TIGHTNESS VALUES FOR TEST 5

The difference between Test 1 and Test 5 leakage areas is the reduction in air tightness accomplished by the weatherizing contractors. The average percent reduction ELA for all houses is 36%. Sixty-eight percent of the total sample lie within the 20 to 45% range. One house showed an increase in ELA of 16.5 percent after sealing, and has been excluded from the analysis. The remaining houses range from a low of 9% to a maximum reduction of 70%. (Refer to Table 3.9.)

The correlation between original and final air tightness, for all 65 houses, is an extremely significant 0.89 and indicates a consistent 36% improvement for houses regardless of the Test 1 value In order for houses to achieve similar percentage reductions, the houses with larger Test 1 values must have achieved larger absolute reductions in leakage area. It follows that the houses benefitting most from a given amount of weatherizing work were those with the largest initial leakage areas.

Table 3.10 A to E compares Test 1 and Test 5 leakage areas for different housing categories. The percentage reductions are based on averaging the reductions for each house in each category. There is a consistent trend towards smaller percentage reductions in taller houses. There is also a trend towards larger percentage reductions in newer housing stock. In both cases the trends are significant in relation to the deviation of the total sample.

The percentage reductions in leakage area from Test 1 to Test 5 have been graphically presented in Figures 3.2 to 3.11. The graphs show a fairly normal distribution around the mean, but with a surprising number of houses in the high percentage area of 60-80% reduction.

3.5.3 INTERMEDIATE AIR TIGHTNESS VALUES (STAGES OF AIR TIGHTENING)

The ELA values for each of the five stages of air tightening for each house are tabulated. Average reductions for each stage and for various categories of housing have been summarized in Table 3.11. The detailed analysis of reductions for different categories of housing is summarized in Appendix B4.

The statistics on ELA reductions include only houses where consecutive air tightness data was available for the stage in question. On occasion data would be unavailable due to omissions, poor correlation or due to house features such as flat roofs or slab-on-grade that made air tightening impossible.

TABLE 3.10A

ELA & SLA BEFORE/AFTER BY HOUSE AGE

Age	Pre 1920	1921-1945	1946-1960	1961-1970	Post 1970
Mean ELA Test 1	2940.1	2086.7	1779.0	2094.6	1342.7
Std. Dev.	1580.8	771.6	752.9	1046.6	748.0
Mean SLA Test 1	12.4	12.0	8.9	9.0	6.1
Std. Dev.	8.4	5.4	3.4	3.5	3.5
Mean ELA Test 5	1887.0	1533.6	1248.7	1212.4	850.8
Std. Dev.	484.6	699.2	618.3	566.4	495.4
Mean SLA Test 5	7.5	8.3	5.9	5.4	3.9
Std. Dev.	2.1	4.5	2.6	2.3	2.4
% Reduction (1 to 5)	36%	27%	30%	42%	37%

TABLE 3.10B

ELA & SLA BEFORE/AFTER BY HOUSE TYPE

Number of Storeys	One	One & Half	Two	Two & Half
Mean ELA Test 1	1789.1	2489.6	1905.3	2517.0
Std. Dev.	992.5	1601.6	834.2	702.9
Mean SLA Test 1	9.8	11.8	8.6	8.0
Std. Dev.	5.3	8.3	3.5	1.5
Mean ELA Test 5	1221.7	1523.9	1171.8	1846.3
Std. Dev.	705.7	573.1	599.8	674.4
Mean SLA Test 5	6.3	7.3	5.2	5.5
Std. Dev.	3.8	3.5	2.5	1.2
% Reduction (1 to 5)	32%	39%	38%	27%

TABLE 3.10C

ELA & SLA BEFORE/AFTER BY COMMUNITY

Location	Sault St. Marie	Ottawa	Peter-borough	Cambridge
Mean ELA Test 1	1351.6	2545.4	2835.9	1694.7
Std. Dev.	547.1	1729.2	694.1	674.5
Mean SLA Test 1	6.1	10.7	13.1	9.5
Std. Dev.	2.7	8.9	3.8	3.7
Mean ELA Test 5	943.2	1492.2	2107.6	1049.9
Std. Dev.	402.9	582.8	502.0	545.8
Mean SLA Test 5	4.2	5.7	10.3	5.5
Std. Dev.	1.8	2.7	3.0	2.5
% Reduction (1 to 5)	30%	41%	26%	38%

ELA and SLA Values are in cm 2

TABLE 3.10D

ELA & SLA BEFORE/AFTER ELECTRIC HOUSES

Location	
Mean ELA Test 1	1581.6
Std. Dev.	914.0
Mean SLA Test 1	7.9
Std. Dev.	5.0
Mean ELA Test 5	1002.6
Std. Dev.	685.1
Mean SLA Test 5	4.9
Std. Dev.	3.8
% Reduction (1 to 5)	37%

TABLE 3.10E

ELA & SLA BEFORE/AFTER POLYURETHANE SEALED HOUSES

Location	
Mean ELA Test 1	2116.6
Std. Dev.	536.2
Mean SLA Test 1	11.2
Std. Dev.	2.9
Mean ELA Test 5	1202.2
Std. Dev.	430.7
Mean SLA Test 5	6.2
Std. Dev.	2.2
% Reduction (1 to 5)	43%

Average reductions for each stage of weatherizing varied somewhat from house to house with an associated uncertainty of about 75 percent for each stage. The only exception is the final stage (attics) where the standard deviation is much higher and represents about 150 percent of the average value.

The first stage of weatherizing, "openings", produced the greatest reduction in the original leakage area at 12.8 percentage points (or an average reduction in area of 260 cm2). The second stage "cracks" was a very close second at 12.2 percentage points or 250 cm2. These two component packages together account for almost three-quarters of the total reduction achieved by the weatherizers.

At 7.1 percentage points, the "foundation" sealing was accountable for only half the reductions achieved by either cracks or openings. The "attic and by-pass" sealing produced, on average, an insignificant 4.3 percentage points to the overall reduction of 36%.

Much of the reason for the reduced impact of basement and attic work is the limited accessibility to leakage sites, mentioned earlier. There is also a need for better techniques for sealing leaks in these locations, to help overcome difficulties encountered by contractors.

Average reductions for the whole housing sample would have been much improved if contractors had managed to better seal the leakage site in attic and basement areas. The effect on energy reductions would also have been much improved, especially because it is the basement and attic sites that are subjected to constant stack pressures in cold weather housing, and thus contribute disproportionately large quantities of infiltration and exfiltration.

Figure 3.2 : All Houses

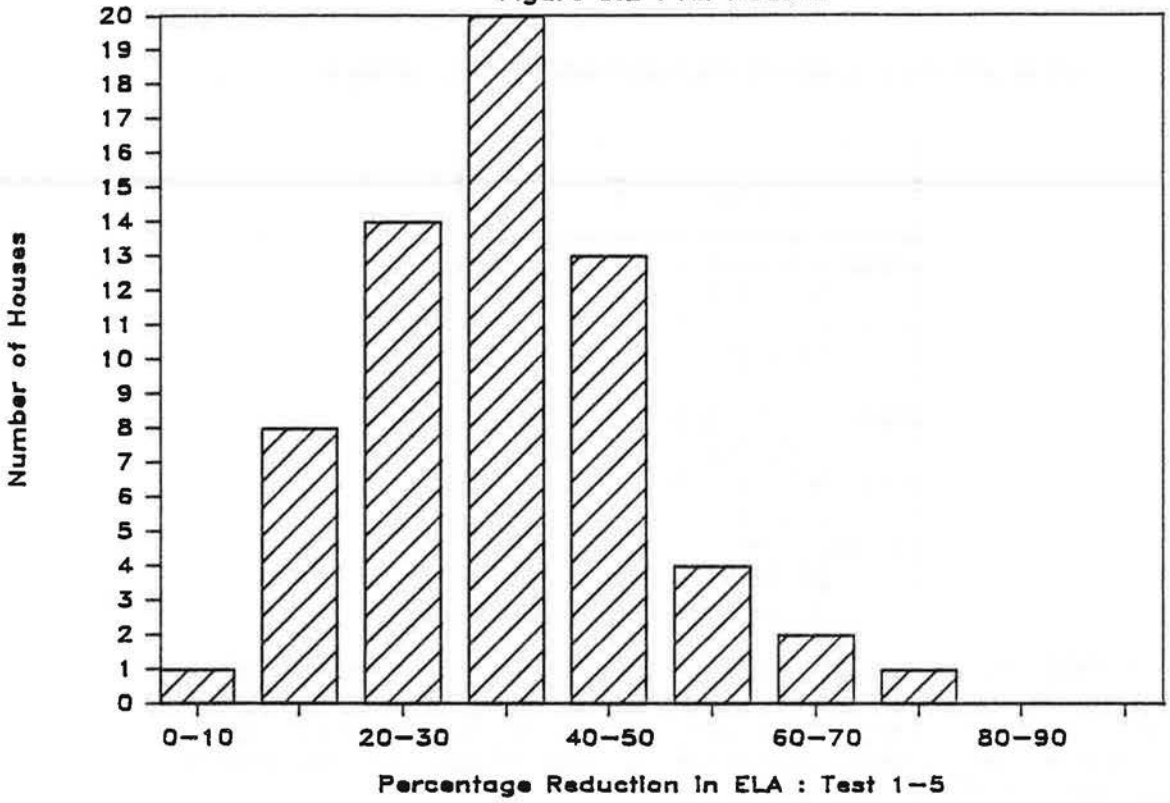


Figure 3.3 : One Storey Houses

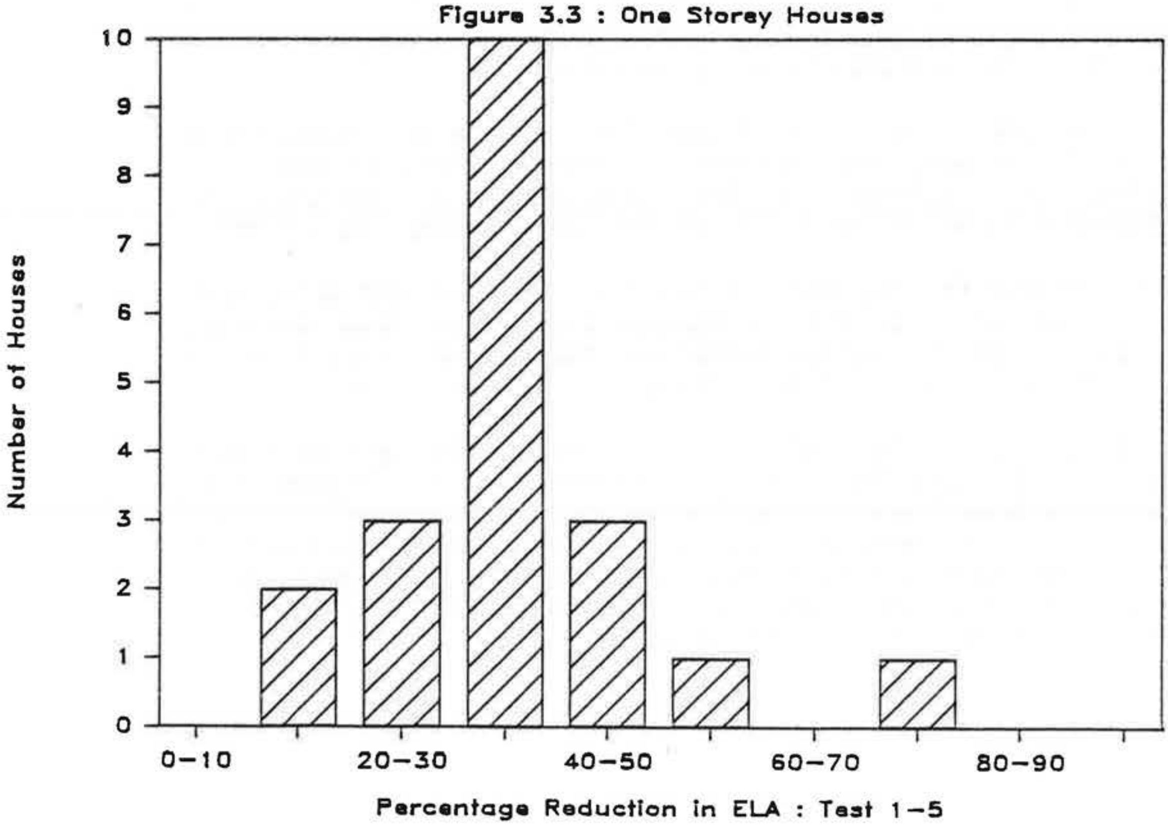


Figure 3.4 : 1 1/2 Storey Houses

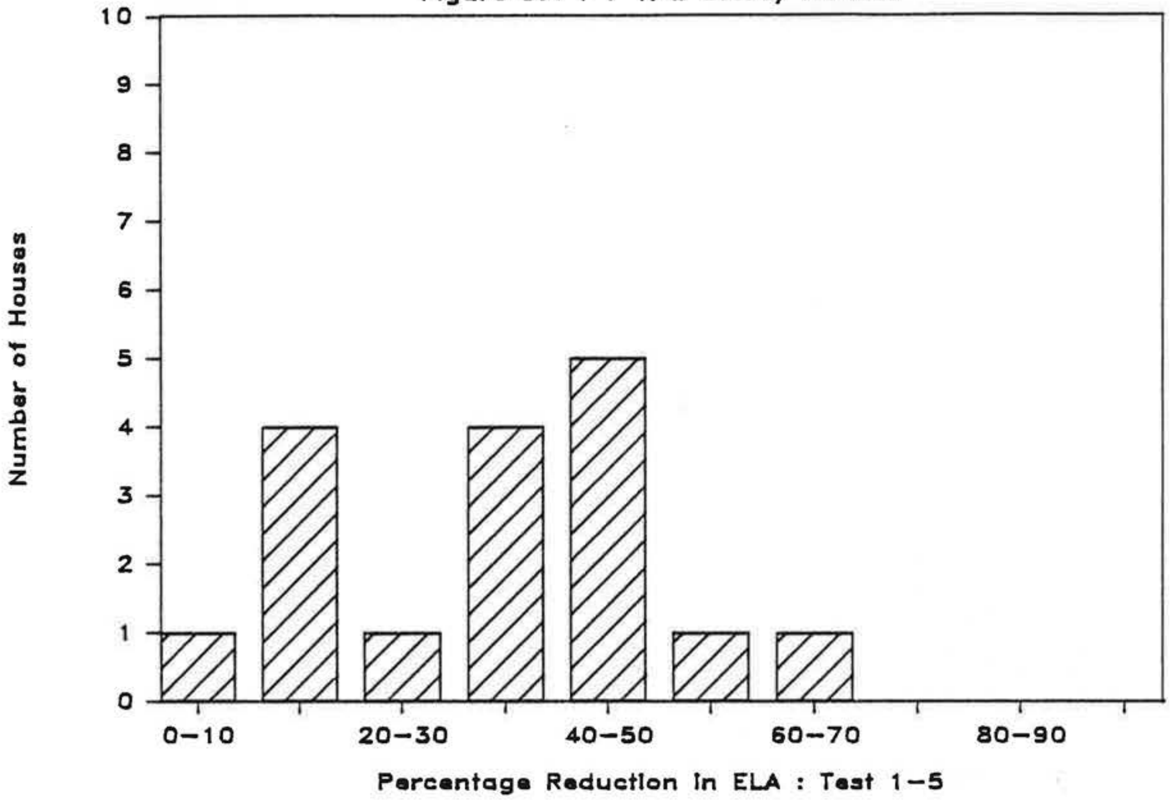


Figure 3.5 : 2 Storey Houses

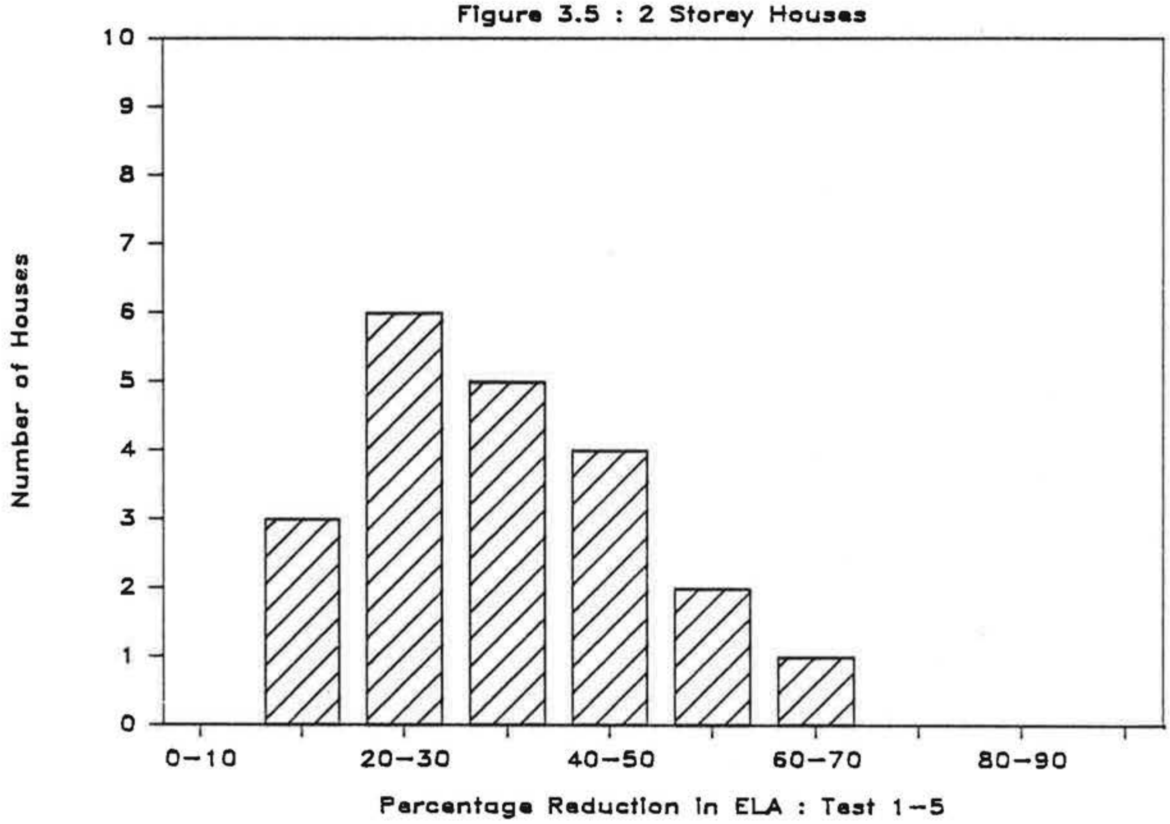


Figure 3.6 : 2 1/2 Storey Houses

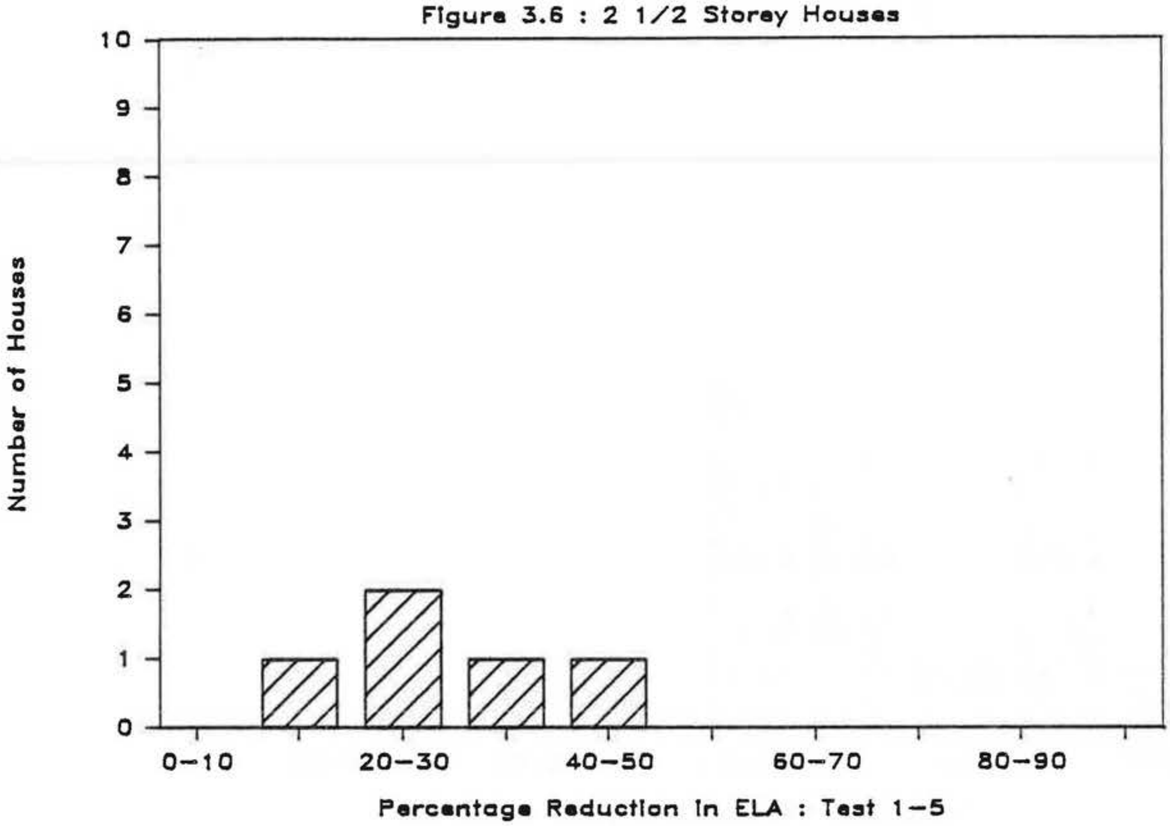


Figure 3.7 : Pre 1920 Houses

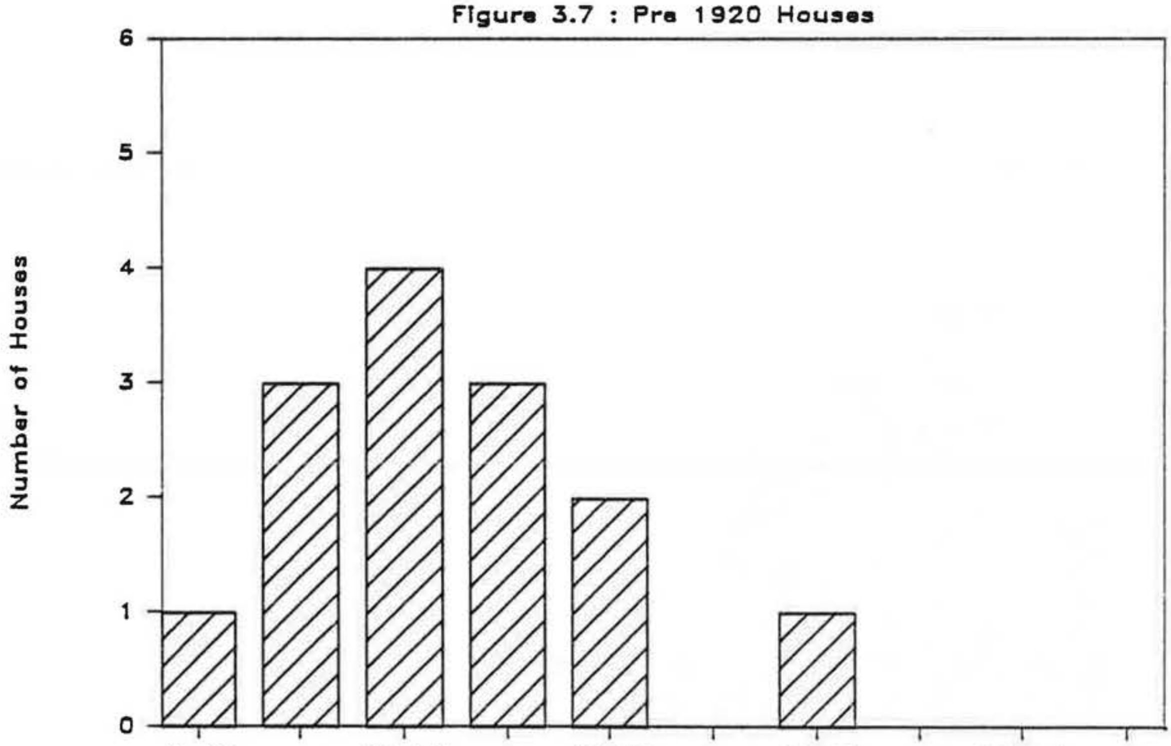


Figure 3.8 : 1920-45 Houses

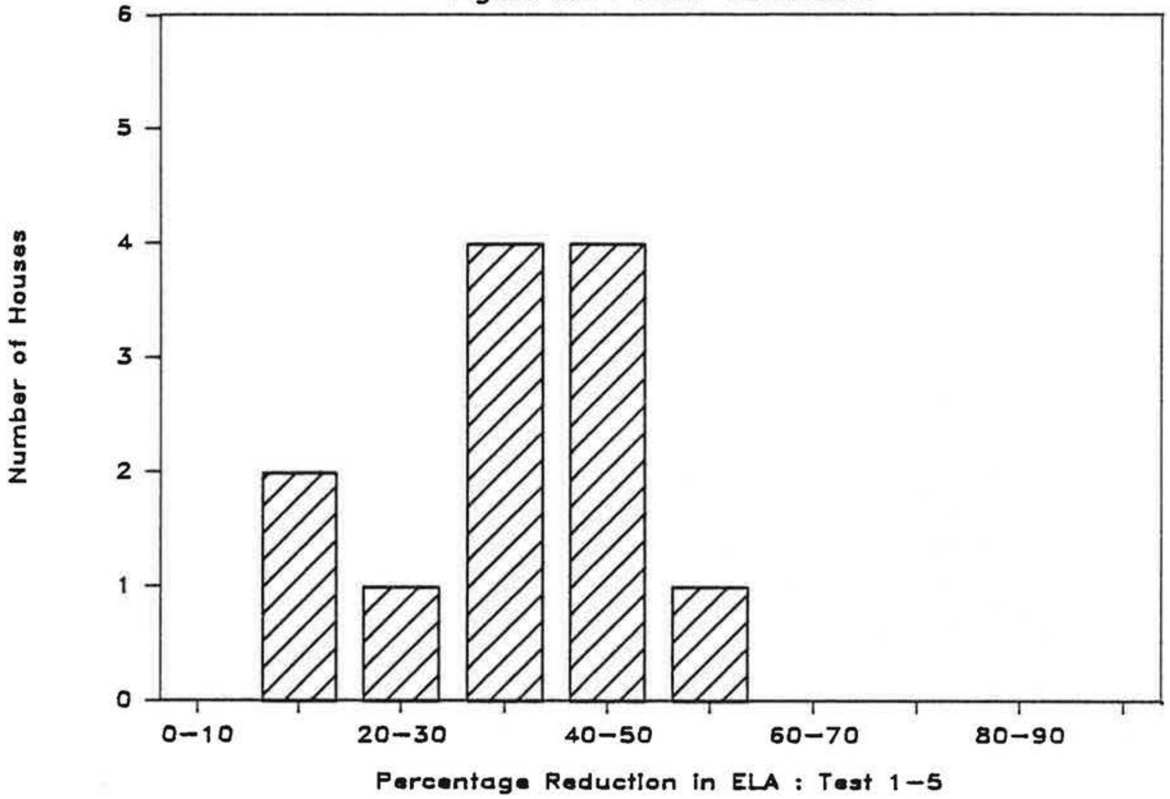
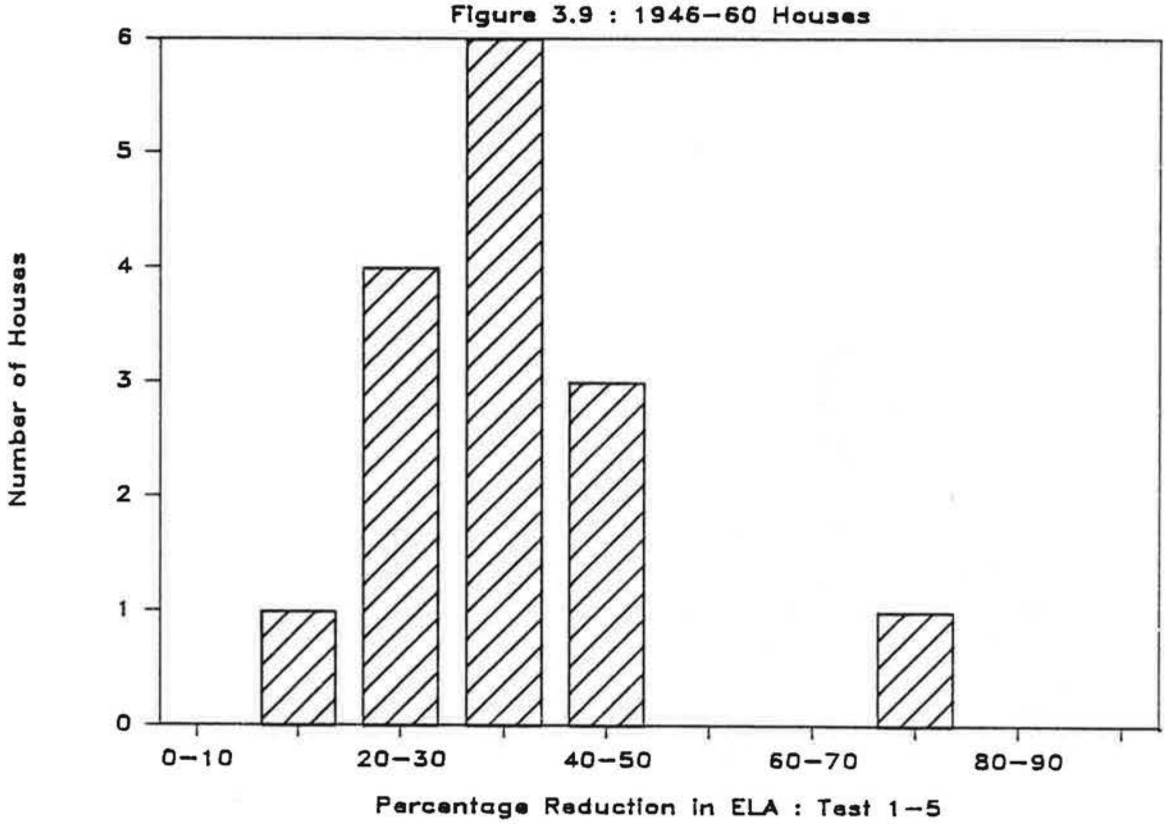


Figure 3.9 : 1946-60 Houses



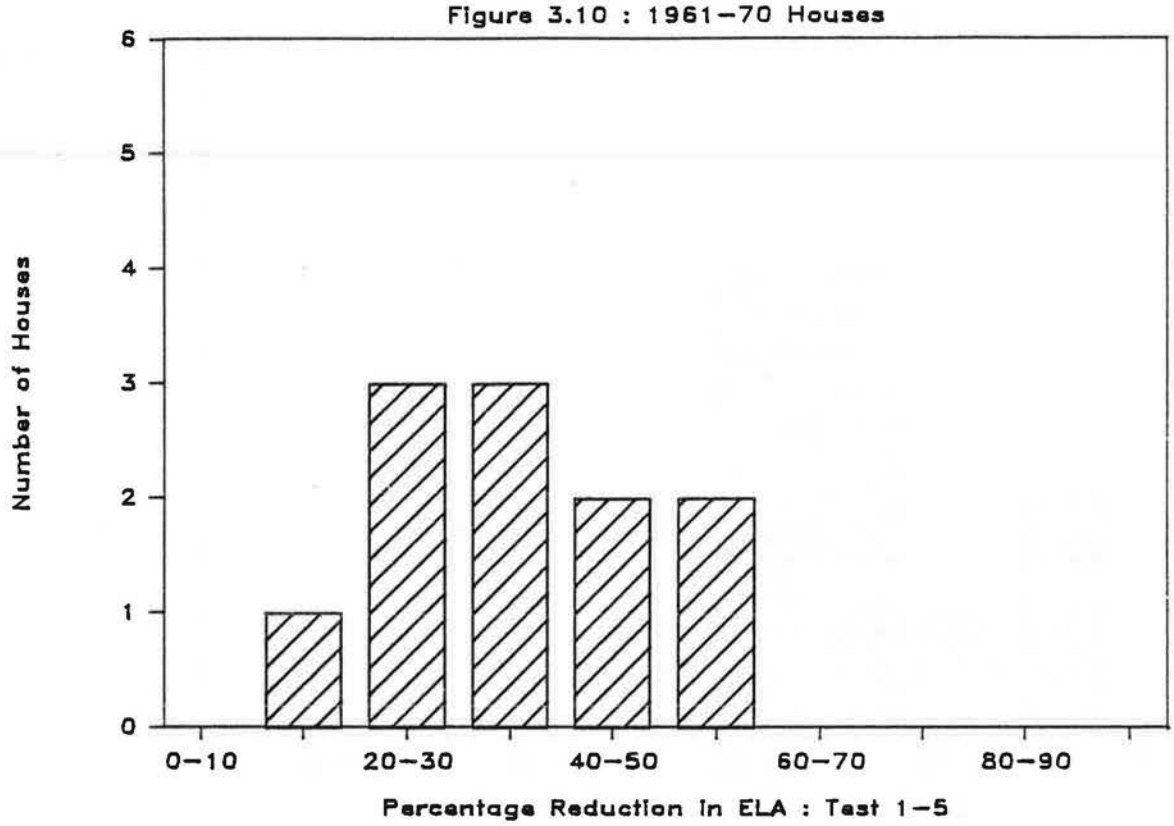


Figure 3.10 : 1961-70 Houses
Number of Houses
0
1
2
3
4
5
6
0-10
20-30
40-50
60-70
80-90
Percentage Reduction in ELA : Test 1-5

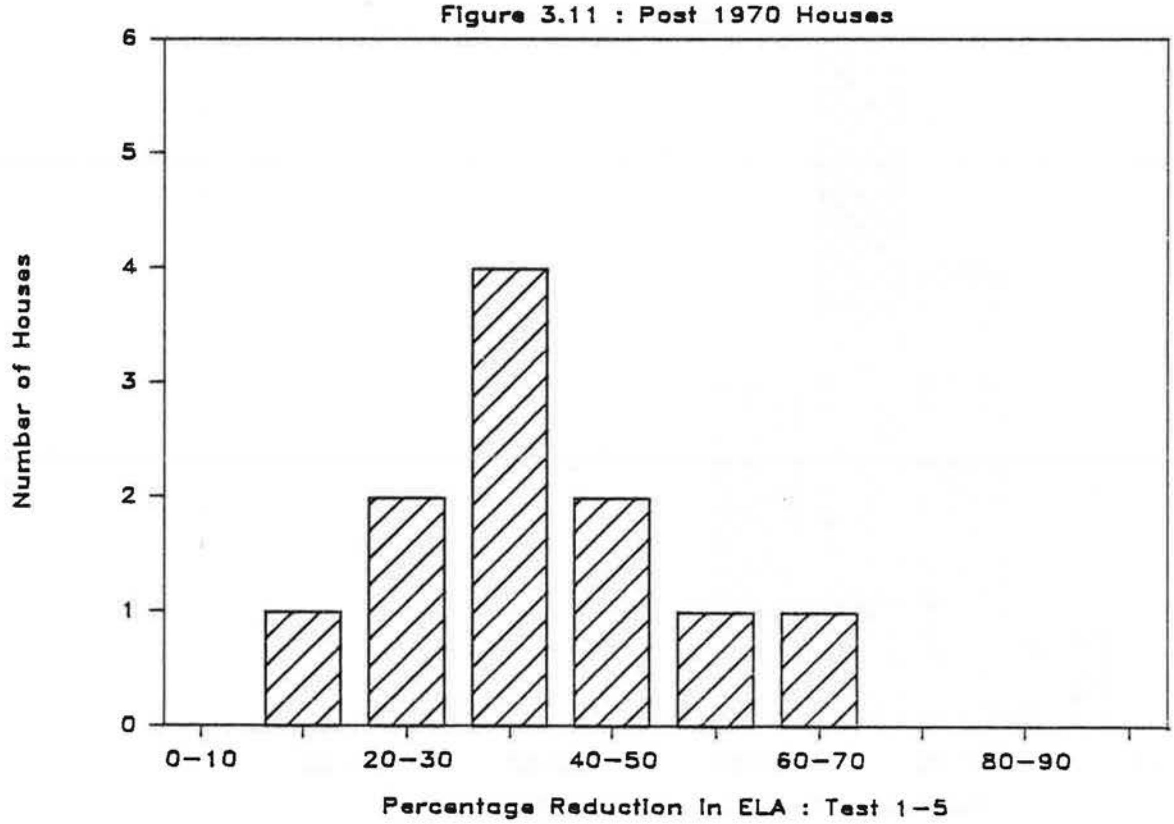


Figure 3.11 : Post 1970 Houses
Number of Houses
0
1
2
3
4
5
6
0-10
20-30
40-50
60-70
80-90
Percentage Reduction in ELA : Test 1-5

TABLE 3.11

PERCENTAGE REDUCTIONS
IN ORIGINAL LEAKAGE AREA FROM EACH STAGE OF WEATHERIZING

REDUCTIONS IN LEAKAGE AREA (%)

HOUSING SAMPLE	FOUNDATION	FOUNDATION	FOUNDATION	FOUNDATION
HOUSING SAMPLE	TEST 1-2 OPENINGS	TEST 2-3 CRACKS	TEST 3-4 FOUNDATION	TEST 4-5 ATTIC AND BY-PASS
ALL HOUSES (cm^2)	12.8% (236)	12.9% (225)	7.1% (124)	4.3% (39)
ONE STOREY	11.7%	12.8%	6.2%	6.3%
1-1/2 STOREY	14.3%	11.6%	7.8%	0.9%
TWO STOREY	13.5%	12.7%	8.1%	4.0%
2-1/2 STOREY	9.3%	9.5%	5.1%	6.7%
PRE - 1920	13.9%	9.8%	4.9%	4.9%
1921 - 1945	10.6%	14.4%	6.5%	5.2%
1946 - 1960	12.0%	10.9%	9.4%	2.4%
1961 - 1970	11.2%	15.6%	5.8%	4.8%
PAST 1970	16.5%	11.0%	8.7%	4.0%

3.5.4 AIR TIGHTNESS VALUES FOR TEST 6: APPLICATION OF THE CGSB TEST PROCEDURE TO WEATHERIZERS

The first five air tightness tests (1 to 5) were conducted with all intentional building openings sealed, (e.g. inlet and exhaust ducts taped and fireplaces plugged). Otherwise the procedure is similar to the CGSB standard test for testing new construction. At the completion of air sealing work a CGSB test was also conducted on each house (Test 6). A comparison of these tests is presented in Table 3.12. The mean increase in ELA between the final SEALED test (5) and the CGSB test (6) was approximately 96 cm2. This will produce a variation in the tightness ratings of about 5% before weatherizing, and about 10% after. However, in 20% of the houses there was virtually NO difference between Test 5 and Test 6 because these houses lacked any special air inlets to seal or unseal. For the remaining houses, the unsealing of intentional openings results in an average increase of ELA 160 cm2 per house - a significant variation that can be attributed solely to the changes in test procedure.

The SEALED test procedure is a way of achieving lower ELA ratings before and after weatherizing. The lower rating require lower air flows, which is an advantage in testing leaky houses that can exceed fan capacities. Lower ratings also facilitate greater precision in measuring the impact of weatherizing and emphasize the overall percentage reduction. Sealing fireplaces has an added benefit as a means of avoiding ashes spilling into the rooms!

Since neither procedure represents the actual operating configuration of the houses, and since the CGSB standard was designed for new houses only, it would seem preferable for weatherizers to employ a variation of the CGSB standard, in which all chimneys and inlet or exhaust ducts or fans are SEALED prior to test, in addition to the primary heating flues. Sealing of openings would include free areas only, so not to cover leaky trim work around ducts or fans where caulking may be required. Only in cases where weatherizing involves the retrofit or replacement of exhaust fans or chimney dampers should these be left UNSEALED, with the exceptions noted in any test reports.

3.6 AIR SEALING APPLICATIONS

3.6.1 MATERIALS AND TIME REQUIREMENTS

Contractors were requested to investigate and seal all significant air leakage sites identified in the houses, using conventional methods and materials. On average this process required three person days per house, using 22 tubes of caulk, 39 meters of window and door weatherstripping, 2 sweeps or thresholds, 27 sets of gaskets and an unspecified amount of foam and packing material.

TABLE 3.12

COMPARISON OF ELA VALUES FOR TEST 5 (SEALED) AND TEST 6 (UNSEALED CGSB)

HOUSE NO.	ELA (cm^2) TEST 5	ELA (cm^2) TEST 6	ELA (5-6)
1	1298	1054	244
2	995	995	0
3	927	927	0
4	1286	1286	0
5	1151	1151	0
6	415	413	2
7	986	1132	-146
8	NA	NA	NA
9	1284	1445	-161
10	800	845	-45
11	335	369	-34
12	825	828	-3
13	493	565	-72
14	556	530	26
15	1854	1854	0
16	2550	2754	-204
17	2664	2572	92
18	2959	3265	-306
19	NA	2849	NA
20	2129	2472	-343
21	1471	1645	-174
22	1645	1663	-18
23	2304	2186	118
24	1328	1320	8
25	1957	2145	-188
26	NA	NA	NA
27	NA	NA	NA
28	2069	NA	NA
29	NA	NA	NA
30	NA	1261	NA
31	503	616	-113
32	1531	1796	-265
33	NA	470	NA
34	NA	2053	NA
35	774	865	-91
36	1927	1913	14
37	232	301	-69
38	NA	519	NA
39	NA	895	NA
40	1732	1843	-111
41	585	679	-94
42	880	895	-15

TABLE 3.12 (Continued)

COMPARISON OF ELA VALUES FOR TEST 5 (SEALED) AND TEST 6 (UNSEALED CGSB)

HOUSE NO.	ELA (cm^2) TEST 5	ELA (cm^2) TEST 6	ELA (5-6)
43	NA	NA	NA
44	371	552	-181
45	759	805	-46
46	1029	1057	-28
47	1486	1553	-67
48	1804	1950	-146
49	616	764	-148
50	1519	1820	-301
51	1647	1647	0
52	NA	717	NA
53	1565	1565	0
54	1710	2291	-581
55	1666	1943	-277
56	2479	2550	-71
57	1752	NA	NA
58	1038	1314	-276
59	NA	1713	NA
60	561	584	-23
61	1980	1980	0
62	1911	2232	-321
63	1619	1939	-320
64	1459	1459	0
65	271	271	0

The application was close to state-of-the-art for 1981. Aside from the use of a depressurization fan, there were few materials or tools employed by contractors that would not be available to the average householder in a well equipped hardware store. An exception would be the use of polyurethane foam in the Cambridge houses, and the application of high quality spring vinyl weatherstrips. Recent developments in specialized weatherstrips and hybrid sealants could be expected to improve performance. Only two contractors had much previous experience using depressurization fans to facilitate comprehensive sealing. More extensive experience and training could also be expected to improve performance. (Some contractors claimed to have achieved a steady improvement in the average reduction in ELA for houses, in the range of 5 percentage points per year of experience.)

Contractors completed a record of material and time requirements for each house. Table 3.13 summarizes these records, and provides a breakdown of total and per unit requirements for houses of different age brackets.

The sealants used by contractors included primarily acrylic latex and silicones, with some butyl based caulking for basements and attics. Quantities of sealants appear to decrease slightly for newer homes, although the difference is not significant. The average of 22 tubes per house is surprisingly high relative to the "several tubes" suggested by many How-To Manuals* and suggests a thorough job by installers. The larger cracks in basements and attics account for at least half of this quantity, with the remainder applied to the interior trimwork or gaps around plumbing and other penetrations.

Most windows in the housing sample were either wood double hung or sashless sliders. Viny V strip weatherstrip was widely employed, in varying widths, and with some additional closed cell foam along sills and rails. The exterior doors were commonly weatherstripped with V-strip or vinyl door sets and sweeps.

Weatherstripping quantities per house are also substantial, which corresponds with the priorities established earlier for air leakage sites. The only significant variation in weatherstripping requirements is for the post 1970 houses, where the presence of manufacturer weatherstripping or sealed window units may explain a 25% reduction in required material. As well, the badly warped and worn frames in the older houses often required two or three different weatherstripping applications on the same window or door. Door weatherstripping accounts for about 30% of the total. Some homes required as much as 80 meters of door weatherstripping, to seal attic hatches, knee wall doors, cold room doors and exterior doors.

TABLE 3.13

SUMMARY OF MATERIAL AND TIME REQUIREMENTS

House Category		Material Record And Time Log				
Age Bracket	No. Of Units	Caulking (No. Of 300 ml Tubes)	Weather-stripping (meters)	Door Thresholds And Sweeps	Electrical Gaskets	Person - Hours
All Ages	65	(22)	(39)	(2)	(27)	(26)
Pre 1920	14	388 (28)	502 (36)	15 (1)	220 (16)	530 (38)
1921 1945	11	258 (23)	448 (41)	18 (2)	149 (14)	290 (26)
1946 1960	17	325 (19)	749 (44)	38 (2)	360 (21)	396 (23)
1961 1970	12	221 (18)	486 (41)	18 (2)	265 (22)	292 (24)
Post 1970	11	253 (23)	336 (31)	14 (2)	364 (33)	203 (18)

Note: 1) (#) Denotes per unit basis.

2) Average poundage of two (2) component polyurethane foam used for basement and attic in 20 Cambridge houses was 33 lbs. (= $99.00) per unit.

Electrical gaskets and plug requirements increase dramatically for newer housing, with post 1970 houses showing double the requirements of the oldest homes. Changes in building codes are partly responsible; as well gaskets are sometimes not required on the older homes because of layers of paint and wallpaper. An average of 27 gaskets per house for the entire sample is another indication of the high priority given to these leakage sites.

An estimated retail value for the average material requirements per house totals $168.00 (in 1984 dollars). This estimate assumes average rates of $4.00/tube, $1.20/meter of window weatherstripping, $3.00/meter door weatherstripping, $6.00/threshold, and $0.25/gasket. If polyurethane foam is used to replace 50% of the caulking, the costs per unit could inrease by up to $50.00 (the average for the foam sealed Cambridge homes was 15 kg/unit for a cost of $100).

Any householder attempting to complete comprehensive weatherizing would certainly incur additional costs due to wastage, mistakes, and unnecessary applications, increasing costs by at least another 50%. Thus it can be estimated that the average do-it-yourself cost of air sealing lies in the range of $250 to $300 (tools and time not included). These costs are much in excess of the "$50 to $100 commonly sited in consumer brochures."**

The number of person-hours required for air sealing varies with the age of the house, from 18 person-hours for post 1970 houses, to 38 person-hours for the oldest houses, (see Table 3.13). Since the older homes are also much leakier, there is a clear correlation between the size of the leakage area and the time required for weatherizing.

Actual time requirements for contractors could be expected to be reduced in non-research jobs, since the thorough quality control and record keeping required for this project tended to extend the time on-site by at least 4 hours and reduced efficiency. Nevertheless, in a professional installation, the average pre 1970 house would appear to require at least a full day's work from a two or three person crew in order to achieve results comparable with the Weatherize Project. The 1/2 day "HOUSE DOCTOR" retrofits (which include weatherizing, along with other low cost conservation measures) advocated by a number of research and government agencies would certainly fall short of matching the potential for effective air sealing in most Ontario houses.

3.6.2 EFFICIENCY AND PERFORMANCE

Table 3.14 summarizes the reductions in leakage area per person-hour worked for each stage of weatherizing. For the entire sample a reduction of 28.39 cm^2 is typical. The variations between contractors is partly explained by the variations in housing types in each community, and by the use of more intensive polyurethane foam sealing in the Cambridge housing.

* e.g. Keeping the Heat In, 1983, Energy Mines & Resources.

** e.g. First Seal Your House, 1981, Ontario Ministry of Municipal Affairs & Housing.

Weatherstripping doors and windows eliminated about 37.5 cm^2 of ELA per person-hour of effort, with an associated uncertainty of less than 100%; consequently this was the surest and most effective of the weatherize stages. (It is not necessarily the most cost-effective stage because of the much greater material costs.)

The sealing of cracks and trim work produced the lowest reduction per person-hour, at 21.1 cm2. The use of the door fan helps considerably in identifying leaky trim work, and without a fan this stage would likely be less effective still. One reason for lower efficiency when sealing cracks is the time required in moving furniture away from walls. If the sealants are to remain hidden, further time is required in removing and replacing trim and covers; if not, extra time is needed to ensure neat application. And because the living area cracks are often very thin, it can take considerable time to make significant reductions in leakage area.

Work requirements for foundation sealing at a reduction of 26.51 cm^2 varied considerably with access to the sill plates. Older houses with unfinished basements could also have numerous holes leading to by-pass cavities. On occasion the contractors reported finding that sealing off large and obvious leaks around perimeter of basements would have relatively little effect on the ELA measurements. No explanation for this phenomenom is provided, other than equipment error.

Sealing attic and by-pass routes produced the second greatest reductions per person-hour at 29.5 cm^2, although the deviations indicate the need for more careful leak identification, or more efficacious techniques. If attics are accessible, and if leaks can be properly identified the results would appear to be very rewarding. One reason for the efficiency of attic sealing is the pressence of large discrete holes like chimney chases that present opportunities for rapid reductions in ELA.

The difficulties encountered in trying to locate and seal attic leaks pointed to the need for more specialized techniques. The use of polyurethane foam in the Cambridge houses was especially valuable for attic work, where the reduction per person-hour is more than three times the overall average. Both the Ottawa and Peterborough contractors suggested that a rake-and-spray method might be another alternative to coping with the deep insulation and difficult caulking encountered in attics.

The great potential for reducing air leakage and condensation problems by sealing attics prior to or in combination with reinsulation cannot be over-emphasized. In this regard the financial assistance and promotion of insulation programs has been only partially successful. The value of insulation is severely negated by the continuous air leakage. The new insulation only obscures the air leaks and in fact this proved to be a major obstacle in this sealing project.

TABLE 3.14

REDUCTIONS IN ELA PER PERSON-HOUR WORKED

Test No. / Building Components Sealed		Sault Ste. Marie Mean	Sault Ste. Marie S.Dev.	Peterborough Mean	Peterborough S.Dev.	Cambridge Mean	Cambridge S.Dev.	Ottawa Mean	Ottawa S.Dev.	Total Mean
1-2 Openings	cm2 red.	199	146	286	155	205	152	557	1265	307.1
	hours	3.5	1.64	8.85	3.58	9.27	3.91	10.58	5.47	8.19
	cm2/hr	56.86		32.32		22.11		52.65		37.5
	No. of Houses		14		14		19		15	62
2-3 Cracks & Trim	cm2 red.	101	95	265	185	270	146	281	322	233.3[illegible]
	hours	4.25	1.37	11.32	4.55	16.37	5.71	10.43	4.22	11.06
	cm2/hr	23.76		23.4		16.49		26.94		21.11
	No. of Houses		14		14		19		15	62
3-4 Foundation	cm2 red.	54	85	180	129	119	77	174	134	131.4[illegible]
	hours	2.14	1.73	6.16	3.78	4.21	3.81	7.41	10.43	4.96
	cm2/hr	25.23		29.22		28.26		23.48		26.51
	No. of Houses		14		13		19		14	62
4-5 Attic	cm2 red.	54	165	78	81	64	72	121	133	78.69
	hours	1.5	.55	2.42	1.39	2.89	4.04	3.70	3.26	2.67
	cm2/hr	36		32.23		22.15		32.70		29.52
	No. of Houses		14		10		14		12	62
1-5 All Comp.	cm2 red.	408	280	770	248	641	262	1098	1301	728.0[illegible]
	hours	11.28	3.58	28.77	10.03	30.49	11.99	30.02	14.64	25.65
	cm2/hr	36.17		26.76		21.02		36.58		28.39
	No. of Houses		14		14		19		15	62

3.6.3 MATERIAL APPEARANCE AND DURABILITY

An evaluation was conducted on the appearance and durability of the weatherizing materials by means of telephone interviews with houseowners. Two surveys were conducted. The first contacted 37 houseowners in the spring following the applications. At this time 92% of the houseowners were generally very satisfied and pleased with their results. Complaints included too much caulking (1 house), sloppy workmanship (2 houses), and a few areas that had been missed (2 attics, 1 door, 1 basement ceiling, and 1 baseboard).

Seventy-eight percent of respondents rated material durability as good. Eight percent attested to loose tape and loose weatherstripping. One houseowner mentioned minor shrinkage problems with caulking, and another had difficulty removing safety plugs.

The second telephone survey was conducted the next winter with 24 houseowners. Again the great majority of respondents were very pleased with material durability and effectiveness. There were, however, several minor complaints: weatherstripping coming off the door in places (four); caulk peeling (three); window weatherstripping (especially on sliders) loosing adhesion (three); caulk discolouring (two); and too much caulking (one).

3.6.4 POLYURETHANE FOAM SEALANTS

An analysis of variance on raw ELA data was performed to determine whether the Cambridge results were significantly different from other communities, possibly because of more frequent use of polyurethane foam sealant. The analysis showed a significant improvement in ELA Reductions (Test 1 - Test 5) for the Cambridge contractor as compared to the other three communities. The mean reduction in ELA for the polyurethane sealed houses was 43% as compared with 36% for the sample as a whole.

The Cambridge contractor employed a two-part urethane foam system to facilitate sealing of attic and basement sites and to seal behind trim and electrical boxes. Urethane based foam contains no formaldehyde, and is permitted for cavity filling in residences, and as a surface application when used in limited quantities as a sealant. The two-part foams rapidly expand on application and fill cracks from 10 to 50 mm. The foam adheres very strongly to most materials, and tightly seals and insulates cavities by virtue of a closed cellular structure containing freon gas. Foam sealants are expensive and difficult to apply, but are felt to be a much superior sealing method by a number of professional weatherizing companies. For comparison purposes the Cambridge contractor received additional funds from the Ministry to cover the higher costs of this technique on five houses.

The statistical analysis of ELA data provides argument for the use of foam sealants as a way to achieve greater reductions in leakage area. When 14 houses from each town are compared, the differences between communities are greater than the variation of tests within each community (at the 95% confidence level). But when the 14 houses from Cambridge are removed from the sample, the relationship no longer holds true. Consequently the Cambridge data introduces a significant variation.

3.7 INDOOR ENVIRONMENTS

3.7.1 COMFORT

The first telephone survey with participating households asked a number of questions regarding benefits of air sealing. Thirty-six of the 37 houseowners questioned claimed they would recommend a professional caulking and weatherstripping job to neighbours, a very positive response. At this time the impact on energy bills was not well known by houseowners, and the primary factor appears to be improvements in comfort. Thirty-four houseowners (92 percent) had noted that the house was definitely less drafty; two of the three remaining houses had not noticed drafts before weatherizing. More than half the respondents claimed a significant improvement in the comfort of their homes, and another third indicated at least a small improvement. Half the respondents had lowered the thermostat settings at night. There was no noticeable change in the humidity levels in half the houses but another 35 percent indicated a benefit from increased humidity levels indoors.

Seventy percent of the respondents now considered comfort improvement to be as important as cost savings, and the remainder were evenly divided on whether comfort was more important or less important a factor.

* The ELA values and percentage reductions differ slightly from values in the rest of the report because raw data was used in the regression analysis.

The second telephone survey, conducted the following winter, focused specifically on tighter houses with potential moisture problems and involved only 24 houseowners. Consequently the results may be less indicative of the overall sample. Nevertheless the responses closely matched the earlier survey. Twenty of the 24 houseowners reported that the house seemed less drafty. Ten of the respondents had been able to turn down indoor thermostats (1.5°C on average). Eleven houseowners found that humidity levels had increased after weatherizing, and in five of these cases the higher humidity levels added to comfort in the home.

In general the weatherizing work appears to have produced major improvements in overall comfort levels in the houses, by means of reduced drafts, increased humidity, and more even heat distribution.

3.7.2 CHANGES IN RELATIVE INDOOR HUMIDITY LEVELS

On a number of occasions before and after weatherizing the sample houses were inspected and occupants queried to assess relative indoor humidity levels and identify moisture problems. The initial on-site interview with the houseowner addressed indicators of indoor humidity such as dryness, static electricity, window fogging, dripping and condensation on cold surfaces, staining, mildew and mould growth. In addition, the moisture sources within each house were catalogued, and the operation of ventilation equipment was described.

The first telephone survey following weatherization (spring 1982), questioned houseowners about noticeable changes in humidity levels. The survey results indicated that a couple of houses had experienced an excessive amount of indoor humidity, ostensibly as a result of weatherizing, and this prompted a second, more detailed telephone survey (November, 1982).

The second survey was confined to 24 houses that were exceptionally tight or had previously experienced a high level of indoor humidity. The survey addressed the existence and severity of possible moisture problems, and repeated questions about sources of humidity and the use of ventilation systems.

The second survey revealed two houses with serious problems, and three houses with moderate problems.

Although the survey information was felt to be reliable, more indepth information was required. Consequently, a comprehensive on-site inspection was conducted in the spring of 1983. A detailed ON-SITE MOISTURE INSPECTION CHECKLIST was prepared for this purpose.

Indoor humidity levels were measured, and indications of moisture problems were ranked on a room-by-room basis. The on-site surveys revealed four houses of the 65 that were experiencing extreme moisture problems.

The humidity data from initial interviews, telephone surveys, and on-site inspections has been summarized for each house in Table 3.15. The information on moisture inputs and exhaust ventilation such as clothes drying, humidification, and use of fans refers to the situation in the house prior to weatherizing and has been phrased so that YES (Y) responses indicate high moisture inputs and little exhaust ventilation. YES responses have been totalled and provide a rough measure of moisture sources in each house.

Table 3.15 also rates the incidence of moisture problems, both before and after weatherizing. Two kinds of problems are examined, condensation or mould growth on wall and ceiling surfaces; and condensation or mould growth on the window surfaces. Information on final leakage area (CGSB Test 6), reductions in leakage areas, and house volumes is also listed to assist in explaining the incident of moisture problems.

More than 60% of the householders had employed some degree of mechanical humidification prior to weatherizing. This would suggest that most conventional Ontario housing is too leaky to maintain adequate humidity levels, and that the extra cost and effort to purchase, operate and maintain humidifiers is the standard solution to avoid problems of low humidity (such as dry skin, static electricity, respiratory problems, and evaporative cooling).

Following the weatherizing, the use of humidifiers was greatly reduced, especially in the tighter houses. (The second survey indicated that of the 15 houses employing humidifiers, 14 had shut off the system).

The use or disuse of automatic humidifiers tend to obscure the real impact of weatherizing on humidity levels, since the levels of moisture input before and after weatherizing can be highly variable. Survey One indicated that 57% of respondents perceived no noticeable change in humidity levels following weatherizing. The remainder encountered increased humidity levels, and in all but 5% this was a welcome change in terms of occupant comfort. Presumably the increased humidity levels would have been more noticeable without the compensating effects of automatic humidifiers.

In a number of cases, increased humidity levels appear to have provoked or aggravated moisture problems such as dripping, staining and mildew. A brief discussion is warranted, before analysing the problem occurrences.

Higher humidity levels are desirable only to the point at which condensation becomes a problem in a house. For human health, a level of 60% is close to ideal, and levels below 25% can create uncomfortable dryness for some persons. For Ontario houses it is usually necessary to keep levels below 35% to avoid surface condensation on double glazed windows during cold weather. In the coldest weather some amount of condensation is inevitable if indoor humidity is not to be too dry for comfort. Condensation will always be heavier at specific times and locations.

in bathrooms and kitchens were moisture is produced,

behind curtains or in closed-off rooms,

during the night because of cooler indoor temperatures,

during the fall because the buildings and furnishings are still drying out, and

on ineffective storm windows or next to leaky, uninsulated wall and ceiling cavities because of lower surface temperatures.

Consequently some amount of condensation in houses is acceptable and to be expected.

The second telephone survey confirmed the expected condensation patterns in the group of 24 tighter houses. Acceptable levels of condensation were occurring in most houses, with only six houseowners noticing evidence of any moisture build-up (mildew, staining, mould).

Eighteen of the 24 houseowners reported some degree of fogging on their windows; 7 reported condensation on all windows and 11 on some windows only. Ten of the houseowners reported interior surface condensation only; three reported fogging between panes only; and three reported fogging in both locations. Two were unsure where it occurs.

Light fogging was the most common problem mentioned (10); 6 houseowners said they have to mop up on occasion; and two reported mildew or paint peeling. Five people stated that the condensation occurs throughout the heating season; 6 report problems during cold spells only; 5 during the fall only; and two were unsure when it occurs.

Five houseowners said that condensation was a new condition but none of them described it as severe. Of the homes showing a history of previous window condensation, 7 are oil heated; 4 gas heated; and 6 electrically heated. Four people felt that the tightening work had increased their previous condensation problems.

Further information on occurrence of moisture problems is provided by the comprehensive on-site investigation of moisture problems completed in all 65 houses. Moisture problems identified in these inspections have been categorized in Table 3.15 using the following ratings:

INSIGNFICANT (0) = light fogging or condensation on coldest days;

SLIGHT (1) = regular condensation;

MAJOR (2) = dripping, heavy condensation (mopping up), or mould and mildew growth.

Prior to weatherizing, 47% of the houses had SLIGHT window problems; only 6% had SLIGHT problems on walls and ceilings. MAJOR problems on windows were identified in 12% of the sample, and on walls and ceilings in 17% of the housing.

It is clear that moisture problems are common on windows even in the pre-weatherized houses where humidity levels are mostly average or below normal. This is because many of these initial windows problems were actually a function of leaky interior windows that permitted humid indoor air to escape and condense between the window panes. "Inter-pane" moisture problems are a common occurrence in houses with leaky windows (which includes most of the housing sample) and will occur regardless of the relative indoor humidity levels.

No significant changes occurred in the overall number of moisture problems before and after weatherizing. However there was a definite change in the type of moisture problem; in 16 houses the window moisture problems were eliminated, presumably because the caulking and weatherstripping restricted air exfiltration between window panes. In a similar number of houses problems were encountered from condensation on the innermost panes due to increased humidity levels. In the telephone survey some houseowners remarked that their window moisture problem had moved from between the panes to the indoor surfaces!

The on-site moisture inspections identified fourteen houses as having MAJOR moisture problems on indoor window, wall or ceiling surfaces. A number of correlations exist for these 14 problem houses:

Thirteen had SLIGHT or MAJOR moisture problems prior to weatherizing. This suggests that weatherizing is more likely to aggravate existing moisture problems, than turn a dry house into a wet one.

Ten of the 14 houses had a high number of moisture sources indoors (more than 5 YES responses in Table 3.14). The amount of moisture input (or the source strength) is thus a key factor.

Nine of the problem houses were among the 24 tight houses in the sample (i.e. SLA 5cm2). Tighter houses also appear to experience more moisture problems.

TABLE 3.15 MOISTURE PROBLEM OCCURRENCES AND RELATED VARIABLES

HOUSE NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13

INCIDENCE OF MOISTURE PROBLEMS*

WALL OR CEILING													
BEFORE	0	0	0	0	0	0	0	0	0	0	2	0	2
AFTER	0	0	0	0	0	0	0	0	0	0	2	0	1
WINDOW SURFACES													
BEFORE	0	1	0	0	0	1	0	0	1	0	2	1	2
AFTER	0	0	0	0	0	0	0	0	1	0	2	2	2

BUILDING CHARACTERISTICS

ELA_{10} (CGSB)	1298	995	927	1286	1151	415	986	NA	1284	800	335	825	493
% REDUCTION (TEST 1 TO TEST 5)	44	36	40	36	22	30	31	NA	34	32	38	27	31
VOLUME (m^3)	341	322	237	480	521	446	182	374	523	529	463	422	585

MOISTURE INPUTS

NO. OF OCCUPANTS	2	1	2	2	1	2	2	1	3	4	2	4	4
INDOOR HUMIDIFICATION	Y	Y	N		Y	N	Y	Y	N	Y	N	Y	N
FAN USE INFREQUENT OR NEVER	-	-	-		-	Y	Y	Y	Y	Y	N	Y	N
PLANTS (>5)	Y	N	N		N	N	N	N	N	N	Y	Y	Y
INDOOR CLOTHES DRYING	Y	N	N		Y	N	N	Y	N	N	N	N	N
REGULAR SHOWERS (ONE OR MORE/DAY)	Y	Y	Y		N	Y	N	N	Y	Y	N	Y	Y
DAMP BASEMENT	N	N	N		N	N	N	N	N	N	N	N	N
FIRE PLACE USED REGULARLY OR DAMPERS LEFT OPEN	Y	Y	-		Y	-	Y	N	Y	N	-	N	N
NO MAKE-UP AIR SUPPLY	Y	Y	Y		Y	N	Y	N	Y	N	N	-	Y
ELECTRICAL HEATING	N	N	N	N	N	N	N	N	N	N	N	Y	Y
DAY TIME OCCUPANTS	2	2	2		1	2	2	1	1	0	1	1	1
MOISTURE INPUT INDICES	6	4	2	-	4	2	4	3	4	3	1	5	4

*INCIDENCE OF MOISTURE PROBLEMS (0-NONE; 1-SLIGHT; 2=MAJOR)

TABLE 3.15 MOISTURE PROBLEM OCCURRENCES AND RELATED VARIABLES (Continued)

HOUSE NUMBER	14	15	16	17	18	19	20	21	22	23	24	25	26
INCIDENCE OF MOISTURE PROBLEMS*													
WALL OR CEILING													
BEFORE	0	0	0	2	1	0	0	0	0	0	2	0	1
AFTER	2	0	0	0	0	0	0	1	0	0	0	0	0
WINDOW SURFACES													
BEFORE	0	1	1	2	1	1	1	1	1	2	1	0	1
AFTER	0	0	0	2	1	0	2	2	2	1	1	0	0
BUILDING CHARACTERISTICS													
ELA_{10} (CGSB)	556	1474	2550	2664	2959	2981	2129	1471	1645	2304	1328	1957	NA
% REDUCTION (TEST 1 TO TEST 5)	18	16	17	14	17	19	30	23	38	31	38	28	NA
VOLUME (m^3)	412	498	309	305	529	396	457	373	394	389	284	470	366
MOISTURE INPUTS													
NO. OF OCCUPANTS	3	2	2	4	4	2	3	2	5-8	4	1	2	4
INDOOR HUMIDIFICATION	Y	Y	Y	N	Y		Y	Y	Y	N	Y	N	Y
FAN USE INFREQUENT OR NEVER	Y	-	-	-	-	-	Y	-	Y	N	-	-	Y
PLANTS (>5)	N	N	N	Y	Y		Y	Y	Y	N	N	N	N
INDOOR CLOTHS DRYING	N	Y	N	N	Y		Y	N	N	Y	Y	Y	N
REGULAR SHOWERS (ONE OR MORE/DAY)	Y	N	N	Y	Y		Y	Y	Y	Y	Y	Y	Y
DAMP BASEMENT	N	N	Y	N	Y		N	N	Y	N	N	Y	N
FIRE PLACE USED REGULARLY OR DAMPERS LEFT OPEN	Y	N	-	Y	N		N	Y	Y	N	Y	N	Y
NO MAKE-UP AIR SUPPLY	N	Y	Y	Y	Y		Y	Y	Y	Y	Y	Y	N
ELECTRICAL HEATING	N	N	N	N	N	N	N	N	N	Y	N	N	N
DAY TIME OCCUPANTS	3	1	2	1	3		1	0	1	1	1	2	0
MOISTURE INPUT INDICY	4	3	3	4	6		6	5	7	4	5	4	4

*INCIDENCE OF MOISTURE PROBLEMS (0-NONE; 1-SLIGHT; 2=MAJOR)

TABLE 3.15 MOISTURE PROBLEM OCCURRENCES AND RELATED VARIABLES (Continued)

HOUSE NUMBER	27	28	29	30	31	32	33	34	35	36	37	38	39
INCIDENCE OF MOISTURE PROBLEMS*													
WALL OR CEILING													
BEFORE	0	0	2	0	0	2	2	0	0	0	2	2	0
AFTER	0	0	0	0	0	2	0	0	0	0	2	0	0
WINDOW SURFACES													
BEFORE	1	1	2	1	1	1	2	0	1	2	2	1	1
AFTER	0	0	0	0	0	2	1	1	0	0	2	0	0
BUILDING CHARACTERISTICS													
ELA_{10} (CGSB)	1678	2069	2678	768	503	1531	420	2019	744	1927	232	487	880
% REDUCTION (TEST 1 TO TEST 5)	21	33	31	45	46	28	73	25	40	19	62	50	41
VOLUME (m^3)	425	290	447	384	280	502	420	675	360	595	455	462	224
MOISTURE INPUTS													
NO. OF OCCUPANTS	2	2	2	2	2	4	1	6	1	2	3	4	1
INDOOR HUMIDIFICATION	Y	N	Y	Y	N	Y	N	N	Y	N	N	Y	Y
FAN USE INFREQUENT OR NEVER	-	-	-	N	-	N	Y	Y	-	Y	Y	N	-
PLANTS (>5)	N	N	Y	Y	Y	Y	N	N	N	N	Y	-	Y
INDOOR CLOTHES DRYING	Y	Y	N	N	N	Y	Y	N	N	Y	N	N	Y
REGULAR SHOWERS (ONE OR MORE/DAY)	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
DAMP BASEMENT	Y	N	N	N	N	N	N	N	N	0	Y	N	Y
FIRE PLACE USED REGULARLY OR DAMPERS LEFT OPEN	Y	Y	N	N	N	-	N	-	N	-	-	-	-
NO MAKE-UP AIR SUPPLY	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
ELECTRICAL HEATING	N	Y	N	N	N	N	Y	N	N	N	Y	Y	N
DAY TIME OCCUPANTS	1	2	1	2	2	2	0	1	1	2	2	3	0
MOISTURE INPUT INDICY	6	4	4	4	2	5	5	3	3	4	6	4	5

*INCIDENCE OF MOISTURE PROBLEMS (0-NONE; 1-SLIGHT; 2=MAJOR)

TABLE 3.15 MOISTURE PROBLEM OCCURRENCES AND RELATED VARIABLES (Continued)

HOUSE NUMBER	40	41	42	43	44	45	46	47	48	49	50	51	52
INCIDENCE OF MOISTURE PROBLEMS*													
WALL OR CEILING													
BEFORE	2	2	0	0	0	0	0	0	0	0	0	0	0
AFTER	0	2	0	0	0	0	2	0	0	0	0	0	0
WINDOW SURFACES													
BEFORE	1	1	0	1	1	1	0	1	0	0	1	1	0
AFTER	0	2	1	0	2	1	1	0	0	1	1	0	1
BUILDING CHARACTERISTICS													
ELA_{10} (CGSB)	1732	585	880	1016	371	759	1029	1486	1804	616	1519	1647	709
% REDUCTION (TEST 1 TO TEST 5)	39	48	39	20	56	56	44	17	37	58	43	30	9
VOLUME (m^3)	440	416	480	411	308	530	460	475	540	440	420	311	319
MOISTURE INPUTS													
NO. OF OCCUPANTS	2	5	4	2	1	2	4	2	3	4	2		
INDOOR HUMIDIFICATION	N	N	Y	Y	N	Y	N	Y	N	N	Y	N	Y
FAN USE INFREQUENT OR NEVER	Y	Y	N	-	-	Y	Y	Y	-	-	-	Y	Y
PLANTS (>5)	Y	Y	Y	N	N	Y	Y	Y	N	Y	Y	N	Y
INDOOR CLOTHES DRYING	N	-	N	Y	N	N	N	N	N	N	N	Y	N
REGULAR SHOWERS (ONE OR MORE/DAY)	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N
DAMP BASEMENT	N	N	N	N	Y	N	N	N	N	N	N	Y	N
FIRE PLACE USED REGULARLY OR DAMPERS LEFT OPEN	-	-	-	-	-	-	-	N	-	-	-	Y	Y
NO MAKE-UP AIR SUPPLY	Y	Y	N	N	Y	Y	Y	Y	Y	Y	N	Y	Y
ELECTRICAL HEATING	N	Y	N	N	N	Y	Y	N	N	N	N	N	N
DAY TIME OCCUPANTS	2	1.5	0	2	1	0	0	2	2.5	1	2	2	2
MOISTURE INPUT INDICY	4	5	3	2	2	6	5	5	2	3	3	6	5

*INCIDENCE OF MOISTURE PROBLEMS (0-NONE; 1-SLIGHT; 2=MAJOR)

TABLE 3.15 MOISTURE PROBLEM OCCURRENCES AND RELATED VARIABLES (Continued)

HOUSE NUMBER	53	54	55	56	57	58	59	60	61	62	63	64	65
INCIDENCE OF MOISTURE PROBLEMS*													
WALL OR CEILING													
BEFORE	0	0	0	0	0	0	0	1	0	0	1	0	0
AFTER	0	0	0	0	0	0	0	1	0	0	1	0	0
WINDOW SURFACES													
BEFORE	0	0	0	0	0	0	0	1	0	1	0	0	0
AFTER	1	0	1	0	0	0	0	2	0	1	1	0	2
BUILDING CHARACTERISTICS													
ELA_{10} (CGSB)	1565	1710	1666	2479	1653	1038	1450	561	1980	1911	1619	1459	271
% REDUCTION (TEST 1 TO TEST 5)	36	42	29	69	35	47	36	21	26	51	25	42	35
VOLUME (m^3)	463	483	378	290	232	456	301	447	459	635	380	634	330
MOISTURE INPUTS													
NO. OF OCCUPANTS													
INDOOR HUMIDIFICATION	Y	-	Y	N	Y	Y	Y	Y	Y	Y	Y	N	N
FAN USE INFREQUENT OR NEVER.	Y	N	Y	Y	-	Y	Y	Y	Y	Y	-	Y	Y
PLANTS (>5)	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
INDOOR CLOTHES DRYING	-	N	Y	N	Y	N	Y	N	N	Y	N	N	N
REGULAR SHOWERS (ONE OR MORE/DAY)	Y	Y	Y	Y	N	Y	N	Y	Y	Y	Y	Y	Y
DAMP BASEMENT	N	N	N	N	N	N	N	N	Y	N	N	N	N
FIRE PLACE USED REGULARLY OR DAMPERS LEFT OPEN	-	Y	N	N	Y	N	Y	Y	N	N	Y	N	Y
NO MAKE-UP AIR SUPPLY	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	-
ELECTRICAL HEATING	N	N	N	N	N	N	N	N	N	N	N	Y	Y
DAY TIME OCCUPANTS	0	1	-	4	1	0	0	1	0	2	1	-	0
MOISTURE INPUT INDICY	5	4	6	3	5	5	6	6	6	6	4	5	5

*INCIDENCE OF MOISTURE PROBLEMS (0-NONE; 1-SLIGHT; 2=MAJOR)

Six of the problem houses were among the 12 electrically heated houses in the sample, which suggests that electrically heated houses are especially prone to serious moisture problems.

Only five of the problem houses were among 26 houses in the sample with above average reductions in leakage area (>36%). This percentage reduction is not a significant factor; four of these five houses were also among the "tight" houses.

It is clear from an analysis of "MAJOR" moisture problems in the Weatherize Houses, that a few simple guidelines could have greatly alleviated the occurrence of moisture problems. These lessons may have relevance to contractors and houseowners involved in weatherization work.

Houses already experiencing indoor moisture problems should have had these problems diagnosed and remedied prior to or in combination with weatherizing.

Humidifiers should be disconnected when houses are weatherized, and houseowners carefully instructed in methods of reducing moisture inputs in cold weather or increasing the use of ventilation systems. Ideally an audit of moisture sources should be completed prior to weatherizing, and for houses that score high the audit should be used to develop specific guidelines for reducing moisture inputs or specifying ventilation controls.

Electrically heated houses should have a bathroom or exhaust fan installed (if not already present) with a humidistatic control to operate the fan in cold weather after weatherizing.

Tighter houses where the "SEALED" pre-retrofit ELA is less than 1000cm2, should not be weatherized unless the intention is to install a controlled ventilation system.

3.8 SPACE HEATING ENERGY REQUIREMENTS

3.8.1 EXPECTED CHANGES IN FUEL CONSUMPTION RATES

Weatherizing houses has been promoted as a cost-effective measure for reducing energy costs in housing. Much of the conventional wisdom is based on what can be accomplished by weatherizing in a conventional house, and on theoretical calculations of fuel reductions. The Weatherize Project offered an opportunity to undertake a specific program of comprehensive air sealing in a broadly representative housing sample, and to monitor subsequent changes in fuel consumption.

In theory, the reductions in leakage areas in the houses should have a roughly proportional impact on the natural infiltration rates. In most mathematical models for estimating natural seasonal air change rates, the single most important factor is the size of the leakage area. In the Weatherize houses, most other factors remain constant, except for possible changes in weather patterns and changes in the relative distribution of leaks over the building envelope.

The distribution of leaks is a factor that definitely varies in the case of the Weatherize Project, because contractors did not make similar reductions in ELA during each stage of weatherizing. The reductions in openings and cracks were much greater than reductions in basement and attic leaks. The "imbalance" would tend to have a greater impact on reducing wind induced infiltration, and a lesser impact on the more predominant stack forces which are concentrated at the top and bottom of the house.

The actual percentage of heat loss attributable to infiltration in a house will vary both with the rate of air change and with the thermal resistance of the building envelope. As the insulation levels increase, for example, the total fuel requirements are reduced but the proportion attributed to air infiltration increases. Consequently, in well insulated houses the impact of weatherizing should be greater, in percentage terms, than in the older and less-insulated housing stock. Variations in average thermal resistance of 200 percent are not uncommon, and can generate variations in air change heat loss percentages of up to 50 percent.

Tracer gas tests on some of the Weatherize houses, and on other conventionally-built Canadian houses, would suggest that natural average seasonal air change rates are in the range of 0.4 to 0.7 air changes per hour. With typical variations in the building thermal resistance, it is expected that air infiltration would account for a proportion of heating costs ranging from 20 to 45 percent. Thus with an average reduction in ELA values of 36 percent, the theoretical decrease in space heating fuel consumption should be in the order of 7 to 16 percent.

The expected decrease could be somewhat below these figures since a portion of the air change may be independent of leakage area. The operation of doors, windows, exhaust fans and heating appliances can account for 15% of air leakage, and the effect of air sealing would more likely produce a decrease in fuel consumption in the range of 6 to 13%.

3.8.2 ACTUAL CHANGES IN FUEL CONSUMPTION RATES

An examination of fuel records was undertaken on all 65 houses. Records were obtained for a period of one complete year prior to weatherizing, and compared to another complete year following weatherizing. The intention was to obtain a general indication of the impact of weatherizing on energy requirements for space heating.

It was assumed that many of the critical factors influencing natural infiltration rates and overall heat loads would remain relatively constant from one year to the next. These include factors such as average wind speeds, solar exposure, occupancy, operation of applicances, indoor temperatures and the building characteristics in general. A survey of the householders was conducted, both before and after weatherizing, to ensure that no major changes were made that might affect these key variables.

To adjust for changes in the length of the heating periods, and for changes in the average outdoor temperatures, the fuel consumption was expressed as a ratio of total degree days. These ratios of consumption per degree day, before and after weatherizing, were compared and any changes have been expressed in percentage terms.

Wherever possible, the records were used for the entire heating season so as to include the "shoulder" months (spring and fall heating). In cases where the entire season was not recorded, the time periods were reduced similarly to avoid any biases from the often erratic heating patterns in the shoulder months.

Local weather office degree days (18°C base) were totalled for each fuel consumption period. No attempt was made to adjust these figures for variations in indoor temperature, heat load, internal gains and solar gains.

Fuel consumption in oil heated homes was used for space heating only and this made for easy data analysis. In the gas and electrically heated houses, it was necessary to first subtract any summer consumption to eliminate additional input from hot water heaters and other appliances. The hot water and appliance consumption figures were not extracted for winter heating periods, for reasons of practicality. (In theory, the inclusion of this extra fuel consumption will tend to slightly underestimate any percentage reduction or increase in space heating requirements.)

Table 3.16 presents a summary of changes in fuel consumption per degree day for all but six houses in the sample. The six houses were eliminated due to incomplete records. Table 3.16 also presents changes for houses grouped on the basis of heating system and community. The changes are averaged and totalled separately depending on whether a house showed an overall increase or decrease in consumption rates.

Thirty-nine houses (or sixty-six percent of the sample) decreased fuel consumption the winter following weatherizing. The average decrease was 10.8 percent. Another twenty houses, however, increased their fuel consumption rates following weatherizing, by an average of 6.9 percent. When all houses are considered together, the result is an average net decrease in fuel consumption of .4.8 percent.

Although data indicates a definite trend towards decreased fuel consumption following weatherization, there are a surprising number of houses where fuel consumption rates actually showed considerable increases. These inconsistencies cast suspicion on the analytical technique. Some of the inherent difficulties of measuring energy savings are mentioned in the following discussion, along with the specific problems encountered in the Weatherize Project.

The most consistent decreases in fuel consumption are apparent in the Ottawa houses and in the oil heated houses. These two categories overlap, since Ottawa has 11 oil heated houses, much higher than average. Cambridge housing also shows a significant decrease in fuel consumption, although only 4 of the 20 Cambridge houses are oil heated. The higher reductions in Cambridge fuel consumption rate may be related to the higher ELA reductions.

Changes in fuel consumption for each house are graphically presented in Figures 3.12 to 3.15. The houses are listed numerically and hence grouped by community. The line graphs provide, at a glance, an indication of the range and deviations in fuel reductions. Houses 35, 56, 60 and 65 all achieved reductions greater than 25 percent. The highest increase is 29 percent while the highest decrease is 53%. The deviations for specific houses show little bearing to size of reduction in ELA and SLA values. It is difficult to draw any firm conclusion from the data.

Figure 3.16 presents changes in fuel consumption for oil heated houses and shows much greater consistency in the size and direction of the change. There is still little agreement between the ELA reductions and the fuel reductions, but such a relationship would be strongly influenced by variations in the building characteristics and heating load. There would appear to be special problems associated with trying to measure space heating energy savings in gas or electrically heated houses since the data for these houses is so inconsistent and contradictory.

The manipulation of gas and electric data to extract the space heating components may be responsible for some of the discrepancies. The gas heating records required further modifications to avoid confusing estimates with actual meter readings, since the gas company has a policy of alternately substituting projected for actual consumption. Moreover the weatherizing work took place in winter time, often between readings or fuel fill-ups or take additional meter readings at the start and finish of weatherizing.

Because of the need to modify the records obtained from houseowners, only half of the total housing sample had a complete record of consumption for a full year on both sides of weatherizing. The incomplete data may have further biased the results.

TABLE 3.16

CHANGES IN YEARLY FUEL CONSUMPTION PER DEGREE-DAY RATIOS BEFORE AND AFTER WEATHERIZING

HOUSING SAMPLE	UNITS IN SAMPLE	CONSUMPTION DECREASED		CONSUMPTION INCREASED		NET CHANGE (%)
		HOUSING UNITS	AVERAGE CHANGE (%)	HOUSING UNITS	AVERAGE CHANGE (%)	
ALL HOUSES WITH COMPLETE RECORDS	59	39	-10.8	20	6.9	-4.8
OIL HEATED	24	17	-14.2	7	5.9	-8.4
GAS HEATED	25	16	-6.5	9	5.2	-2.3
ELECTRIC HEATED	10	6	-12.6	4	12.4	-2.6
SAULT STE. MARIE (HOUSES 1-15)	15	7	-9.7	8	7.7	-0.4
PETERBOROUGH (HOUSES 16-30)	11	6	-4.9	5	7.6	+0.8
CAMBRIDGE (HOUSES 31-50)	20	14	-10.7	6	5.5	-5.8
OTTAWA (HOUSES 51-65)	13	12	-14.5	1	5.0	-13.0

Figure 3.12 : Sault Ste. Marie

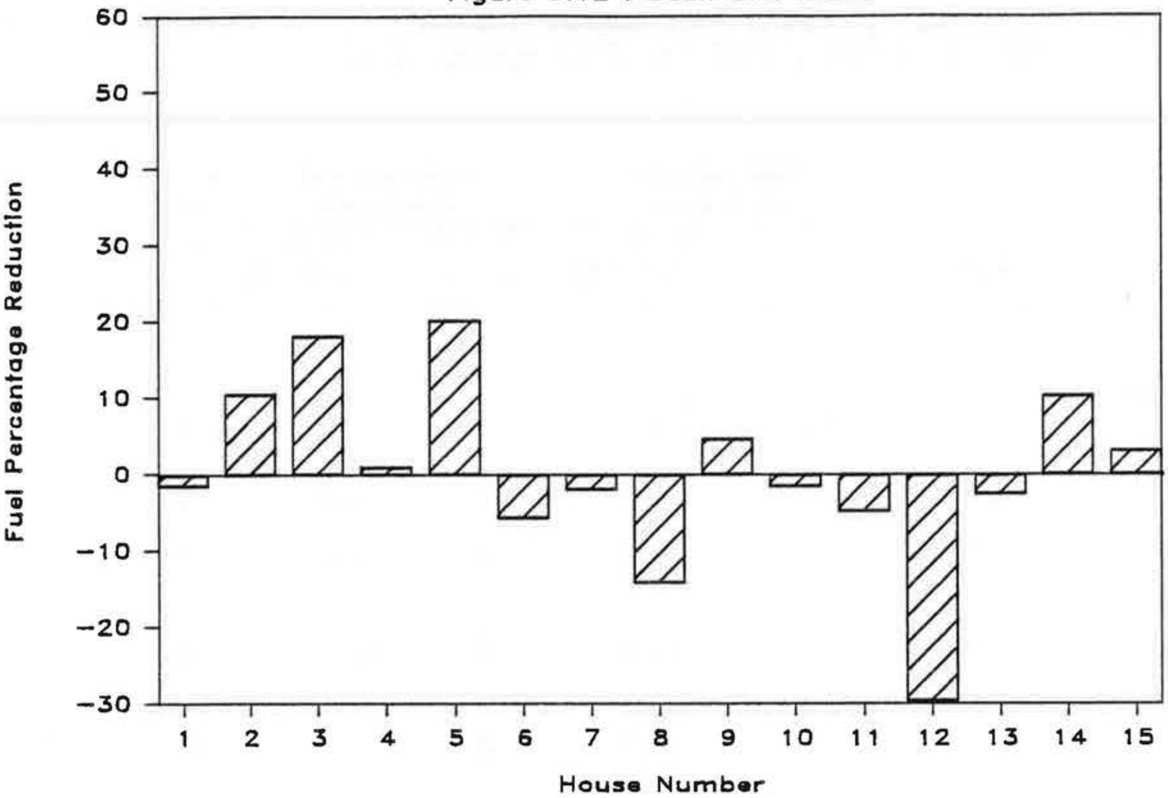


Figure 3.13 : Peterborough

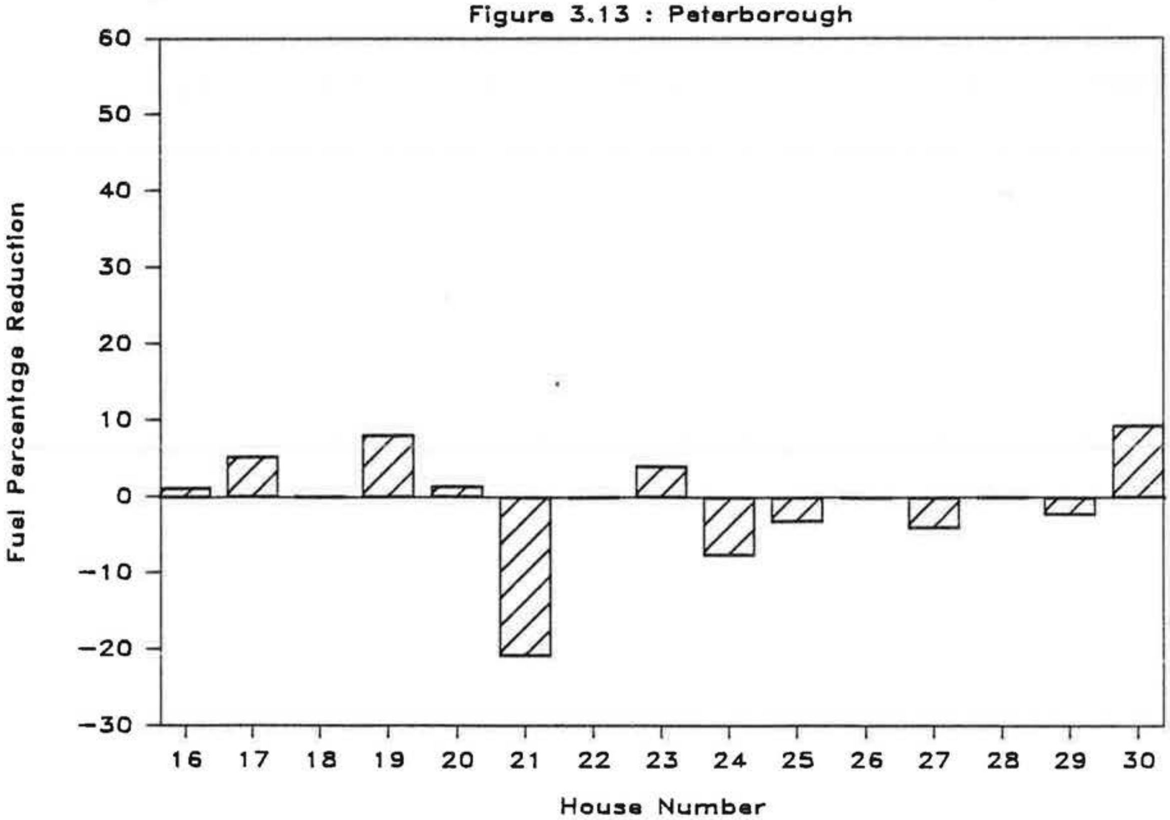


Figure 3.14 : Cambridge

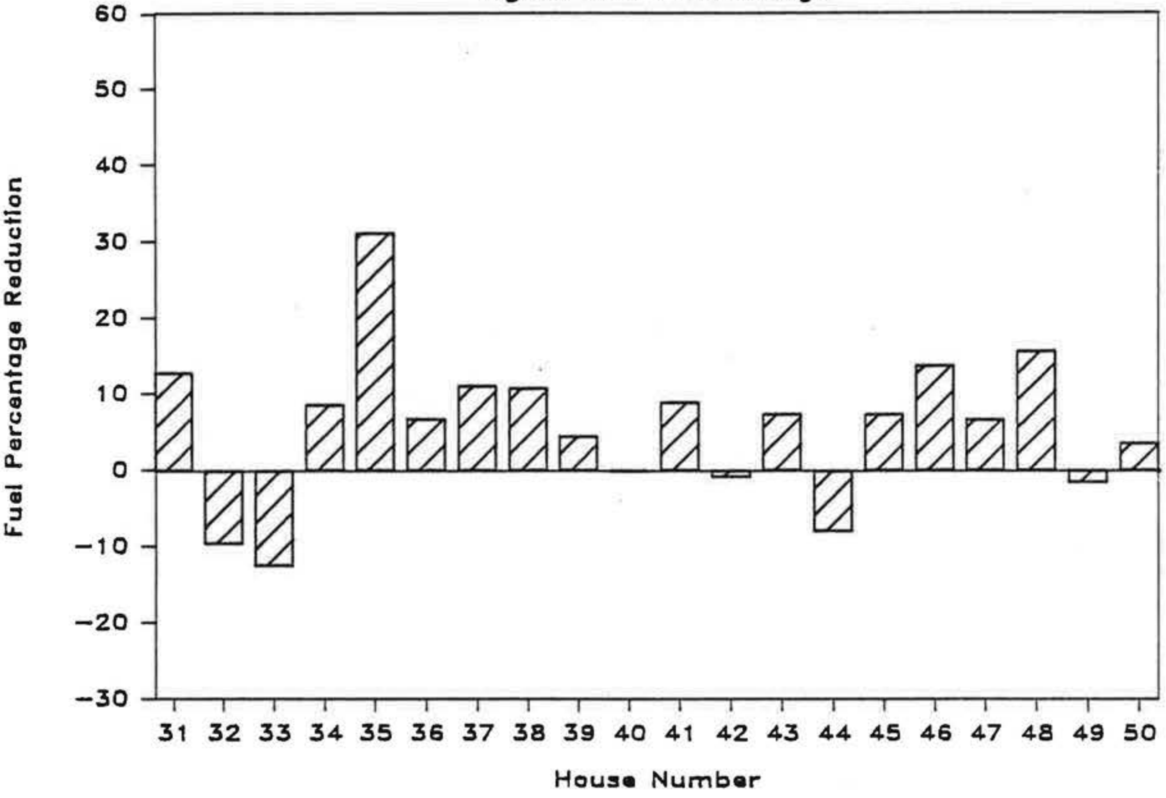
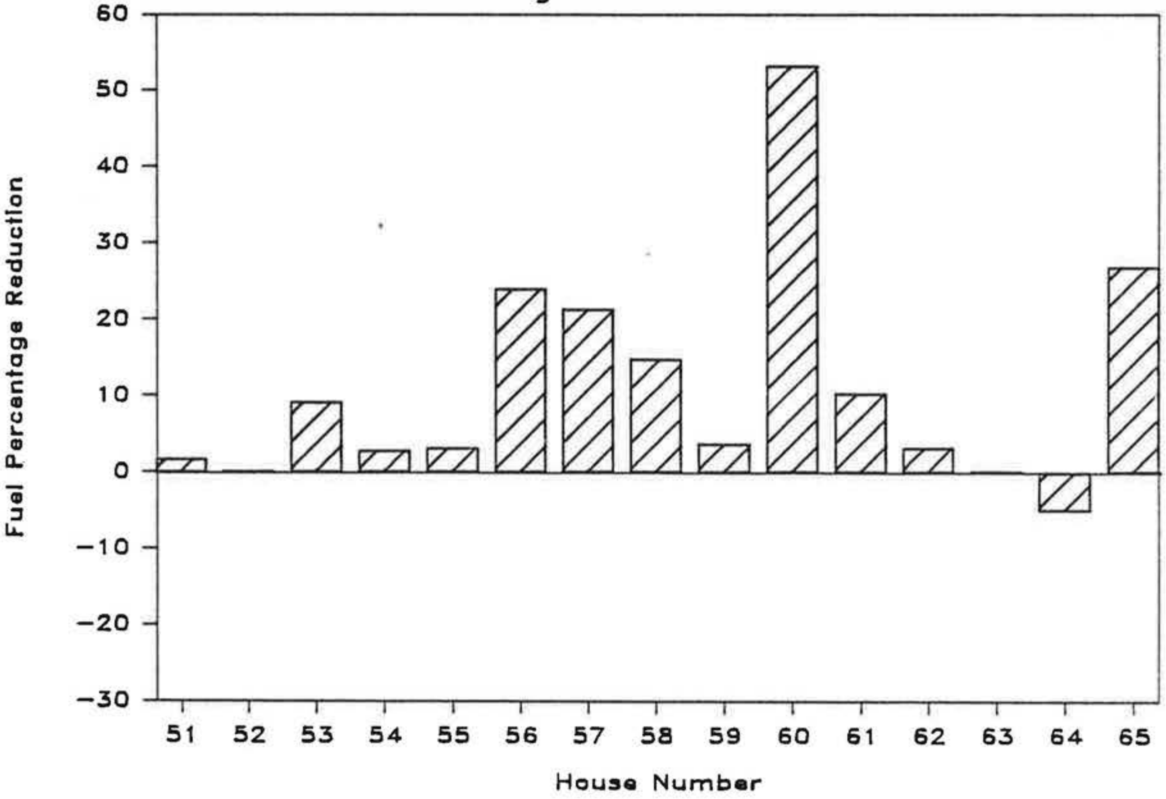


Figure 3.15 : Ottawa



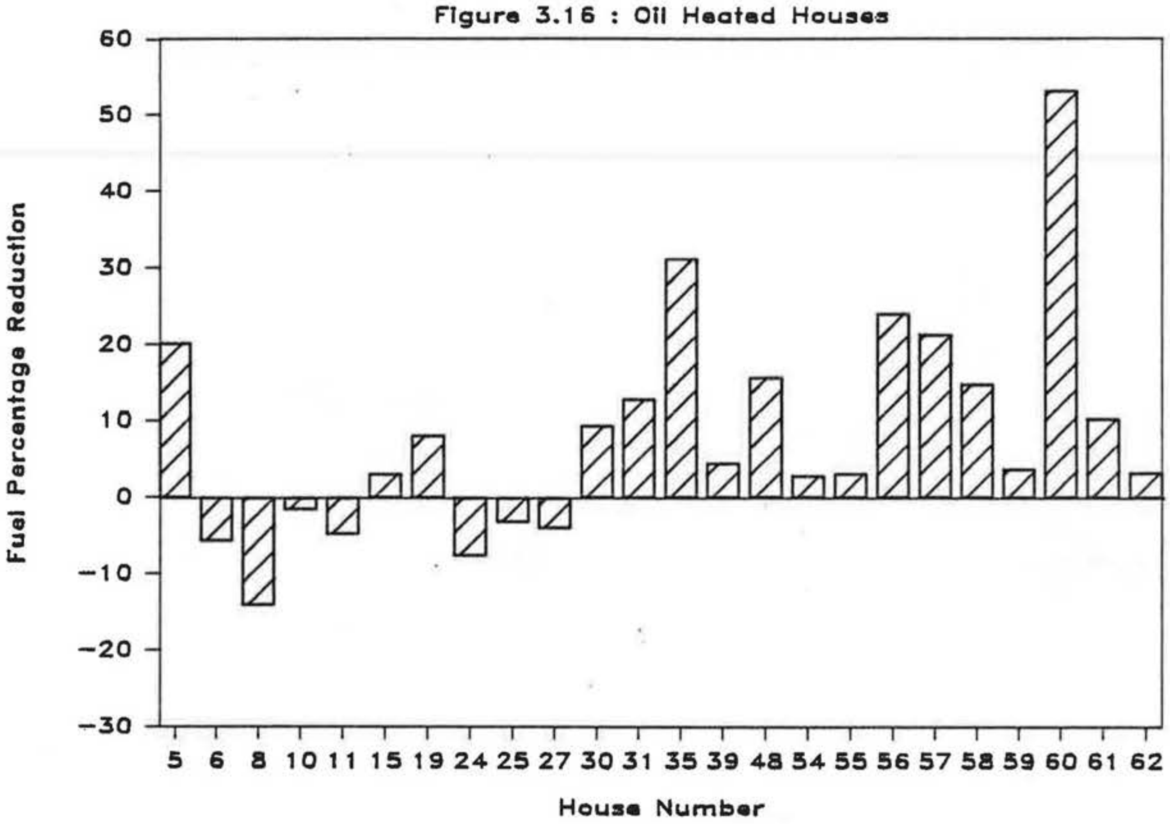


Figure 3.16 : Oil Heated Houses
Fuel Percentage Reduction
60
50
40
30
20
10
0
-10
-20
-30
5 6 8 10 11 15 19 24 25 27 30 31 35 39 48 54 55 56 57 58 59 60 61 62
House Number

A number of other obstacles may have prevented valid measurements of energy savings using fuel records:

- supplementary heating sources such a wood heaters and electric baseboards are difficult to document and monitor;

- fuel oil deliveries do not always "top-up" the tank;

- changes in holidays, number of residents, appliance use, indoor temperatures and heated space may significantly alter heat requirements;

- the houseowners may have become more energy conscious the year following retrofit when their performance was being monitored;

- furnace servicing, downsizing, night-time temperature setbacks and other minor retrofits are difficult to avoid;

- the variations in average temperatures and wind speeds over a two year cycle can be quite high. The use of degree day ratios as a correction factor is not always sufficient since large temperature fluctuations on a day by day basis can result in a large number of degree days. The house is not likely to require proportionately more heat since the thermal inertia (or flywheel effect) will dampen the temperature swings, especially in the warmer weather when excess heat is often stored in the building mass.

- the quantities of free heat from sunshine and indoor activities can be altered significantly. South facing walls and windows can become sources of heat on sunny days. If one winter is sunny and the next is relatively cloudy the heating requirements can vary drastically, more so for houses with good southern exposure.

For all of the reasons listed above, and in light of the difficulties encountered with the Weatherize date, it is not recommended to measure savings from yearly fuel bills unless the sample of houses is extremely large and widely distributed. There are so many uncontrolled variable that houses commonly require more heat after energy conservation measures. In other words, no reductions are measured because the degree of potential error within the measurement technique can easily exceed the impact of weatherizing, (or other conservation measures).

In an attempt to explore low cost alternatives to measuring energy savings in the Weatherize houses, the Ottawa contractor was required to measure and compare furnace on-time ratios between the test houses and a number of control houses before and after retrofit. The evaluation of furnace on-time ratios as a means of measuring the impact of weatherizing is the subject of a separate report. Since the technique appears to be a promising alternative, a brief description is provided.

The technique of furnace on-time ratios requires installation of time totalizers, programmable thermostats and clockswitches in houses that are to be studied, and in other, similar houses where no alterations are made. The time totalizers are connected to the 24 hour switches, and are used to record the operating time of the heating system during specific hours of the day for a brief period before and after the implementation of energy conservation work. The thermostats ensure consistent indoor temperature settings. The control houses provide a measure of comparison.

The technique assumes that the ratio of on-time between control and test houses will remain fairly constant since all houses are exposed to similar weather conditions (wind, sun, cold) and since the seasonal efficiencies, thermal mass, solar aperture and occupancy of the houses are within a given range. If the ratio between the test house on-time and the control houses is changed significantly following the retrofit, it can only be due to the impact of that particular energy conservation measure.

This technique would require a period of time before and after weatherizing sufficient to smooth out daily variations and cut out holidays and weekends; eight days is probably sufficient. A reasonable measure of energy savings is thus obtained in a very brief time period, with no corrections required for variables such as weather or house operation.

3.9 THERMOGRAPHIC EVALUATION

A thermographic evaluation was completed on one-third of the Ottawa homes in an attempt to understand why the reductions in leakage areas were so variable from house to house. The results of this investigation have been detailed in a separate study and only a brief summary is presented here.

An interior scan and photographic report was completed on all building components using an AGA 750 Thermovision camera. The houses were depressurized or pressurized to emphasize the thermal expressions.

Windows were generally seen to be effectively sealed, as well as ceiling fixtures, baseboards, and trim work. Electrical gaskets were only partially effective, and outlets continued to leak badly around the receptacles.

Door thresholds showed significant leakage after weatherstripping in all cases; additional sealant underneath the threshold strips might have helped. Some door frames continued to leak around badly warped doors, which suggested a need for greater throw on the adjustable weatherstrip.

Attic hatches were definite failures. Despite a careful insulation and weatherstripping job, leakage was evident in all cases. A more effective method for sealing and clamping the hatches is essential.

Butyl caulking had only limited effectiveness when applied to the edges of electrical panels, plumbing and other penetrations through the foundation wall. Urethane spray foam would have been better adapted to these large and irregular cracks.

In a few cases the contractor had entirely missed leakage sites. For example, the panelling joints along finished basement walls, and cracks on unpainted brickwork continued to show large, diffuse leakage patterns. Sliding pocket doors defied any effective treatment.

In general the weatherizing crew seemed to emphasize windows, doors, fixtures, trim work, and sill plates, to the exclusion of the more complex basement and attic details. Finished basements represented a major impediment to comprehensive air sealing, since considerable leakage was apparent behind the drywall. Similarly, a network of leakage paths would be commonly seen stretching down into particular walls from the attic spaces, and confirmed the need for more comprehensive attic work. In many cases weatherizers were obviously reluctant to cut access holes or work in the cramped attic spaces, and may have failed to recognize the value of such work.

The thermographic scanner did not appear to be an essential tool for a weatherizing crew, since few leaks were apparent that would not be discovered by a knowledgeable person with a three dollar smoke pencil and a little more time. In fact the smoke pencil proved essential around cold windows or shiny bathroom walls. Even in attics, where the expensive thermographic equipment might be expected to earn its keep, the information value was negligible. Diffusion of air leaks through knee deep insulation obscured much of the thermal imagery.

4. CONCLUSIONS

The Weatherize Project incorporates a variety of research studies, each focusing on a particular aspect of air sealing work on part or all of a standard 65 house sample. As a consequence, the results touch on a lot of issues, and provide a wide perspective on weatherizing existing housing. Highlights have been extracted from the main body of the report and are presented below.

1. The assessment of leakage area in the houses revealed that the most extreme air leakage sites were varied and rather obscure in nature. It can be concluded that air sealing applications are best carried out after a fairly comprehensive inspection of all building components.

2. Most houses had a discrete selection of leakage sites that commonly exhibited significant air leakage. These high priority sites included outlets and switches (especially on interior walls), windows and doors, attic hatches, light fixtures, plumbing holes and floor mouldings.

3. A number of specific building components were determined to be low priority for existing houses, because, if leaky, they generally contribute only insignificant amounts of air leakage. These sites include bathtubs and shower enclosures, medicine cabinets, heating ducts and pipes, basement wiring and cable penetrations.

4. The older houses tended to leak more often around windows, mouldings and cracked plaster. Sill plates, joist areas and leaks around exhaust ventilation ducts were more noticeable in the newer housing.

5. The initial leakage areas in the diverse housing sample revealed a wide range of ELA and SLA values that were independent of building size and crack length. One-and-a-half storey houses were slightly leakier than one and two storey houses. The most definite relationship was in age brackets and SLA values; houses built after 1945 appear about one-third tighter than pre-war housing, and houses after 1970 appear half again as tight.

6. Contractors using depressurization equipment, to measure reductions in leakage area, experienced difficulties in obtaining sufficient resolution and accuracy with equipment than currently available. Discrepancies in the data suggested the need for improvements in techniques and equipment design, including: the use of pressure averaging taps to modulate wind pressures; the use of identical pressure increments for each consecutive test; a greater number of flow/pressure readings at lower pressure points (except during high wind conditions); the use of fans calibrated using orifice pressures rather than rpm; improved training for technicians, and; the use of computerized fans capable of calculating errors and rejecting poor-fit data on-site.

7. Fan test data was analysed using two separate operations, each using a different mathematical technique for modeling the laminar and turbulent flow components of air leakage into a house.

   There was no significant difference in the air leakage results estimated by the two models. The simpler equation ($Q = C \times P^n$) was used to produce air tightness parameters, so as to remain consistent with the CGSB standard on Airtightness Testing (GP14910M). This equation did result in some difficulties for contractors measuring reductions in leakage area, because minor alterations in the flow exponent (n) could produce major differences in the air tightness parameters. The greatest problem occurs in measuring air change per hour at 50 Pascals. The tightened houses usually exhibited steeper profiles, and this phenomenon would minimize the impact of weatherizing on air tightness ratings. The use of an ELA at 10 Pascals proved to be a better indication of relative tightness in a weatherizing house, although a need was identified for an alternative analysis in cases where major changes occur in the flow exponent value.

8. Air tightness testing by weatherizing contractors included two different house preparations: one test as per the CGSB standard with only the flue plugged and the other with all inlets and vents sealed in addition to flues. The "sealed" test procedure appeared to be more appropriate than the CGSB approach, and resulted in a mean reduction in ELA values of 160cm2, for those houses with components to be "sealed".

9. The mean reduction in leakage areas resulting from air sealing was 36%. For approximately two-thirds of the housing sample, the reductions fell within a range of 20 to 40 percent.

10. Percentage reductions in leakage areas were fairly consistent, regardless of the initial ELA. Generally, the larger the leakage area, the greater the benefit resulting from "comprehensive" weatherizing.

11. The percentage reductions in leakage area decreased slightly with increases in height and/or age of a building.

12. Air sealing of windows, doors, and other openings achieved a reduction, on average, that was equivalent to air sealing of trim work and other cracks in the living areas of the houses. Together, these components comprised three-quarters of the total average reduction from air sealing.

13. Air sealing of foundations accounted for less than one-fifth of the total average reduction. Foundation leaks comprised a smaller, and more discrete area than leaks in the living areas, and were often more difficult to access.

14. Air sealing in attic spaces produced insignificant reductions on average, but the impact was very unpredictable. Limited accessibility to leakage sites was the primary reason why contractors had difficulty sealing attics effectively. There was also a need for more sophisticated techniques, such as foaming and spraying, to facilitate air sealing in the cramped, reinsulated attic spaces.

15. Average reduction in leakage area, per person-hour worked is 28.4 cm2. The most consistent reductions were achieved with weatherstripping doors and windows, eliminating 37.5 cm2 per person-hour of effort. Cracks and trim work produced the lowest reduction, at 21.1 cm2/hour.

16. Sealing attics and by-pass routes produced the second greatest reductions per person-hour of 29.5 cm2/hour although deviations were also high. In cases where attics were accessible, and where an attempt was made to identify leaks, the results were very rewarding. The repeated difficulties encountered in trying to locate and seal attic leaks emphasized the need for more specialized techniques. The use of polyurethane foam spray systems allowed the Cambridge contractor to achieve reductions 3 times greater than average.

17. Comprehensive air sealing required, on average, 3 person-days per house, using 22 tubes of caulk, 39 meters of window and door weatherstripping, 2 sweeps or thresholds, 27 sets of gaskets and an unspecified amount of foam and packing material. This represents a materials cost of approximately $168 (1984), (without any allowance for wastage), and exceeds most estimates in published literature for material requirements.

18. The average pre-1970 house would appear to require at least a full day's work from a two or three person crew to achieve results comparable with the Weatherize Project. Older houses required more time than newer houses, with an average of 18 person-hours for post 1970 houses, to 38 person-hours for the pre-1970 houses.

19. Householders were generally very satisfied with material durability and appearances. The most common complaints included loose tape, weatherstripping, especially around doors and on sliding windows, and discolouring of caulking.

20. The extensive use of polyurethane foam sealants by one of the four contractors did not result in any significant improvements in overall reductions in leakage area. However, the effect of the polyurethane foam definitely assisted the contractor in achieving much higher than average reductions in sealing attics and by-pass routes.

21. An interior thermographic scan of houses following weatherization revealed a number of areas where sealing applications were only partly effective - particularly cover plate gaskets, door thresholds, attic hatches, and the larger cracks in foundation walls. Thermographic images also revealed areas that had been commonly missed or avoided by contractors, especially diffuse leakage patterns around panelling and brickwork, sliding pocket doors, and a large network of leakage paths stretching behind finished basement walls and between interior walls and attic spaces.

22. The use of thermographic scanner did not appear to be an essential tool for a weatherizing crew, since few leaks were apparent in the infrared images that would not be discovered by a knowledgeable person with a smoke pencil and a little more time.

23. In general, the weatherizing work appears to have produced major improvements in overall comfort levels in the houses, by means of reduced drafts, increased humidity, and more even heat distribution. These comfort improvements were the most noticeable and the most appreciated change to occur in the houses.

24. The vast majority of householders were pleased with the results of weatherizing and stated they would now be willing to recommend a professional weatherizing job to neighbours.

25. Householders using mechanical humidification in their homes, discovered they could turn-off or disconnect the humidifier after weatherizing. Those without mechanical humidification typically encountered increased humidity following weatherizing - and for most houses this was a welcome change.

26. In a small minority of cases, increased humidity levels, resulting from weatherizing, appear to have provoked or aggravated moisture problems such as dripping, staining and mildew. The most common problem was heavy dripping on window surfaces during cold weather or in conjunction with moisture generating activities.

    In the future it should be possible for contractors to avoid humidity problems altogether by adhering to lessons outlined in this report. Particular attention needs to be given to a pre-weatherization moisture audit. Provision of special ventilation systems for those houses that are electrically heated or with leakage areas smaller than 1000 cm2.

27. A number of "moisture problems" were actually eliminated in some instances by air sealing, most noticeably window fogging between the panes.

28. For the entire housing sample, a comparison of yearly fuel consumption per degree day showed an average net decrease of 4.3 percent. Data inconsistencies, however, revealed serious problems with trying to use fuel records and degree days to determine energy savings. This technique appears to be far too simplistic to adequately reflect heating requirements in occupied houses over different winters, and may be inherently flawed because of inappropriate record keeping. A preferable technique appears to be the use of furnace on-time ratios over shorter periods of time and under more controlled conditions.

5. REFERENCES

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(4) Thermographic Evaluation for Airtightening Work, 1982. A report for Ontario Ministry of Municipal Affairs & Housing, Queen's Park, Toronto, by S. Moffatt.

(5) Energy Savings from Airtightening, May, 1982. A report for Ontario Ministry of Municipal Affairs and Housing, by S. Moffatt.

APPENDIX A

A.1 SAMPLE DATA COLLECTION FORMS (A to J) FOR USE BY CONTRACTORS

A.2 PRINCIPLES OF AIRTIGHTNESS TESTING, ELA CALCULATIONS AND HOUSE PREPARATION

APPENDIX A.1 SAMPLE DATA COLLECTION FORM (A to J) FOR USE BY CONTRACTORS

A. CLIENT INTERVIEW

CLIENT IDENTIFICATION

NAME		COMPANY	
ADDRESS		DATE	
		TIME	
PHONE		INTL'S	

RESIDENCE IDENTIFICATION

TYPE		SINGLE		SEMI DETACHED		DUPLEX		TRIPLEX		ROW
YEAR OF CONSTRUCTION		BEFORE 1920		1920-45		1946-60		1961-70		AFTER 1970
NUMBER OF STOREYS		ONE		ONE AND A HALF		TWO		TWO AND A HALF		THREE
WALL CONSTRUCTION		WOOD FRAME		SOLID MASONRY		SOLID LOG				
PRIMARY HEATING FUEL		OIL		GAS		ELECTRIC		PROPANE		WOOD
SECONDARY HEATING FUEL		OIL		GAS		ELECTRIC		PROPANE		WOOD
PRIMARY HEATING SYSTEM		AIR		WATER		FORCED		GRAVITY		RADIANT
SECONDARY HEATING SYSTEM		AIR		WATER		FORCED		GRAVITY		RADIANT
DOMESTIC HOT WATER SYSTEM		GAS		ELECTRIC		OIL		TANKLESS		COIL
AIR CONDITIONING		NONE		CENTRAL		ROOM				

RETROFIT HISTORY

GOVERNMENT GRANTS		CHIP		COSP		RRAP/OHRP	
GAS ON STREET		N/A		YES		NO	
PREVIOUS INSULATION MEASURES		ATTIC		WALLS		BASEMENT	OTHER
YEAR							
AMOUNT		MM		MM		MM	MM
STORM WINDOWS INSTALLED WITHIN LAST TWO YEARS		N/A		NO		HOW MANY?	
HEATING SYSTEM CHANGES (NOTE YEAR)		NEW SYSTEM		NEW BURNER		DOWN SIDE	THERMO-STAT SET BACK DEVICE

OPERATION OF HOUSE

NORMAL TEMPERATURE SETTING		°F DAYTIME			°F NIGHT TIME		
CLOTHES DRYING IN WINTER		HUNG/VENTED OUTSIDE				HUNG/VENTED INSIDE	
WINTER HUMIDIFICATION		NONE		SOME		REGULAR	
NUMBER OF FIREPLACES		NONE		ONE		TWO	
FREQUENCY OF USE		N/A		SELDOM		ONCE PER WEEK/MORE	
WINDOWS PERIODICALLY LEFT OPEN IN WINTER		NONE		BEDROOMS		UPSTAIRS	BASEMENT
HOT WATER APPLIANCES		NONE		DISH WASHER		CLOTHES WASHER	
LENGTH OF OCCUPANCY AT THIS ADDRESS		ONE YEAR		TWO		THREE TO FIVE	MORE

ENVIRONMENTAL CONDITIONS

AVERAGE NUMBER OF OCCUPANTS		ONE		TWO		THREE	FOUR		5-8		9-12
WINTER HUMIDITY LEVELS		DRY	STATIC ELECTRICITY			NORMAL	LIGHT FOGGING		HUMID		
OBSERVED WINDOW FOGGING		NONE				LIGHT			HEAVY		
EVIDENCE OF STAINS OR MOLD ON SILLS		NONE				YES					
NUMBER OF OCCUPANTS WHO SMOKE		NONE				ONE			TWO/MORE		
HARD TO HEAT ROOMS		NO				YES					
COLD OR UNCOMFORTABLE DRAFTS		NONE				FEW			MANY		
LINGERING ODORS OR POOR AIR QUALITY		NONE				OCCASIONAL			OFTEN		

B. ENERGY CONSUMPTION RECORDS

(PAST TWO HEATING SEASONS IF POSSIBLE)

ADDRESS ____________________

PRIMARY HEATING SYSTEM	SECONDARY HEATING SYSTEM
UTILITY NAME ____________	UTILITY NAME ____________
UTILITY PHONE NO. ____________	UTILITY PHONE NO. ____________
CLIENT ACCOUNT NO. ____________	CLIENT ACCOUNT NO. ____________

DATE*			AMOUNT	DATE*			AMOUNT
MONTH	DAY	YEAR	LITRES MJ KWH GAL. FT3	MONTH	DAY	YEAR	LITRES MJ KWH GAL FT3

*DATE REFERS TO THE DAY OF DELIVERY FOR FUEL OIL AND THE DAY OF METER READING FOR GAS OR ELECTRICITY.
LEAVE A BLANK SPACE BETWEEN READINGS OR DELIVERIES THAT ARE NOT CONSECUTIVE.
RECORD SUMMERTIME CONSUMPTION IF POSSIBLE.

C. EXTERIOR MEASUREMENTS

ADDRESS

(ENTER BASIC BUILDING DIMENSIONS, SIZE AND TYPE OF WINDOWS AND DOORS, AMT. OF FOUNDATION ABOVE GRADE)

FRONT VIEW

ORIENTATION

REAR VIEW

RIGHT SIDE VIEW

LEFT SIDE VIEW

FIRST FLOOR PLAN VIEW

(ENTER DIMENSIONS; NOTE LOCATION OF MAJOR OBSTACLES WITHIN 10 METERS OF HOUSE)

HOUSE VOLUME WORK SHEET

	LENGTH	WIDTH	HEIGHT	VOLUME (M^3)
RECTANGULAR AREAS				
			TOTAL VOL	

WALL AREA WORKSHEET — INCLUDE DOORS AND WINDOWS, EXCLUDE FOUNDATION WALLS

	PERIMETER	HEIGHT	AREA
INSULATED SECTIONS			
		TOTAL AREA	
UNINSULATED SECTIONS			
		TOTAL AREA	

D. ENVELOPE AREA AND BASEMENT INSPECTION DETAILS

ADDRESS

COMPONENT AREAS AND INSULATION LEVELS (ABOVE GRADE)

B.C. BUILDING COMPONENT	L LENGTH OR PERI-METER	W WIDTH OR HEIGHT	A AREA M^2	AMOUNT OF INSULATION (MM)					
				UN-KNOWN	NONE	25 TO 50	50 TO 100	100 TO 150	150 +
INSULATED MAIN WALLS FROM WORK SHEET									
UNINSULATED MAIN WALLS FROM WORK SHEET									
INSULATED ABOVE GRADE FOUNDATION WALL									
UNINSULATED ABOVE GRADE FOUNDATION WALL									
MAIN ATTIC									
ROOF/CEILING/SECOND ATTIC									
SIDE ATTIC WALL									
SIDE ATTIC RAFTER SPACE									
SIDE ATTIC FLOOR									
EXPOSED FLOOR									
ADDITIONAL :									
BUILDING ENVELOPE AREA ABOVE GRADE (M^2)			A_1						

BASEMENT INSPECTION DETAILS

BASEMENT MOISTURE CONDITION	☐ DRY	☐ DAMP	☐ WET		
PERCENTAGE INSULATED OF BELOW GRADE BASEMENT WALL	☐ NONE	☐ 25%	☐ 50%	☐ 75%	☐ 100%
MOTORIZED VENT DAMPER ON FURNACE FLUE	☐ N/A	☐ YES	☐ NO		
FURNACE LOCATION	☐ N/A	☐ ROOM	☐ ROOM W/DOOR	☐ OPEN BASEMENT	
COMBUSTION AIR INTAKE	☐ N/A	☐ NOT IN PLACE	☐ DIRECT TO PLENUM	☐ DIRECT TO BASEMENT	
DOMESTIC HOT WATER TANK INSULATION THICKNESS	☐ NONE	☐ 25 - 50 MM		☐ MORE THAN 50 MM	

LEAKAGE IDENTIFICATION AND WORK DESCRIPTION

E. OPENINGS

ADDRESS

(THIS COMPONENT PACKAGE INCLUDES DIRECT LEAKS TO OUTSIDE FROM LIVING SPACE)

LEAKAGE AREAS	EXISTING IN HOUSE	TIGHTENING POSSIBLE	AIR FLOW PRIOR TO TIGHTENING			AREAS THAT LEAK SIGNIFICANTLY AFTER TIGHTENING (EXPLANATION)
			INSIGNIFICANT	NORMAL	EXTREME	
BASEMENT						
OUTSIDE DOOR						
WINDOWS						
LIVING AREA						
WINDOWS						
DOORS						
CABLE PENETRATIONS						
MAIL SLOT						
DELIVERY DOORS						
ATTIC ACCESS HATCH/DOOR						
FIREPLACE DAMPER						
OTHERS (SPECIFY)						

MATERIAL RECORD

	TYPE			TYPE	
CAULKING			OTHER		

TIME LOG (HOURS)

START	STOP	SUB TOTAL	# PERSON	TOTAL

Ontario Ministry of Municipal Affairs & Housing

LEAKAGE IDENTIFICATION AND WORK DESCRIPTION	ADDRESS

F. CRACKS

(THIS COMPONENT PACKAGE INCLUDES LEAKS INTO WALL AND CEILING CAVITIES FROM LIVING SPACE)

LEAKAGE AREAS	EXISTING IN HOUSE	TIGHTENING POSSIBLE	AIR FLOW PRIOR TO TIGHTENING			AREAS THAT LEAK SIGNIFICANTLY AFTER TIGHTENING (EXPLANATION)
			INSIGNIFICANT	NORMAL	EXTREME	
CRACKS IN WALL FINISH						
CRACKS IN CEILING						
ALL FLOOR MOULDING						
CEILING MOULDINGS						
WINDOW FRAMES						
DOOR FRAMES						
INTERIOR WALL OUTLETS, SWITCHES						
EXTERIOR WALL OUTLETS, SWITCHES						
LIGHT FIXTURES, CEILING						
LIGHT FIXTURES, WALL						
FLOOR LEVEL CHANGES						
STAIR RISERS						
ADDITION ATTACHMENT TO HOUSE						
PLUMBING HOLE IN WALL/FLOOR						
PLUMBING ACCESS,HATCH						
AROUND BATHTUB, SHOWER						
MEDICINE CABINET(S)						
HEATING DUCTS AND PIPES						
DOUBLE HUNG WINDOW PULLIES						
DRAWERS INTO ATTIC KNEEWALLS						
OTHERS (SPECIFY)						

MATERIAL RECORD					
	TYPE			TYPE	
CAULKING			OTHER		

TIME LOG (HOURS)				
START	STOP	SUB TOTAL	# PERSON	TOTAL

Ontario Ministry of Municipal Affairs & Housing

F. CRACKS

LEAKAGE IDENTIFICATION AND WORK DESCRIPTION

G. FOUNDATION

ADDRESS

BASEMENT AND FOUNDATION COMPONENT PACKAGE

LEAKAGE AREAS	EXISTING IN HOUSE	TIGHTENING POSSIBLE	AIR FLOW PRIOR TO TIGHTENING			AREAS THAT LEAK SIGNIFICANTLY AFTER TIGHTENING (EXPLANATION)
			INSIG-NIFICANT	NORMAL	EXTREME	
WINDOW/DOOR FRAMES						
HOLES/CRACKS IN WALLS						
WIRING HOLES TO UPSTAIRS						
WIRING HOLES TO OUTSIDE						
WALL/SILL PLATE JOINT						
BAND JOIST SPACE						
BEAM FILLED SPACE						
PLUMBING, UTILITY PENETRATIONS						
DRYER VENT						
COMBUSTION AIR INLET						
OTHERS (SPECIFY)						

MATERIAL RECORD

	TYPE			TYPE	
CAULKING			OTHER		

TIME LOG (HOURS)

START	STOP	SUB TOTAL	# PERSON	TOTAL

LEAKAGE IDENTIFICATION AND WORK DESCRIPTION	ADDRESS

H. BYPASSES

(THIS COMPONENT PACKAGE INCLUDES MAJOR BYPASSES AND ALL REMAINING LEAKS)

LEAKAGE AREAS	EXISTING IN HOUSE	TIGHTENING POSSIBLE	AIR FLOW PRIOR TO TIGHTENING			AREAS THAT LEAK SIGNIFICANTLY AFTER TIGHTENING (EXPLANATION)
			INSIGNIFICANT	NORMAL	EXTREME	
BASEMENT						
WIRING INTO CEILING						
PLUMBING INTO CEILING						
OPEN WALL CAVITIES (EXTERIOR)						
OPEN WALL CAVITIES (PARTITION)						
ATTIC						
PLUMBING PENETRATIONS						
WIRING PENETRATIONS						
HEATING DUCTS OR PIPES						
EXHAUST VENTILATION INTO ATTIC						
OPEN WALL CAVITIES (EXTERIOR)						
OPEN WALL CAVITIES (PARTITION)						
DROPPED CEILINGS						
CHIMNEY CAVITY						
HEATED ROOM FLOOR CAVITY						
OTHERS (SPECIFY)						

MATERIAL RECORD					
	TYPE			TYPE	
CAULKING			OTHER		

TIME LOG (HOURS)				
START	STOP	SUB TOTAL	# PERSON	TOTAL

I. AIR TIGHTNESS TESTS REPORTING FORM

ADDRESS

ABOVE-GRADE ENV. AREA ☐ m^2
TOTAL HOUSE VOLUME ☐ m^3

1. CONTROL TEST

DATE / /81
TIME ☐ AM/PM

AMBIENT CONDITIONS:
TEMP. ☐ °C IN. ☐ °C OUT.
HUMIDITY ☐ %IN. ☐ % OUT.
BA PRESSURE ☐ KPA
WIND ☐ KPH
GUSTING ☐ YES ☐ NO

TEST RESULTS:
LINE SLOPE ☐
AIR FLOW AT 1 PA ☐ l/S
AIR FLOW AT 10 PA ☐ l/S

INDOOR – OUTDOOR PRESSURE (Pa)	READING (V OR Pa)	MEASURED AIR FLOW (l/S)
10		
15		
20		
25		
30		
35		
40		
45		
50		
55		

2. OPENINGS PKG. SEALED

DATE / /81
TIME ☐ AM/PM

AMBIENT CONDITIONS: (CHANGES ONLY)
TEMP. ☐ °C IN. ☐ °C OUT.
BA PRESSURE ☐ KPA
WIND ☐ KPH
GUSTING ☐ YES ☐ NO

TEST RESULTS:
LINE SLOPE ☐
AIR FLOW AT 1 PA ☐ l/S
AIR FLOW AT 10 PA ☐ l/S

INDOOR – OUTDOOR PRESSURE (Pa)	READING (V OR Pa)	MEASURED AIR FLOW (l/S)
10		
15		
20		
25		
30		
35		
40		
45		
50		
55		

3. CRACKS PKG. SEALED

DATE / /81
TIME ☐ AM/PM

AMBIENT CONDITIONS: (CHANGES ONLY)
TEMP. ☐ °C IN. ☐ °C OUT.
BA PRESSURE ☐ KPA
WIND ☐ KPH
GUSTING ☐ YES ☐ NO

TEST RESULTS:
LINE SLOPE ☐
AIR FLOW AT 1 PA ☐ l/S
AIR FLOW AT 10 PA ☐ l/S

INDOOR – OUTDOOR PRESSURE (Pa)	READING (V OR Pa)	MEASURED AIR FLOW (l/S)
10		
15		
20		
25		
30		
35		
40		
45		
50		
55		

4. FOUNDATION PKG. SEALED

DATE / /81
TIME ☐ AM/PM

AMBIENT CONDITIONS: (CHANGES ONLY)
TEMP. ☐ °C IN. ☐ °C OUT.
BA PRESSURE ☐ KPA
WIND ☐ KPH
GUSTING ☐ YES ☐ NO

TEST RESULTS:
LINE SLOPE ☐
AIR FLOW AT 1 PA ☐ l/S
AIR FLOW AT 10 PA ☐ l/S

INDOOR – OUTDOOR PRESSURE (Pa)	READING (V OR Pa)	MEASURED AIR FLOW (l/S)
10		
15		
20		
25		
30		
35		
40		
45		
50		
55		

5. BYPASS PKG. SEALED

DATE / /81
TIME ☐ AM/PM

AMBIENT CONDITIONS: (CHANGES ONLY)
TEMP. ☐ °C IN. ☐ °C OUT.
BA PRESSURE ☐ KPA
WIND ☐ KPH
GUSTING ☐ YES ☐ NO

TEST RESULTS:
LINE SLOPE ☐
AIR FLOW AT 1 PA ☐ l/S
AIR FLOW AT 10 PA ☐ l/S

INDOOR – OUTDOOR PRESSURE (Pa)	READING (V OR Pa)	MEASURED AIR FLOW (l/S)
10		
15		
20		
25		
30		
35		
40		
45		
50		
55		

6. CGSB STANDARD

DATE / /81
TIME ☐ AM/PM

AMBIENT CONDITIONS: (CHANGES ONLY)
TEMP. ☐ °C IN. ☐ °C OUT.
BA PRESSURE ☐ KPA
WIND ☐ KPH
GUSTING ☐ YES ☐ NO

TEST RESULTS:
LINE SLOPE ☐
AIR FLOW AT 1 PA ☐ l/S
AIR FLOW AT 10 PA ☐ l/S

INDOOR – OUTDOOR PRESSURE (Pa)	READING (V OR Pa)	MEASURED AIR FLOW (l/S)
10		
15		
20		
25		
30		
35		
40		
45		
50		
55		

This equation reduces to the following expression:

$$ELA10\ (cm^2) = 11.57 * C * 10^{(n-.5)}$$

The resulting ELA value will vary considerably from some of the test results published in American literature. Commonly the American calculations (Sherman et al) are based upon air flow at 4 pascals pressure, averaged from pressurization and depressurization flows, and with no allowance for a discharge coefficient. Assuming an average n value of 0.67, this results in a leakage area which is only 53% of the CGSB estimate.

PREPARATIONS FOR AIR TIGHTNESS TESTING

The following preparations were required before completing each of the first five air leakage tests.

a) Close and latch all exterior doors and windows (except for the opening required for depressurization apparatus).

b) Open all partition doors, including the door to the basement and any other heated spaces.

c) Turn off the furnace, pilot lights, and any other combustion appliances. (Throw the main control switch or remove fuses.)

d) Seal any furnace flues, whether or not they contain motorized flue dampers. Seal upstream of the barometric damper or draft hood (use an inflatable balloon, polyethylene and tape, or an equivalent air plug).

e) Similarly seal other flues (e.g. domestic hot water heaters).

f) Seal the face of window air conditioners (not the perimeter).

g) Seal the front grill plate of exhaust vents (use plastic and tape or other appropriate materials). Do not seal the edges of the vent since a leaky installation can be remedied as part of your air tightening measures.

h) Seal dryer vents. (Remove the plastic or steel duct and plug at the exterior wall opening.)

i) Seal fresh air intakes.

j) Seal combustion air intakes.

k) Seal fireplace openings.

Air leakage test #6 was the final test, it was completed according to the CGSB (draft) standard for testing new homes. To complete a CGSB standard test a technician must follow the same procedures as above except for items g) exhaust vents; h) dryer vents; i) fresh air intakes; j) combustion air intakes; k) fireplace openings. These areas should be unsealed. Dampers or other closures that are part of these components should be left in the closed position.